Moisture-dependent physical properties of 12 varieties of rough rice (*Oryza Sativa* L.) grain

Iraj Bagheri[1], Mohammad Bagher Dehpour[1*], Seyed Hossein Payman[1], Hemad Zareiforoush[2]

[1]Department of Agricultural Mechanization, Faculty of Agricultural Sciences, University of Guilan, P.O.Box 41635-1314, Rasht, Iran
[2]Department of Mechanics of Agricultural Machinery, Faculty of Agriculture, Tarbiat Modares University, P.O. Box 14115-111, Tehran, Iran. dehpour@guilan.ac.ir

Abstract: This study was carried out to evaluate the effect of moisture content on some physical properties of different varieties of rough rice grains. 12 rough rice varieties including Gharib, Hasani, Binam, Tarom, Khazar, Domsiah, Hashemi, Alikazemi, Hybrid, Kadoos, Sepidrood and Dorfak were evaluated in this research. The 12 varieties were divided into 3 groups, namely, Local short grain varieties (Gharib, Hasani and Binam), Local long grain varieties (Tarom, Khazar, Domsiah, Hashemi and Alikazemi), and Improved long grain varieties (Hybrid, Kadoos, Sepidrood and Dorfak) and the physical properties of the varieties in each group were determined at four levels of moisture content, including 8, 10, 12 and 14% (w.b.). The results revealed that the average values of grain length, width, thickness, equivalent diameter, surface area, volume, sphericity, aspect ratio, thousand grain mass and angle of repose were in the ranges of 8.74-11.94 mm, 2.14-3.26 mm, 1.84-2.21 mm, 3.36-4.05 mm, 33.24-45.41 mm^2, 19.91-34.90 mm^3, 31.97-45.01%, 0.19-0.37, 21.54-28.12 g, and 29.6-38.04º, respectively. For all of the varieties, by increasing the moisture content the bulk density increased. The static coefficient of friction on five surfaces, including glass, galvanized iron, plywood, iron and aluminum were in the range of 0.2180-0.3939, 0.2890-0.4122, 0.4192-0.6119, 0.3648-0.4621, and 0.2706-0.3843, respectively. Based on the statistical analysis, the effects of moisture content and variety on all of the physical properties of rough rice were significant (P<0.01).
New York Science Journal 2011;4(5):63-73]. (ISSN: 1554-0200). http://www.sciencepub.net/newyork.

Keywords: Physical properties, Rough rice, Moisture content, Variety

1. Introduction

Rice (*Oryza Sativa* L.) is one of the most important cultivated crops serving as the staple food for more than half the world's population. World rice production increased from 520 million ton in 1990 to 605 million ton in 2004 (FAOSTAT, 2005). In Iran, rice is grown on an area of about 615000 ha with a total rough rice 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. Both high yielding and local varieties are grown in the rice cultivated areas in the country. In Guilan province however, the most popular varieties grown are local and aromatic varieties such as Hashemi and Binam. These varieties are characterized by long kernels having awns. 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).

Since the moisture content of rough rice grains varies at the different stages of rice production, from harvesting to processing, it is necessary to study the physical characteristics of rough rice grains as a function of moisture content to optimise the design of equipment used in harvesting, transportation, milling, processing and storage of rice. Principal axial dimensions of rough rice 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. Bulk density, true density and porosity (the ratio of inter granular space to the total space occupied by the grain) are used in design of storage bins and silos, separation of desirable materials from impurities, cleaning and grading and quality evaluation of the products. These properties 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. The angle of repose is important in designing of storage and transporting structures. Flow ability of rough rice grains is usually expressed by using the angle of repose (a measure of the internal friction between kernels) that will be useful in hopper design, where 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 of the rough rice grains against the various surfaces is also necessary in designing of conveying, transporting and storing structures. 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 (Ghasemi Varnamkhasti *et al.,* 2007).

In recent years, physical properties have been studied for various crops such as sorrel seeds (Omobuwajo *et al.* 2000); millet (Baryeh 2002); groundnut kernel (Olajide and Igbeka 2003); lentil seed (Amin *et al.* 2004); sweet corn seed (Coşkun *et al.* 2005); linseed (Selvi *et al.* 2006); peanut (Aydin 2007); jatropha seed (Garnayak *et al.* 2008) and karanja kernel (Pradhan *et al.* 2008). It seems that there is not much published work about moisture-dependent physical properties of rough rice grains.

The objective of this study was to investigate some moisture-dependent physical properties of 12 varieties of rough rice grains, namely, axial dimensions, size, surface area, sphericity, thousand grain mass, bulk density, true density, porosity, angle of repose and static coefficient of friction on various surfaces in the moisture content range from 8 to 14% (w.b.).

2. Material and Methods

2.1. Samples preparation

12 varieties of rough rice grains including Hasani, Gharib, Binam (local short grain varieties), Khazar, Tarom, Hashemi, Alikazemi, Domsiah (local long grain varieties), Sepidrood, Dorfak, Kadoos, and Hybrid (improved long grain varieties) were used in this study. These varieties are being cultivated in Guilan province that is a province located in the north of Iran and in the vicinity of the Caspian Sea. The rice varieties were obtained from the Rice Research Institute of Iran (RRII), Rasht, 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 at 103 ˚C for 48 h (Sacilik *et al.* 2003). The initial moisture content of the grains was in the range of 14.8 to 16.2% (w.b.).

2.2. Experimental procedure

The physical properties of rough rice grains were investigated at four moisture levels of 8, 10, 12 and 14% (w.b.). In order to obtain four desired moisture levels below the initial moisture content, the samples were kept in an oven at a constant temperature of 43 ˚C until the desired moisture content of the samples were obtained (Yang *et al.* 2003). After making the desired levels of moisture contents below the initial moisture content the samples were poured into polyethylene bags and the bags sealed tightly. Before starting each test, the required quantities of the samples were taken out of the bags.

The length (*L*), width (*W*) and thickness (*T*) of rough rice grains were measured in randomly selected 100 rough rice grains. The length, width and thickness of grains were measured using digital calipers to an accuracy of 0.01 mm (Mytutoyo, Japan). The equivalent diameter (D_p) in mm considering a prolate spheroid shape for a rough rice grain, was calculated using (Mohsenin 1986):

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

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):

$$\phi = \frac{(LWT)^{\frac{1}{3}}}{L} \quad (2)$$

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

$$S = \frac{\pi B L^2}{(2L - B)} \quad (3)$$

Where:

$$B = \sqrt{WT} \quad (4)$$

The aspect ratio (R_a) was calculated by (Maduako and Faborode 1990):

$$R_a = \frac{W}{L} \quad (5)$$

The thousand grain mass was determined by means of a digital electronic balance having an accuracy of 0.01 g (AND, Japan). To evaluate the thousand grain mass, 100 randomly selected grains from the bulk sample were averaged.

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 rough rice 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 rough rice grains in the measured toluene (Sacilik *et al.* 2003; Garnayak *et al.* 2008; Pradhan *et al*. 2008).

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

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \qquad (6)$$

Where ε is the porosity (%), ρ_b is the bulk density (kg/m^3) and ρ_t is the true density (kg/m^3).

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 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 static coefficient of friction of rough rice grains against five different surfaces, namely, glass, galvanized iron, aluminum, iron and plywood was determined using a cylinder of diameter 75mm and depth 50mm filled with grains. With the cylinder resting on the surface, the surface was raised gradually until the filled cylinder just started to slide down. The static coefficient of friction (μ) was then calculated from the following relationship (Razavi and Milani 2006; Ghasemi varnamkhasti *et al.* 2008):

$$\mu = \tan \alpha \qquad (7)$$

Where μ is the coefficient of friction and α is the angle of tilt in degrees.

2.3. Experimental design & statistical analysis

This study was carried out based on a factorial statistical design. 48 treatments (obtained from 12 varieties and four levels of moisture content) were evaluated based on the randomised complete blocks design. The mean, standard deviation and correlation coefficient of the physical properties of rough rice grains were determined using Microsoft Excel 2007 software program. The effects of variety and moisture content a on the physical properties were investigated using analysis of variance (ANOVA), and mean significant differences were compared using Duncan's multiple range test at 5% significant level using SAS 9.1 software.

3. Results and discussion

3.1. Results of statistical analysis

Based on the ANOVA, the effects of moisture content and variety on all of the physical properties of rough rice grains were statistically significant. The mean squares of the physical properties of the rough rice grains are illustrated in Table 1.

Table 1- Mean squares of the physical properties of rough rice grains as obtained through analysis of variance.

Dependent variable	NO. of observations	Sources		
		Variety	Moisture content	Variety × Moisture content
Length	100	449.19**	11.18**	0.42*
Width	100	32.21**	4.73**	0.09**
Thickness	100	2.68**	2.01**	0.06**
Equivalent diameter	100	8.31**	5.57**	0.09**
Surface area	100	3442.17**	2186.65**	35.34**
Volume	100	3925.97**	2677.54**	43.21**
Sphericity	100	6442.82**	130.89**	6.62**
Aspect ratio	100	1.08**	0.02**	0.01ns
Thousand grain mass	5	44.08**	51.01**	0.69**
Bulk density	5	5010.26**	10257.33**	65.11**
True density	5	298780.06**	786.47ns	47385.16**
Porosity	5	197.97**	84.69**	24.80**
Angle of repose	5	32.73**	220.79**	1.59**
Static coefficient of friction – Glass	5	0.0223**	0.0144**	0.0003**
Static coefficient of friction – Galvanized iron	5	0.0110**	0.0134**	0.0001ns
Static coefficient of friction – Plywood	5	0.0444**	0.0309**	0.0001ns
Static coefficient of friction – Iron	5	0.0082**	0.0172**	0.0001ns
Static coefficient of friction – Aluminum	5	0.0091**	0.0167**	0.0001ns

**:significant at 1% probability level; *:significant at 5% probability level; ns: not significant

3.2. Grain dimensions

The average values of the three principal dimensions of rough rice grain (length, width and thickness), surface area, volume and sphericity for the 12 varieties evaluated at different levels of moisture contents are presented in Table 2. As shown, for all of the rough rice varieties evaluated, the principal dimensions increased with increasing the moisture content from 8 to 14% (w.b.).

Table 2- Dimensional properties of 12 varieties of rough rice grains at different levels of moisture content.

Variety Grouping	Variety	MC (%w.b.)	L (mm)	W (mm)	T (mm)	D_P (mm)	S (mm^2)	V (mm^3)	R_a	ø (%)
LSGV*	Gharib	8	9.01±0.50	2.86±0.28	1.98±0.13	3.75±0.19	38.87±3.57	27.87±2.15	0.32±0.03	41.22±2.51
		10	9.05±0.51	2.96±0.21	2.04±0.11	3.84±0.18	40.47±3.48	29.78±3.29	0.33±0.03	41.99±2.14
		12	9.06±0.57	3.02±0.22	2.09±0.11	3.90±0.16	41.61±3.42	31.18±3.93	0.33±0.04	42.64±2.21
		14	9.07±0.53	3.03±0.21	2.11±0.21	3.91±0.18	41.86±3.77	31.54±3.14	0.34±0.03	42.73±2.73
	Hasani	8	8.74±0.52	3.10±0.23	2.09±0.12	3.89±0.17	40.99±3.50	31.02±4.30	0.35±0.03	44.03±2.44
		10	8.82±0.41	3.22±0.45	2.17±0.12	4.00±0.24	43.06±4.14	33.89±3.08	0.36±0.05	44.79±2.35
		12	8.87±0.46	3.25±0.18	2.19±0.11	4.03±0.13	43.81±2.76	34.47±3.40	0.37±0.03	44.98±2.54
		14	8.89±0.54	3.26±0.22	2.21±0.12	4.05±0.16	44.18±3.59	34.95±4.54	0.37±0.03	45.01±2.43
	Binam	8	9.06±0.40	2.76±0.14	1.99±0.13	3.71±0.13	38.31±2.79	26.83±2.82	0.30±0.02	40.58±1.46
		10	9.15±0.85	2.81±0.19	2.05±0.16	3.77±0.20	39.75±4.02	28.43±4.24	0.31±0.08	41.34±2.79
		12	9.19±0.51	2.84±0.16	2.11±0.14	3.83±0.15	40.81±3.28	29.61±3.52	0.31±0.02	41.45±1.78
		14	9.25±0.52	2.89±0.18	2.14±0.10	3.88±0.13	41.71±2.87	30.66±3.20	0.32±0.03	41.71±2.02
LLGV	Tarom	8	9.56±0.36	2.31±0.15	1.83±0.10	3.45±0.12	34.70±2.26	21.64±2.31	0.24±0.02	35.95±1.25
		10	9.59±0.43	2.35±0.20	1.86±0.09	3.49±0.14	35.31±2.62	22.34±2.75	0.24±0.03	36.22±1.32
		12	9.79±0.40	2.42±0.18	1.93±0.13	3.59±0.15	37.39±2.89	24.39±3.04	0.25±0.02	36.54±1.49
		14	9.82±0.44	2.57±0.19	2.03±0.12	3.73±0.16	39.94±3.12	27.39±3.44	0.26±0.02	37.84±1.60
	Khazar	8	10.10±0.49	2.47±0.11	1.97±0.13	3.68±0.12	39.29±2.69	26.14±2.54	0.24±0.02	36.29±1.33
		10	10.21±0.55	2.54±0.14	1.99±0.15	3.74±0.16	40.51±3.34	27.56±3.47	0.25±0.02	36.48±1.88
		12	10.33±0.58	2.58±0.18	2.04±0.16	3.80±0.15	41.82±3.42	28.92±3.36	0.25±0.03	36.67±1.85
		14	10.39±0.57	2.60±0.18	2.05±0.11	3.82±0.16	42.35±3.33	29.47±3.64	0.26±0.02	36.69±1.74
	Domsiah	8	9.54±0.47	2.14±0.12	1.84±0.12	3.36±0.12	33.24±2.54	19.91±2.23	0.22±0.01	35.16±1.38
		10	9.63±0.51	2.22±0.15	1.85±0.12	3.41±0.14	34.30±2.87	21.01±2.66	0.23±0.02	35.43±1.58
		12	9.72±0.46	2.26±0.13	1.87±0.09	3.46±0.11	35.12±2.39	21.77±2.30	0.23±0.02	35.51±1.42
		14	9.91±0.49	2.33±0.15	1.90±0.13	3.54±0.14	36.71±2.76	23.37±256	0.23±0.03	35.63±1.70
	Hashemi	8	9.93±0.43	2.41±0.19	1.87±0.16	3.57±0.14	37.05±2.06	23.88±2.88	0.24±0.02	35.74±1.41
		10	9.98±0.44	2.45±0.14	1.91±0.08	3.62±0.13	38.07±2.75	24.93±2.85	0.25±0.02	36.10±1.73
		12	10.03±0.39	2.47±0.17	1.93±0.08	3.65±0.14	38.66±2.89	25.57±3.73	0.25±0.03	36.23±1.47
		14	10.07±0.46	2.50±0.19	1.97±0.11	3.69±0.15	39.53±2.95	26.54±2.12	0.25±0.02	36.54±1.83
	Alikazemi	8	9.35±0.49	2.57±0.14	1.91±0.13	3.61±0.11	37.04±2.24	24.76±2.27	0.27±0.02	38.35±1.53
		10	9.67±0.34	2.68±0.15	2.01±0.11	3.76±0.11	40.09±2.19	27.94±2.51	0.28±0.02	38.64±1.38
		12	9.74±0.51	2.74±0.16	2.02±0.11	3.80±0.14	40.92±2.54	28.95±3.03	0.28±0.04	38.80±1.60
		14	9.93±0.47	2.79±0.16	2.06±0.09	3.88±0.12	42.55±2.59	30.68±2.84	0.28±0.02	38.82±1.52
ILGV	Hybrid	8	11.53±0.58	2.40±0.11	1.94±0.09	3.79±0.12	43.16±2.77	28.54±2.59	0.20±0.02	32.76±1.19
		10	11.58±0.48	2.41±0.10	1.95±0.07	3.81±0.09	43.63±2.22	28.99±2.20	0.21±0.01	32.78±1.08
		12	11.65±0.55	2.43±0.14	1.97±0.09	3.83±0.13	44.13±2.95	29.55±1.21	0.21±0.02	32.79±1.21
		14	11.77±0.50	2.48±0.12	1.99±0.09	3.88±0.11	45.35±2.53	30.84±2.67	0.21±0.03	32.91±1.17
	Kadoos	8	11.23±0.43	2.30±0.17	1.92±0.10	3.68±0.10	40.88±2.29	26.24±2.32	0.20±0.01	32.73±1.20
		10	11.35±0.58	2.36±0.13	1.94±0.08	3.75±0.11	42.11±2.45	27.53±2.38	0.21±0.03	32.91±1.36
		12	11.38±0.43	2.38±0.12	1.95±0.07	3.76±0.10	42.15±2.15	28.02±2.24	0.21±0.01	33.00±1.08
		14	11.42±0.57	2.47±0.13	1.96±0.10	3.83±0.13	43.77±3.11	29.54±3.12	0.22±0.01	33.41±1.22
	Sepidrood	8	11.23±0.60	2.42±0.17	1.95±0.09	3.77±0.14	42.45±3.09	28.19±3.27	0.21±0.02	33.51±1.09
		10	11.24±0.54	2.46±0.15	1.97±0.08	3.81±0.11	43.15±2.50	29.00±2.66	0.22±0.02	33.77±1.48
		12	11.25±0.65	2.47±0.15	1.98±0.10	3.82±0.12	43.37±2.94	29.28±2.93	0.22±0.03	33.87±1.73
		14	11.28±0.62	2.51±0.14	1.99±0.06	3.85±0.11	43.98±2.52	29.97±2.56	0.22±0.02	34.05±1.62
	Dorfak	8	11.76±0.58	2.34±0.17	1.93±0.09	3.77±0.12	43.11±2.69	28.10±2.81	0.19±0.02	31.97±1.47
		10	11.83±0.63	2.38±0.14	1.95±0.11	3.81±0.13	44.07±3.03	29.16±3.01	0.20±0.02	32.17±1.51
		12	11.92±0.55	2.41±0.16	1.96±0.08	3.85±0.12	44.84±2.72	29.95±2.93	0.20±0.01	32.19±1.37
		14	11.94±0.57	2.44±0.19	1.98±0.07	3.88±0.13	45.41±2.93	30.65±3.18	0.20±0.02	32.39±1.42

*LSGV: Local short-medium grain varieties; LLGV: Local long grain varieties; ILGV: Improved long grain varieties.

The highest values of grain length, width, thickness, equivalent diameter, surface area, volume and aspect ratio were equal to 11.94 mm (Dorfak 14%), 3.26 mm (Hasani 14%), 2.21 mm (Hasani 14%), 4.05 mm (Hasani 14%), 45.41 mm^2 (Dorfak 14%), 34.90 mm^3 (Hasani 14%) and 0.37 (Hasani 14%), respectively; while the lowest values of grain length, width, thickness, equivalent diameter, surface area, volume and aspect ratio were obtained as 8.74 mm (Hasani 8%), 2.14 mm (Domsiah 8%), 1.84 mm (Domsiah 8%), 3.36 mm (Domsiah 8%), 33.24 mm^2 (Domsiah 8%), 19.91 mm^3 (Domsiah 8%) and 0.19 (Dorfak 8%), respectively. The regressions representing the relationship between moisture content (M) and rough rice dimensions for the 12 varieties tested are given in Table 3. Very high correlation was observed between the dimensions and moisture content indicating that upon moisture absorption, the rough rice grain expands in length, width and thickness within the moisture range of 8 to 14% (w.b.).

3.3. Sphericity

The values of sphericity were calculated individually with Eq. (2) by using the data on geometric mean diameter and the major axis of the grain and the results obtained are presented in Table 2. The lowest and highest values of rough rice grain sphericity (31.97% and45.01%) were observed in the case of Dorfak variety at the moisture content of 8% (w.b.) and Hasani variety at the moisture content of 14% (w.b.), respectively. Bal and Mishra (1988) considered the grain as spherical when the sphericity value was more than 70%. Therefore, none of the rough rice varieties could be considered as an equivalent sphere for calculation the surface area. Similar trends have been reported by Reddy and Chakraverty (2004) for raw and parboiled rough rice, Altuntaş *et al.* (2005) for fenugreek seeds, Karababa (2006) for papcorn kernels and Yalçın *et al.* (2007) for pea seed.

Table 3- Equations representing the relationship between moisture content and physical properties of different varieties of rough rice grains

Physical characteristic	Variety Grouping		
	Local short grain varieties (LSGV)		
	Gharib	Hasani	Binam
Length	$L=0.0175M+9.004\ (R^2=0.880)$	$L=0.0524M+8.701\ (R^2=0.952)$	$L=0.0586M+9.016\ (R^2=0.969)$
Width	$W=0.0571M+2.826\ (R^2=0.907)$	$W=0.0509M+3.081\ (R^2=0.798)$	$W=0.0428M+2.719\ (R^2=0.980)$
Thickness	$T=0.0436M+1.951\ (R^2=0.938)$	$T=0.0347M+2.081\ (R^2=0.826)$	$T=0.0502M+1.947\ (R^2=0.975)$
Equivalent diameter	$D_p=0.0539M+3.715\ (R^2=0.916)$	$D_p=0.0505M+3.867\ (R^2=0.839)$	$D_p=0.0564M+3.658\ (R^2=0.993)$
Surface area	$S=1.0097M+38.182\ (R^2=0.916)$	$S=1.0154M+40.461\ (R^2=0.865)$	$S=1.1238M+37.336\ (R^2=0.988)$
Volume	$V=1.2395M+26.995\ (R^2=0.926)$	$V=1.2203M+30.519\ (R^2=0.813)$	$V=1.2678M+25.718\ (R^2=0.990)$
Sphericity	$\o=0.5194M+40.486\ (R^2=0.914)$	$\o=0.3130M+43.922\ (R^2=0.880)$	$\o=0.3475M+40.405\ (R^2=0.863)$
Thousand grain mass	$m=0.340M+24.21\ (R^2=0.935)$	$m=0.656M+24.87\ (R^2=0.840)$	$m=1.032M+22.29\ (R^2=0.968)$
Bulk density	$\rho_b=9.884M+511.02\ (R^2=0.893)$	$\rho_b=10.276M+494.64\ (R^2=0.997)$	$\rho_b=10.362M+513.77\ (R^2=0.991)$
True density	$\rho_t=28.81M+1542.1\ (R^2=0.938)$	$\rho_t=-72.847M+1527.9\ (R^2=0.984)$	$\rho_t=-40.213M+1642.6\ (R^2=0.953)$
Porosity	$\varepsilon=-0.377M+66.952\ (R^2=0.827)$	$\varepsilon=-2.916M+68.233\ (R^2=0.977)$	$\varepsilon=-1.627M+68.892\ (R^2=0.971)$
Angle of repose	$\theta=1.658M+28.49\ (R^2=0.962)$	$\theta=1.660M+31.70\ (R^2=0.951)$	$\theta=0.900M+34.60\ (R^2=0.944)$
Static coefficient of friction – Glass	$\mu_g=0.0077M+0.2312\ (R^2=0.979)$	$\mu_g=0.0124M+0.2302\ (R^2=0.960)$	$\mu_g=0.0130M+0.2971\ (R^2=0.994)$
Static coefficient of friction – Galvanized iron	$\mu_{gi}=0.0096M+0.325\ (R^2=0.985)$	$\mu_{gi}=0.0070M+0.3183\ (R^2=0.966)$	$\mu_{gi}=0.0124M+0.3376\ (R^2=0.989)$
Static coefficient of friction – Plywood	$\mu_p=0.0152M+0.4743\ (R^2=0.998)$	$\mu_p=0.0096M+0.4319\ (R^2=0.924)$	$\mu_p=0.0186M+0.3991\ (R^2=0.946)$
Static coefficient of friction – Iron	$\mu_i=0.0139M+0.3738\ (R^2=0.975)$	$\mu_i=0.0097M+0.3902\ (R^2=0.903)$	$\mu_i=0.0128M+0.3559\ (R^2=0.966)$
Static coefficient of friction – Aluminum	$\mu_a=0.0146M+0.2708\ (R^2=0.912)$	$\mu_a=0.0102M+0.2961\ (R^2=0.948)$	$\mu_a=0.0223M+0.2965\ (R^2=0.979)$

Physical characteristic	Local long grain varieties (LLGV)				
	Tarom	Khazar	Domsiah	Hashemi	Alikazemi
Length	$L=0.0991M+9.443\ (R^2=0.890)$	$L=0.0994M+10.011\ (R^2=0.980)$	$L=0.1225M+9.395\ (R^2=0.962)$	$L=0.0471M+9.886\ (R^2=0.997)$	$L=0.1793M+9.227\ (R^2=0.938)$
Width	$W=0.084M+2.207\ (R^2=0.911)$	$W=0.0416M+2.445\ (R^2=0.914)$	$W=0.0603M+2.089\ (R^2=0.983)$	$W=0.0313M+2.381\ (R^2=0.981)$	$W=0.0719M+2.517\ (R^2=0.880)$
Thickness	$T=0.0666M+1.748\ (R^2=0.933)$	$T=0.0280M+1.941\ (R^2=0.913)$	$T=0.0203M+1.817\ (R^2=0.925)$	$T=0.0336M+1.837\ (R^2=0.991)$	$T=0.0432M+1.895\ (R^2=0.868)$
Equivalent diameter	$D_p=0.0945M+3.331\ (R^2=0.940)$	$D_p=0.0503M+3.636\ (R^2=0.965)$	$D_p=0.0594M+3.296\ (R^2=0.985)$	$D_p=0.0413M+3.529\ (R^2=0.990)$	$D_p=0.0847M+3.553\ (R^2=0.939)$
Surface area	$S=1.779M+32.391\ (R^2=0.941)$	$S=1.0489M+38.373\ (R^2=0.972)$	$S=1.1227M+32.037\ (R^2=0.981)$	$S=0.8036M+36.317\ (R^2=0.991)$	$S=1.7391M+35.803\ (R^2=0.941)$
Volume	$V=1.931M+19.115\ (R^2=0.933)$	$V=1.1331M+25.193\ (R^2=0.967)$	$V=1.1132M+18.733\ (R^2=0.980)$	$V=0.8619M+23.073\ (R^2=0.992)$	$V=1.8779M+23.391\ (R^2=0.949)$
Sphericity	$\o=0.5986M+35.144\ (R^2=0.853)$	$\o=0.1393M+36.183\ (R^2=0.923)$	$\o=0.1512M+35.055\ (R^2=0.929)$	$\o=0.2554M+35.515\ (R^2=0.972)$	$\o=0.1540M+38.269\ (R^2=0.861)$
Thousand grain mass	$m=0.258M+21.64\ (R^2=0.967)$	$m=0.8765M+20.568\ (R^2=0.924)$	$m=0.656M+22.14\ (R^2=0.976)$	$m=0.914M+20.89\ (R^2=0.989)$	$m=0.598M+24.66\ (R^2=0.914)$
Bulk density	$\rho_b=7.58M+489.93\ (R^2=0.950)$	$\rho_b=9.786M+476.46\ (R^2=0.922)$	$\rho_b=9.310M+470.55\ (R^2=0.947)$	$\rho_b=7.178M+451.53\ (R^2=0.977)$	$\rho_b=13.201M+442.89\ (R^2=0.995)$
True density	$\rho_t=55.853M+1494.\ 4\ (R^2=0.998)$	$\rho_t=29.254M+1675\ (R^2=0.972)$	$\rho_t=-71.921M+1764.8\ (R^2=0.986)$	$\rho_t=9.750M+1327.5\ (R^2=0.965)$	$\rho_t=-7.251M+1418.8\ (R^2=0.998)$
Porosity	$\varepsilon=0.5998M+67.155\ (R^2=0.905)$	$\varepsilon=-0.1659M+71.394\ (R^2=0.929)$	$\varepsilon=-2.0103M+73.685\ (R^2=0.995)$	$\varepsilon=-0.2984M+65.981\ (R^2=0.951)$	$\varepsilon=-0.7430M+68.620\ (R^2=0.998)$
Angle of repose	$\theta=1.416M+31.22\ (R^2=0.962)$	$\theta=1.322M+31.72\ (R^2=0.899)$	$\theta=1.5M+31.22\ (R^2=0.965)$	$\theta=2.39M+27.44\ (R^2=0.994)$	$\theta=1.776M+30.27\ (R^2=0.986)$
Static coefficient of friction – Glass	$\mu_g=0.0157M+0.2043\ (R^2=0.989)$	$\mu_g=0.0124M+0.2302\ (R^2=0.860)$	$\mu_g=0.0086M+0.2664\ (R^2=0.925)$	$\mu_g=0.0216M+0.2972\ (R^2=0.862)$	$\mu_g=0.0090M+0.2876\ (R^2=0.964)$
Static coefficient of friction – Galvanized iron	$\mu_{gi}=0.011M+0.3031\ (R^2=0.967)$	$\mu_{gi}=0.0094M+0.3342\ (R^2=0.991)$	$\mu_{gi}=0.0107M+0.3228\ (R^2=0.965)$	$\mu_{gi}=0.0151M+0.3524\ (R^2=0.992)$	$\mu_{gi}=0.0135M+0.3521\ (R^2=0.996)$
Static coefficient of friction – Plywood	$\mu_p=0.0236M+0.4366\ (R^2=0.978)$	$\mu_p=0.0135M+0.4811\ (R^2=0.993)$	$\mu_p=0.0155M+0.4053\ (R^2=0.974)$	$\mu_p=0.0193M+0.4522\ (R^2=0.995)$	$\mu_p=0.0186M+0.4325\ (R^2=0.996)$
Static coefficient of friction – Iron	$\mu_i=0.0178M+0.3311\ (R^2=0.985)$	$\mu_i=0.0143M+0.3548\ (R^2=0.990)$	$\mu_i=0.0098M+0.3579\ (R^2=0.994)$	$\mu_i=0.0120M+0.4062\ (R^2=0.983)$	$\mu_i=0.0153M+0.4020\ (R^2=0.995)$
Static coefficient of friction – Aluminum	$\mu_a=0.0119M+0.2788\ (R^2=0.987)$	$\mu_a=0.0089M+0.2839\ (R^2=0.972)$	$\mu_a=0.0098M+0.3081\ (R^2=0.935)$	$\mu_a=0.0106M+0.3411\ (R^2=0.997)$	$\mu_a=0.0091M+0.3152\ (R^2=0.940)$

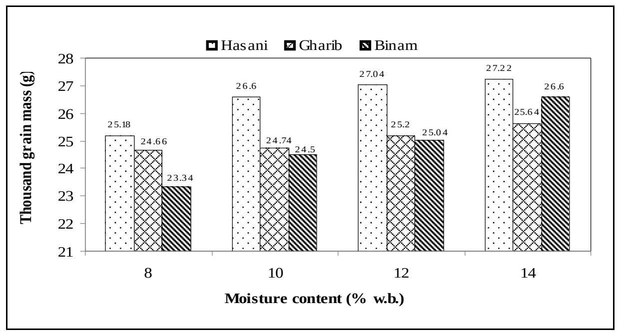
	Improved long grain varieties (ILGV)			
	Hybrid	Kadoos	Sepidrood	Dorfak
Length	L=0.0794M+11.437 (R^2=0.960)	L=0.0608M+11.193 (R^2=0.891)	L=0.0170M+11.211 (R^2=0.934)	L=0.0621M+11.710 (R^2=0.941)
Width	W=0.0246M+2.371 (R^2=0.877)	W=0.0543M+2.246 (R^2=0.946)	W=0.0267M+2.399 (R^2=0.976)	W=0.0346M+2.306 (R^2=0.985)
Thickness	T=0.0158M+1.923 (R^2=0.973)	T=0.0140M+1.907 (R^2=0.995)	T=0.0139M+1.941 (R^2=0.938)	T=0.0162M+1.918 (R^2=0.977)
Equivalent diameter	D_p=0.0322M+3.749 (R^2=0.933)	D_p=0.0463M+3.640 (R^2=0.971)	D_p=0.0252M+3.749 (R^2=0.965)	D_p=0.0365M+3.736 (R^2=0.989)
Surface area	S=0.7083M+42.299 (R^2=0.939)	S=0.9103M+40.057 (R^2=0.971)	S=0.4826M+42.031 (R^2=0.968)	S=0.7666M+42.444 (R^2=0.987)
Volume	V=0.745M+27.621 (R^2=0.933)	V=1.037M+25.242 (R^2=0.967)	V=0.5614M+27.707 (R^2=0.972)	V=0.8434M+27.359 (R^2=0.991)
Sphericity	$ø$=0.0459M+32.697 (R^2=0.845)	$ø$=0.2132M+32.482 (R^2=0.911)	$ø$=0.1719M+33.371 (R^2=0.967)	$ø$=0.1301M+31.858 (R^2=0.925)
Thousand grain mass	m=0.896M+22.60 (R^2=0.972)	m=0.8967M+24.52 (R^2=0.977)	m=0.756M+22.92 (R^2=0.989)	m=0.660M+24.33 (R^2=0.960)
Bulk density	ρ_b=10.934M+483.09 (R^2=0.922)	ρ_b=11.55M+475.14 (R^2=0.964)	ρ_b=6.095M+481.82 (R^2=0.964)	ρ_b=13.717M+456.37 (R^2=0.961)
True density	ρ_t=85.324M+1471.3 (R^2=0.988)	ρ_t=68.102M+1443.1 (R^2=0.995)	ρ_t=52.112M+1483.3 (R^2=0.989)	ρ_t=71.104M+1462.1 (R^2=0.996)
Porosity	ε=0.7081M+67.518 (R^2=0.949)	ε=0.5976M+67.165 (R^2=0.993)	ε=0.6925M+67.169 (R^2=0.953)	ε=-0.4837M+68.791 (R^2=0.957)
Angle of repose	θ=1.1M+29.86 (R^2=0.962)	θ=1.246M+30.38 (R^2=0.982)	θ=1.606M+29.48 (R^2=0.996)	θ=1.11M+31.83 (R^2=0.985)
Static coefficient of friction: Glass	μ_g=0.0075M+0.2480 (R^2=0.983)	μ_g=0.0154M+0.2739 (R^2=0.824)	μ_g=0.0169M+0.2289 (R^2=0.978)	μ_g=0.0106M+0.2503 (R^2=0.987)
Galvanized iron	μ_{gi}=0.0125M+0.3469 (R^2=0.932)	μ_{gi}=0.0370M+0.2489 (R^2=0.921)	μ_{gi}=0.0106M+0.3215 (R^2=0.996)	μ_{gi}=0.0140M+0.2771 (R^2=0.983)
Plywood	μ_p=0.0136M+0.5475 (R^2=0.961)	μ_p=0.0206M+0.494 (R^2=0.870)	μ_p=0.0195M+0.5077 (R^2=0.978)	μ_p=0.0225M+0.5177 (R^2=0.976)
Iron	μ_i=0.0095M+0.3906 (R^2=0.960)	μ_i=0.0108M+0.3895 (R^2=0.975)	μ_i=0.0111M+0.3690 (R^2=0.978)	μ_i=0.0205M+0.3497 (R^2=0.956)
Aluminum	μ_a=0.0144M+0.2772 (R^2=0.996)	μ_a=0.0187M+0.2980 (R^2=0.994)	μ_a=0.0085M+0.2967 (R^2=0.995)	μ_a=0.0162M+0.2576 (R^2=0.974)

3.4. Thousand Grain Mass

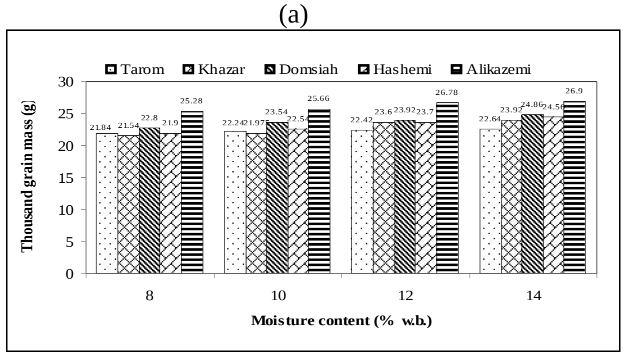
The thousand grain mass of 12 varieties of rough rice grains at four levels of moisture contents of 8, 10, 12 and 14% (w.b.) are illustrated in Fig. 1. It can be seen that for all of the varieties, as the moisture content increased from 8 to 14%, the thousand grains mass increased. The lowest value of thousand grain mass (21.54 g) was obtained for Khazar variety at the moisture content of 8% (w.b.); whilst the highest thousand grain mass (28.12 g) was attributed to Kadoos variety at the moisture content of 14% (w.b.). This relationship between thousand grain mass (m) and moisture content (M) can be represented by the equations given in Table 3. Similar increasing trend has been reported by Sacilik *et al*. (2003) for hemp seed and Garnayak *et al*. (2008) for jatropha seed.

3.5. Angle of Repose

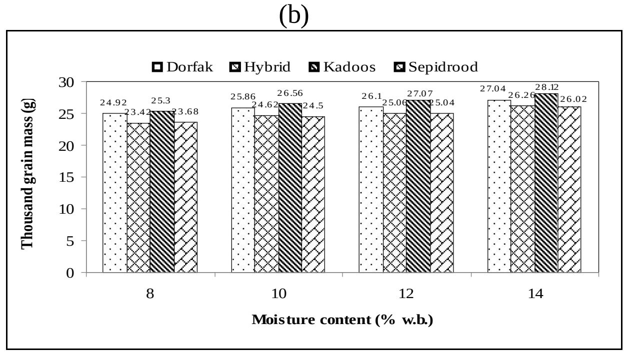
The angle of repose is an indicator of the product's ability to flow. The experimental results for the angle of repose with respect to moisture content are shown in Fig. 2. The lowest angle of repose (29.60º) was obtained for Hashemi variety at the moisture content of 8% (w.b.) and the highest angle of repose (38.20º) was observed in the case of Binam variety at the moisture content of 14% (w.b.). For all of the 12 varieties tested, by decreasing the moisture content from 14 to 8% (w.b.), the angle of repose decreased significantly. The angle of repose at higher levels of moisture is higher because the surface layer of moisture surrounding the particle holds 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), Garnayak *et al*. (2008) and Pradhan *et al*. (2008) for faba bean grains, jatropha seed and karanja kernel.



(a)

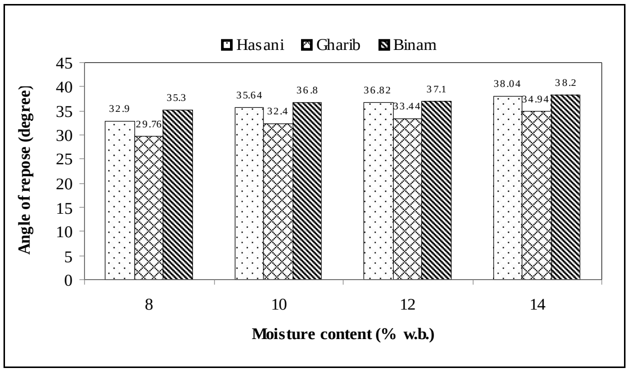


(b)

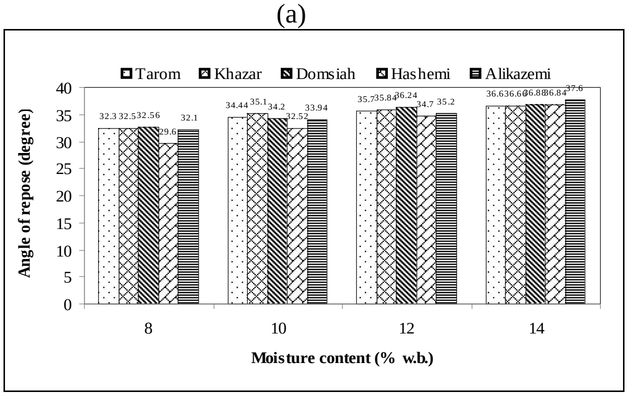


(c)

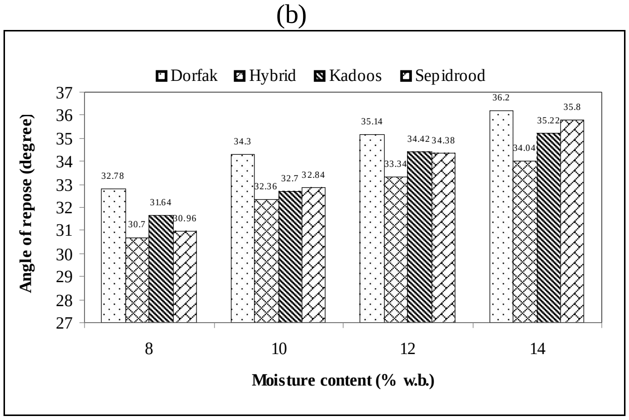
Figure 1- Effect of moisture content on thousand grain mass of: a) Local short grain varieties (LSGV); b) Local long grain varieties (LLGV); c) Improved long grain varieties (ILGV).



(a)



(b)

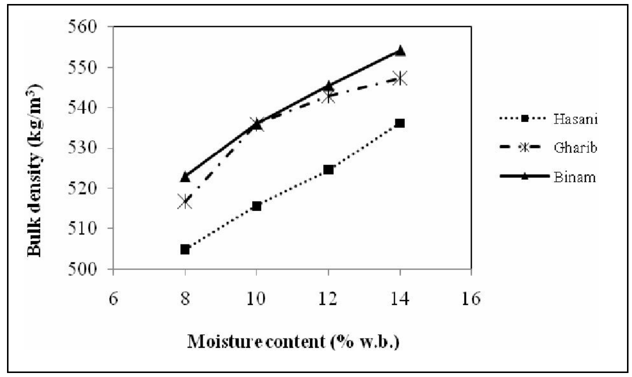


(c)

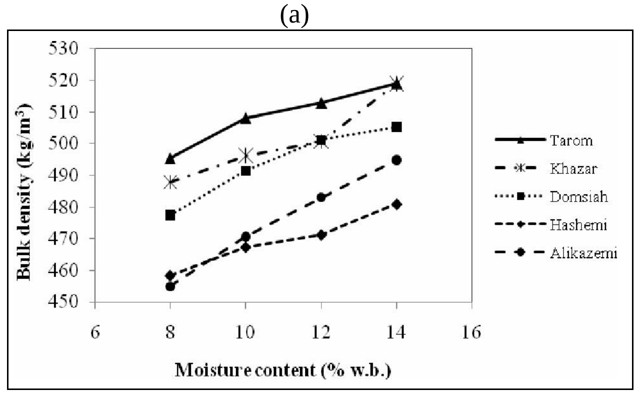
Figure 2- Effect of moisture content on the emptying angle of repose of: a) Local short grain varieties (LSGV); b) Local long grain varieties (LLGV); c) Improved long grain varieties (ILGV).

3.6. Bulk Density

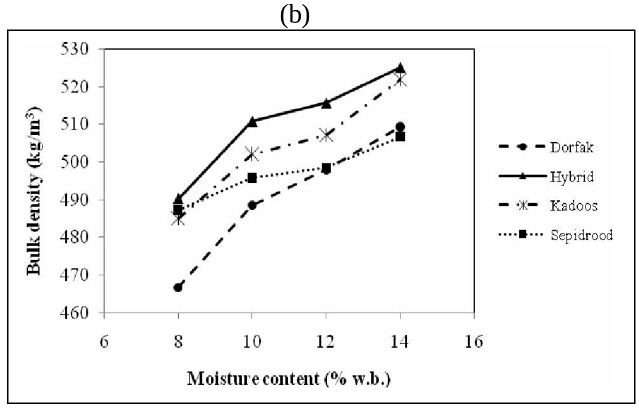
The mean values of bulk density for 12 varieties of rough rice grains at different levels of moisture content are shown in Fig. 3. The highest value of bulk density (554.28 kg/m^3) was observed in the case of Binam variety at the moisture content of 14% (w.b.); while the lowest value of bulk density (454.94 kg/m^3) was obtained for Alikazemi variety at the moisture content of 8% (w.b.). For all of the varieties, decreasing the moisture content from 14 to 8% (w.b.) caused the bulk density to decrease. This was maybe 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. 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. At all of the moisture contents evaluated and among the 12 varieties studied, the highest value of bulk density was corresponded to Binam variety. Thus, Binam variety needs larger bins for storage than the other varieties evaluated. The bulk density (ρ_b) of rough rice grains was found to a linear relationship with moisture content (Table 3).



(a)



(b)

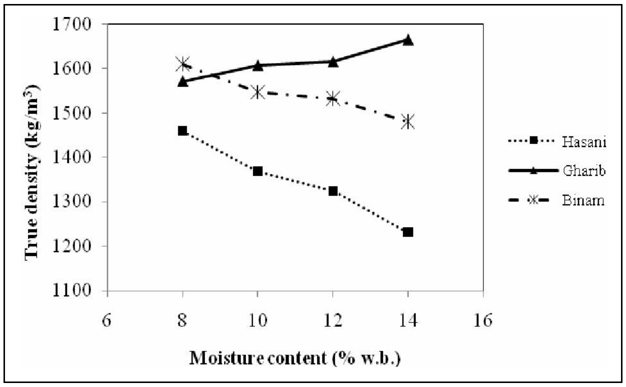


(c)

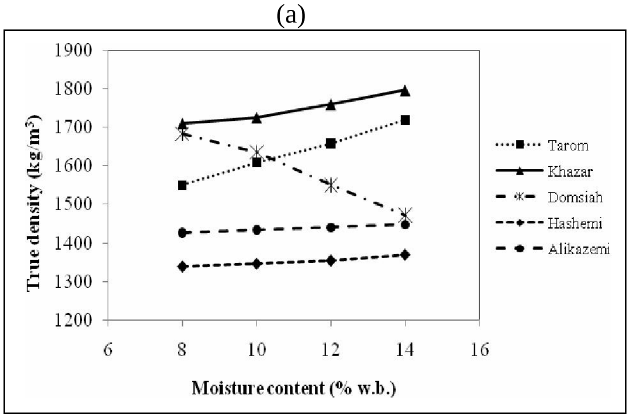
Figure 3- Effect of moisture content on the bulk density of: a) Local short grain varieties (LSGV); b) Local long grain varieties (LLGV); c) Improved long grain varieties (ILGV).

3.7. True Density

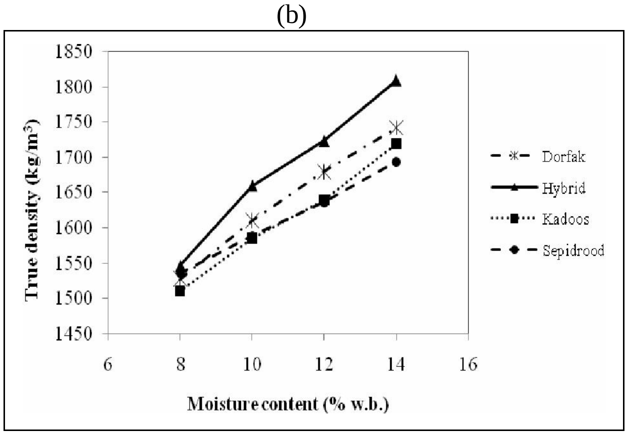
The true density of rough rice varieties at different moisture contents is illustrated in Fig. 4. As the moisture content increased from 14 to 8% (w.b.), the true density of Sepidrood, Kadoos, Hybrid, Dorfk, Khazar, Tarom, Gharib, Alikazemi and Hashemi varieties decreased; while decreasing the moisture content from 14 to 8% (w.b.) caused the true density of Binam, Hasani and Domsiah varieties to increase.



(a)

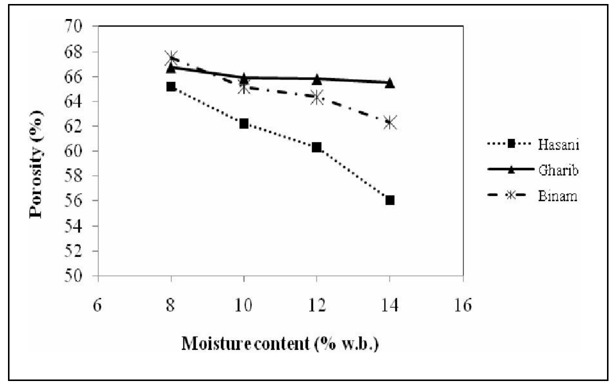


(b)

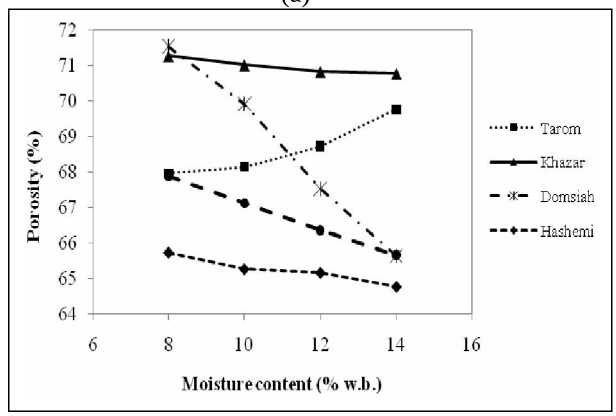


(c)

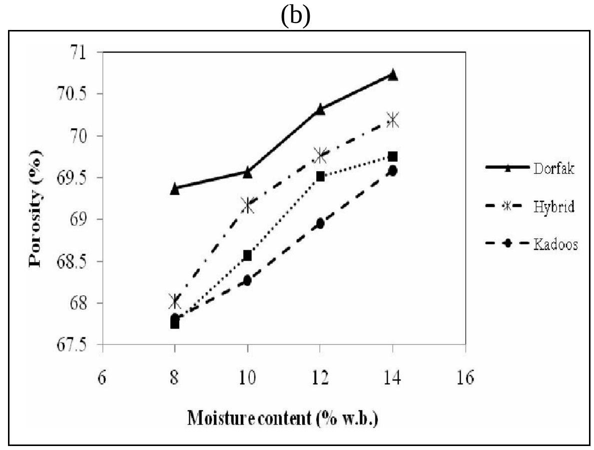
Figure 4- Effect of moisture content on the true density of: a) Local short grain varieties (LSGV); b) Local long grain varieties (LLGV); c) Improved long grain varieties (ILGV).



(a)



(b)



(c)

Figure 5- Effect of moisture content on the porosity of: a) Local short grain varieties (LSGV); b) Local long grain varieties (LLGV); c) Improved long grain varieties (ILGV)

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 reported that increasing the moisture content caused an increase in the value of true density. Howerver, a different trend was reported by Sacilik *et al*. (2003) for hemp seed, Yalçin *et al*. (2007) for pea seed and Cetin (2007) for barbunia bean seed. The dependence of the grains true density

(ρ_t) to the moisture content (*M*) could be described by the equations presented in Table 3.

3.8. Porosity

Porosity was calculated through Eq. (6) by using the data on bulk and true densities of the rough rice grains. The variation of porosity depending upon moisture content is shown in Fig. 5. With decreasing the moisture content from 14 to 8% (w.b.), the porosity of rough rice grains decreased in the case of Sepidrood, Kadoos, Hybrid, Dorfk, and Tarom varieties; whilst the porosity of Khazar, Gharib, Hasani, Binam, Alikazemi, Hashemi and Domsiah varieties increased by decreasing the moisture content.

Sacilik *et al*. (2003) and Kingsly *et al*. (2006) reported increasing trends of porosity versus increasing the moisture content 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. The relationship between porosity (ε) value and the moisture content (*M*) of the grains is presented in Table 3.

3.9. Static Coefficient of Friction

The static coefficients of friction for 12 varieties of rough rice grains evaluated on five surfaces (glass, galvanized iron, aluminum, iron and plywood) against moisture content in the range of 8–14% (w.b.) are presented in Table 4. It is observed that the static coefficient of friction decreased linearly with decrease in moisture content for all contact surfaces. The reason for the increased friction coefficient at higher moisture content may be owing to the water present in the grain offering a cohesive force on the surface of contact (Garnayak *et al*. 2008). In the case of local short grain varieties (LSGV) the highest coefficient of friction (0.5344) was obtained for the Gharib variety at the moisture content of 14% (w.b.) and on plywood surface; whilst the lowest value of coefficient of friction (0.2342) was attributed to the Hasani variety at the moisture content of 8% (w.b.) on glass surface. For local long grain varieties (LLGV) the highest value of coefficient of friction (0.5341) was obtained for Khazar variety at the moisture content of 14% (w.b.) on plywood surface; while the lowest value of coefficient of friction (0.2180) was attributable to Tarom variety at the moisture content of 8% (w.b.) and on the glass surface. Finally, in the case of improved long grain varieties (ILGV) the highest value of coefficient of friction (0.6119) belonged to the Dorfak variety at the moisture content of 14% (w.b.) on plywood surface; and the lowest value of coefficient of friction (0.2456) was attributed to the Sepidrood variety at the moisture content of 8% (w.b.) and on glass surface. At all moisture content, the maximum and minimum friction was offered by plywood and glass surfaces, respectively. The least static coefficient of friction may be owing to smoother and more polished surface of the glass than the other materials used. Plywood also offered the maximum friction for pigeon pea, gram, rape seed, neem nut, Jatropha seed and karanja kernel and the coefficient of friction increased with the moisture content (Garnayak *et al.* 2008; Pradhan *et al*. 2008). The relationships between moisture content (*M*) and static coefficient of friction on glass (μ_g), galvanized iron (μ_{gi}), plywood (μ_p), iron (μ_i) and aluminum (μ_a) can be represented by the equations presented in Table 3.

Table 4- Static coefficient of friction for 12 varieties of rough rice grains at different levels of moisture content.

Variety Grouping	Variety	Moisture content (%w.b.)	Contact surface				
			Glass	Galvanized iron	Plywood	Iron	Aluminum
LSGV*	Gharib	8	$0.2375_{\pm0.0087}$	$0.3357_{\pm0.0073}$	$0.4886_{\pm0.0158}$	$0.3879_{\pm0.0175}$	$0.2897_{\pm0.0062}$
		10	$0.2482_{\pm0.0055}$	$0.3431_{\pm0.0079}$	$0.5057_{\pm0.0191}$	$0.4032_{\pm0.0074}$	$0.2966_{\pm0.0086}$
		12	$0.2549_{\pm0.0057}$	$0.3521_{\pm0.0090}$	$0.5203_{\pm0.0228}$	$0.4113_{\pm0.0049}$	$0.3080_{\pm0.0028}$
		14	$0.2608_{\pm0.0101}$	$0.3648_{\pm0.0073}$	$0.5344_{\pm0.0135}$	$0.4315_{\pm0.0052}$	$0.3346_{\pm0.0090}$
	Hasani	8	$0.2342_{\pm0.0064}$	$0.3268_{\pm0.0043}$	$0.4449_{\pm0.0209}$	$0.4028_{\pm0.0140}$	$0.3049_{\pm0.0069}$
		10	$0.2672_{\pm0.0046}$	$0.3299_{\pm0.0090}$	$0.4467_{\pm0.0308}$	$0.4037_{\pm0.0227}$	$0.3165_{\pm0.0205}$
		12	$0.2687_{\pm0.0068}$	$0.3396_{\pm0.0133}$	$0.4596_{\pm0.0137}$	$0.4220_{\pm0.0138}$	$0.3311_{\pm0.0079}$
		14	$0.2750_{\pm0.0068}$	$0.3471_{\pm0.0097}$	$0.4727_{\pm0.0148}$	$0.4290_{\pm0.0100}$	$0.3342_{\pm0.0042}$
	Binam	8	$0.3103_{\pm0.0048}$	$0.3483_{\pm0.0178}$	$0.4192_{\pm0.0128}$	$0.3679_{\pm0.0113}$	$0.3153_{\pm0.0151}$
		10	$0.3218_{\pm0.0114}$	$0.3644_{\pm0.0127}$	$0.4382_{\pm0.0174}$	$0.3803_{\pm0.0147}$	$0.3471_{\pm0.0136}$
		12	$0.3377_{\pm0.0151}$	$0.3751_{\pm0.0097}$	$0.4466_{\pm0.0170}$	$0.3987_{\pm0.0056}$	$0.3617_{\pm0.0252}$
		14	$0.3483_{\pm0.0131}$	$0.3859_{\pm0.0140}$	$0.4783_{\pm0.0131}$	$0.4044_{\pm0.0058}$	$0.3847_{\pm0.0163}$
LLGV	Tarom	8	$0.2180_{\pm0.0109}$	$0.3153_{\pm0.0079}$	$0.4561_{\pm0.0093}$	$0.3467_{\pm0.0108}$	$0.2924_{\pm0.0065}$
		10	$0.2378_{\pm0.0067}$	$0.3218_{\pm0.0080}$	$0.4883_{\pm0.0196}$	$0.3683_{\pm0.0111}$	$0.3004_{\pm0.0070}$
		12	$0.2527_{\pm0.0142}$	$0.3389_{\pm0.0164}$	$0.5109_{\pm0.0153}$	$0.3875_{\pm0.0057}$	$0.3141_{\pm0.0091}$
		14	$0.2653_{\pm0.0078}$	$0.3463_{\pm0.0144}$	$0.5274_{\pm0.0252}$	$0.3996_{\pm0.0068}$	$0.3276_{\pm0.0082}$

	Khazar	8	$0.2549_{\pm 0.0181}$	$0.3444_{\pm 0.0217}$	$0.4934_{\pm 0.0134}$	$0.3707_{\pm 0.0148}$	$0.2909_{\pm 0.0099}$
		10	$0.2631_{\pm 0.0112}$	$0.3514_{\pm 0.0115}$	$0.5096_{\pm 0.0156}$	$0.3811_{\pm 0.0128}$	$0.3038_{\pm 0.0124}$
		12	$0.2679_{\pm 0.0071}$	$0.3632_{\pm 0.0123}$	$0.5228_{\pm 0.0182}$	$0.3968_{\pm 0.0113}$	$0.3115_{\pm 0.0086}$
		14	$0.2705_{\pm 0.0078}$	$0.3719_{\pm 0.0147}$	$0.5341_{\pm 0.0241}$	$0.4130_{\pm 0.0143}$	$0.3180_{\pm 0.0067}$
	Domsiah	8	$0.2773_{\pm 0.0148}$	$0.3346_{\pm 0.0097}$	$0.4204_{\pm 0.0155}$	$0.3679_{\pm 0.0088}$	$0.3188_{\pm 0.0103}$
		10	$0.2818_{\pm 0.0135}$	$0.3412_{\pm 0.0062}$	$0.4390_{\pm 0.0119}$	$0.3778_{\pm 0.0055}$	$0.3288_{\pm 0.0110}$
		12	$0.2887_{\pm 0.0140}$	$0.3581_{\pm 0.0088}$	$0.4473_{\pm 0.0087}$	$0.3859_{\pm 0.0131}$	$0.3327_{\pm 0.015}$
		14	$0.3038_{\pm 0.0080}$	$0.3647_{\pm 0.0082}$	$0.4694_{\pm 0.0157}$	$0.3980_{\pm 0.0135}$	$0.3502_{\pm 0.0088}$
	Hashemi	8	$0.3268_{\pm 0.0081}$	$0.3659_{\pm 0.0083}$	$0.4698_{\pm 0.0164}$	$0.4183_{\pm 0.0117}$	$0.3522_{\pm 0.0128}$
		10	$0.3346_{\pm 0.0153}$	$0.3851_{\pm 0.0196}$	$0.4930_{\pm 0.0176}$	$0.4315_{\pm 0.0114}$	$0.3620_{\pm 0.0146}$
		12	$0.3490_{\pm 0.0085}$	$0.3975_{\pm 0.0094}$	$0.5105_{\pm 0.0161}$	$0.4394_{\pm 0.0081}$	$0.3719_{\pm 0.0088}$
		14	$0.3939_{\pm 0.0083}$	$0.4122_{\pm 0.0111}$	$0.5281_{\pm 0.0112}$	$0.4558_{\pm 0.0183}$	$0.3843_{\pm 0.0120}$
	Alikazemi	8	$0.2981_{\pm 0.0124}$	$0.3648_{\pm 0.0157}$	$0.4736_{\pm 0.0090}$	$0.4171_{\pm 0.0097}$	$0.3257_{\pm 0.0070}$
		10	$0.3046_{\pm 0.0112}$	$0.3807_{\pm 0.0118}$	$0.4890_{\pm 0.0095}$	$0.4319_{\pm 0.0098}$	$0.3296_{\pm 0.0144}$
		12	$0.3119_{\pm 0.0121}$	$0.3919_{\pm 0.0114}$	$0.5104_{\pm 0.0080}$	$0.4499_{\pm 0.0115}$	$0.3455_{\pm 0.0086}$
		14	$0.3257_{\pm 0.0119}$	$0.4061_{\pm 0.0133}$	$0.5295_{\pm 0.0094}$	$0.4621_{\pm 0.0161}$	$0.3506_{\pm 0.0138}$
ILGV	Hybrid	8	$0.2560_{\pm 0.0088}$	$0.3553_{\pm 0.0101}$	$0.5604_{\pm 0.0209}$	$0.4008_{\pm 0.0161}$	$0.2905_{\pm 0.0107}$
		10	$0.2631_{\pm 0.0091}$	$0.3778_{\pm 0.0069}$	$0.5779_{\pm 0.0188}$	$0.4102_{\pm 0.0201}$	$0.3073_{\pm 0.0134}$
		12	$0.2687_{\pm 0.0088}$	$0.3847_{\pm 0.0083}$	$0.5835_{\pm 0.0186}$	$0.4154_{\pm 0.0101}$	$0.3208_{\pm 0.0215}$
		14	$0.2792_{\pm 0.0125}$	$0.3947_{\pm 0.0077}$	$0.6038_{\pm 0.0137}$	$0.4308_{\pm 0.0052}$	$0.3339_{\pm 0.0196}$
	Kadoos	8	$0.2962_{\pm 0.0116}$	$0.2944_{\pm 0.1445}$	$0.5237_{\pm 0.0104}$	$0.4020_{\pm 0.0143}$	$0.3180_{\pm 0.0117}$
		10	$0.2992_{\pm 0.0080}$	$0.3040_{\pm 0.1491}$	$0.5259_{\pm 0.0114}$	$0.4097_{\pm 0.0125}$	$0.3326_{\pm 0.0081}$
		12	$0.3099_{\pm 0.0079}$	$0.3723_{\pm 0.0074}$	$0.5475_{\pm 0.0106}$	$0.4196_{\pm 0.0130}$	$0.3553_{\pm 0.0140}$
		14	$0.3439_{\pm 0.0093}$	$0.3951_{\pm 0.0118}$	$0.5853_{\pm 0.0099}$	$0.4349_{\pm 0.0164}$	$0.3727_{\pm 0.0075}$
	Sepidrood	8	$0.2456_{\pm 0.0051}$	$0.3315_{\pm 0.0082}$	$0.5296_{\pm 0.0166}$	$0.3783_{\pm 0.0140}$	$0.3046_{\pm 0.0107}$
		10	$0.2605_{\pm 0.0121}$	$0.3440_{\pm 0.0151}$	$0.5454_{\pm 0.0257}$	$0.3943_{\pm 0.0101}$	$0.3141_{\pm 0.0072}$
		12	$0.2841_{\pm 0.0117}$	$0.3526_{\pm 0.0189}$	$0.5613_{\pm 0.0200}$	$0.4016_{\pm 0.0105}$	$0.3230_{\pm 0.0081}$
		14	$0.2939_{\pm 0.0113}$	$0.3640_{\pm 0.0156}$	$0.5892_{\pm 0.0186}$	$0.4130_{\pm 0.0113}$	$0.3300_{\pm 0.0135}$
	Dorfak	8	$0.2623_{\pm 0.0064}$	$0.2890_{\pm 0.0114}$	$0.5421_{\pm 0.0149}$	$0.3648_{\pm 0.0157}$	$0.2706_{\pm 0.0067}$
		10	$0.2698_{\pm 0.0103}$	$0.3084_{\pm 0.0042}$	$0.5630_{\pm 0.0095}$	$0.3979_{\pm 0.0070}$	$0.2943_{\pm 0.0079}$
		12	$0.2811_{\pm 0.0084}$	$0.3183_{\pm 0.0060}$	$0.5788_{\pm 0.0092}$	$0.4126_{\pm 0.0150}$	$0.3073_{\pm 0.0138}$
		14	$0.2939_{\pm 0.0095}$	$0.3322_{\pm 0.0080}$	$0.6119_{\pm 0.0109}$	$0.4282_{\pm 0.0108}$	$0.3203_{\pm 0.0048}$

*LSGV: Local short-medium grain varieties; LLGV: Local long grain varieties; ILGV: Improved long grain varieties.

4. Conclusions

The average values of grain length, width, thickness, equivalent diameter, surface area, volume, sphericity, aspect ratio, thousand grain mass and angle of repose were in the ranges of 8.74-11.94 mm, 2.14-3.26 mm, 1.84-2.21 mm, 3.36-4.05 mm, 33.24-45.41 mm^2, 19.91-34.90 mm^3, 31.97-45.01%, 0.19-0.37, 21.54-28.12 g, and 29.6-38.04º, respectively.

For all of the varieties, by increasing the moisture content the bulk density increased.

The static coefficient of friction on five surfaces, including glass, galvanized iron, plywood, iron and aluminum were in the range of 0.2180-0.3939, 0.2890-0.4122, 0.4192-0.6119, 0.3648-0.4621, and 0.2706-0.3843, respectively.

Based on the statistical analysis, the effects of moisture content and variety on all of the physical properties of rough rice were significant ($P<0.01$).

Acknowledgments

The authors would like to thank the University of Guilan for providing the laboratory facilities and financial support for this project.

Corresponding Author:
Mohammad Bagher Dehpour
Department of Agricultural Mechanization,
Faculty of Agricultural Sciences,
University of Guilan,
P.O.Box 41635-1314, Rasht, Iran
E-mail: dehpour@guilan.ac.ir

References

1. Alizadeh MR, Minaei S, Tavakoli T, Khoshtaghaza MH. Effect of de-awning on physical properties of rough rice. Pakistan Journal of Biological Sciences 2006;9:1726-31.
2. Altuntaş E, Özgöz E, Taser ÖF. Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. Journal of Food Engineering 2005;71:37–43.
3. Altuntaş E, Yıldız M. Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains. Journal of Food Engineering 2007;78:174–83.

4. Amin MN, Hossain MA, Roy KC. Effects of moisture content on some physical properties of lentil grains. Journal of Food Engineering 2004; 65:83–7.
5. Aydin C. Some engineering properties of peanut and kernel. Journal of Food Engineering 2007; 79:810-16.
6. Bal S, Mishra HN, Engineering properties of soybean. In: Proceedings of the National Seminar on Soybean Processing and Utilization in India 1988;146–65.
7. Bart-Plange A, Baryeh EA. The physical properties of Category B cocoa beans. Journal of Food Engineering 2003;60:219-227.
8. Baryeh EA. Physical properties of millet. Journal of Food Engineering 2002;51:39-46.
9. Baryeh EA, Mangope BK. Some physical properties of QP-38 variety pigeon pea. Journal of Food Engineering 2002;56:59–65.
10. Cetin M. Physical properties of barbunia bean (*Phaseolus vulgaris* L. cv. ‘Barbuniz’) seed. Journal of Food Engineering 2007;80:353–8.
11. Coşkun MB, Yalçin I, Özarslan C. Physical properties of sweet corn seed (*Zea mays saccharata Sturt.*). Journal of Food Engineering 2005;74(4):523–8.
12. FAOSTAT. Rice production 2005. Available from http://faostat.fao.org .
13. Garnayak DK, Pradhan RC, Naik SN, Bhatnagar N. Moisture-dependent physical properties of Jatropha seed (*Jatropha curcas* L.). Indian journal of Crops Products 2008;27:123–9.
14. Ghasemi Varnamkhasti M, Mobli H, Jafari A, Keyhani AR, Heidari Soltanabadi M, Rafiee S, Kheiralipour K. Some physical properties of rough rice (*Oryza Sativa*) grain. Journal of Cereal Science 2008;47:496-501.
15. Jain RK, Bal S. Properties of pearl millrt. Journal of Agricultural Engineering Research 1997;66: 85–91.
16. Karababa E.. Physical properties of popcorn kernels. Journal of Food Engineering 2006;72: 100-7.
17. Kingsly ARP, Singh DB, Manikantan MR, Jain RK. Moisture dependent physical properties of dried pomegranate seeds (Anardana). Journal of Food Engineering 2006;75:492-6.
18. Mohsenin NN. Physical Properties of Plant and Animal Materials. Second ed. Gordon and Breach Science Publishers, New York, 1986.
19. Nimkar PM, Chattopadhyay PK. Some physical properties of green gram. Journal of Agricultural Engineering Research 2001;80(2):183–9.
20. Olajide JD, Igbeka JC. Some physical properties of groundnut kernels. Journal of Food Engineering 2003;58:201–4.
21. Omobuwajo TO, Sanni LA, Balami YA. Physical properties of sorrel (Hibiscus sabdariffa) seeds. Journal of Food Engineering 2000;45:37-41.
22. Pradhan RC, Naik SN, Bhatnagar N, Swain SK. Moisture-dependent physical properties of Karanja (*Pongamia pinnata*) kernel. Journal of Industrial Crops and Products 2008;28(2):155-61.
23. Razavi S, Milani E. Some physical properties of the watermelon seeds. Africian Journal of Agricultural Research 2006;13:65–9.
24. Reddy BS, Chakraverty A. Physical Properties of Raw and Parboiled Rough rice. Journal of Biosystem Engineering 2004;88(4):461-6.
25. Sacilik K, Ozturk R, Keskin R. Some physical properties of hemp seed. Biosystems Engineering 2003;86(2):191–8.
26. Selvi KC, Pinar Y, Yeşiloğlu E. Some physical properties of linseed. Biosystems Engineering 2006;95(4):607–12.
27. Tabatabaeefar A. Moisture-dependent physical properties of wheat. International Agrophysics 2003;17:207–11.
28. Yalçın İ, Özarslan C. Physical properties of vetch seed. Biosystem Engineering 2004;**88(4)**: 507–12.
29. Yalçın İ, Özarslan C, Akbaş T. Physical properties of pea (*Pisum sativum*) seed. Journal of Food Engineering 2007;79(2):731-5.
30. Yang W, Siebenmorgen TJ, Thielen TPH, Cnossen AG. Effect of glass transition on conductivity of rough rice. Biosystems Engineering 2003;84:193-200.

4/19/2011