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Effect of hulling and milling on the physical properties of rice grains

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A b s t r a c t. Basic physical properties of agricultural materials play important role for optimizing the design of equipment and facilities for the harvesting, handling, conveying, separation, drying, storing, and processing. In this study, some physical properties of three rice varieties, namely Tarom Mahali, Fajr, and Neda, at three levels of processing, which name rough rice (paddy), brown rice (husked or hulled), and white rice (milled) were investigated. The thousand grains mass and porosity decreased significantly with the rice processing, but the bulk density increased. The rough rice of each variety showed the least value of true density. Unit mass and volume of rice grain decreased with the rice processing. Totally, the static coefficient of friction affected by cultivars, levels of processing, and frictional materials. By processing, the filling angle of repose for all cultivars decreased. The terminal velocity increase significantly for every variety. It was observed that the terminal velocity of the rice's hull and bran is lower than for the rough rice, brown rice, milled rice.

K e y w o r d s: rice, thousand grain mass, bulk and true density, filling angle of repose, static coefficient of friction, terminal velocity

INTRODUCTION

Cultivated rice (*Oryza sativa* L.) is the principle food cereal in the world and is second only to wheat in terms of annual for food consumption. In the world, rice production increased from 520 million tonnes in 1990 to 605 million tones in 2004. It is a major crop in Asia, where 90% of world's rice produced and consumed. Rice is an important staple food in Iran, where rice production increased from 1.3 million Mt in 1980 to 3.4 million Mt in 2004 (FASTAT, 2005).

Knowledge of various physical properties of agricultural grains is important which provides an essential required in order to equipment for harvesting, threshing, handling, conveying, separation, drying, aeration, storage and processing.

Thousand grain mass of rice grain is utilized in determining the effective diameter which can be used in the theoretical estimation of seed volume (Ogunjimi *et al*., 2002). Furthermore, this parameter is used for calculating the head rice yield (USDA, 1990). No rice variety can commercially successful unless it possesses high whole kernel (head) and total milled rice yield. Whole kernel (head) yield is the quantity of intact whole kernels (including broken kernels three-quarters or more in length) of well-milled obtainable from given quantities of rough rice (paddy). Total milled rice yield includes whole kernel (head) and other sizes of broken kernels obtainable from specified amounts of rough rice. The objective of rice milling is removal of hull, bran and germ, with minimum breakage of endosperms (Owens, 2001). Besides, the thousand grain mass of raw paddy is a useful index to milling outturn in measuring relative amount of dockage or foreign material in a given lot of paddy, and amount of shriveled of immature kernels (Luh, 1980).

As it mentioned by Amin *et al.* (2004) bulk density, kernel density and porosity are important factors in planning the drying, aeration and storage systems, as the resistance to air flow of mass impressed by these properties. Cereal grain densities have been of interest in breakage susceptibility and hardness studies. In addition, gravity cleaning with cleaners such as rough-rice separators uses differences in the specific gravity and bulk density of the grain to separate materials that have little difference in size and total mass (De Datta, 1993).

Most of the paddy separators are compartment-type, and these use differences in specific gravity and buoyancy of the grains for separation rough and brown rice from the output of paddy huller (Araullo *et al*., 1976).

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

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information is useful in sizing motor requirements for grain transportation and handling (Ghasemi *et al.*, 2008). Furthermore, because the structure of the paddy grain, which involved cellulosic and fibrous tissue and covered with very hard glass-like spines, makes it necessary to apply friction to the grain surface to removed the husk (Araullo *et al.*, 1976). The angle of repose is important in designing of packaging or storage structure, especially in calculating hopper side-wall slop angle.

It is also necessary to study pneumatic conveying characteristics of seed grains in order to design equipments for cleaning, handling, aeration, storing and processing (Guner, 2007). For example, terminal velocity plays an important role in the cleaning of rice grains to remove impurities like dockage, hollow and immature kernels. The separation of the grain mix in an air stream depend on the ratio between air velocity and the terminal velocity of the particles, and the quantity of particles entrained per unit volume of air flow (Ghasemi *et al.*, 2008). In aeration and drying systems, resistance to airflow through the rice mass is an important consideration in determining the depth of rice to be stored, the fan to select, and the motor size needed (Juliano, 1985).

Several researchers (Arora, 1991; Correa *et al.*, 2007; Ghasemi *et al.*, 2008; Kachru *et al.*, 1994; Morita and Singh, 1979; Muramatsu *et al.*, 2007; Reddy and Chakraverty, 2004; Singh *et al.*, 2005; Tana *et al.*, 2003; Wratten *et al.*, 1969) determined some physical properties of rice grains for some specific varieties, levels of processing, and moisture content. There is less information about the effect of hull and mill processing on physical properties of rice. Hence, the aim of this research was to evaluate some physical properties of three rice varieties in different stages of the rice processing.

MATERIALS AND METHODS

Three paddy cultivars namely Tarom mahali, Fajr, Neda were obtained from Amol city, Mazandaran province, Iran during summer season in 2007. The grains were cleaned manually by removal all foreign matter such as dirt, stones, broken rice. The grains dried to approximately 12% (w.b.) by air convection oven drying at 105±3°C the grains (Correa *et al.*, 2007).

About 5 kg of rough rice sample of each variety was separated and kept in polyethylene bags. Sample of rough rice were dehusked with rice dehuller (Satake, THU-35, Satade Corp., Hiroshima, Japan), and the brown rice obtained. The output of rice dehusker was milled for 30 s in the friction mill (McGell Miller #2, Rapsco, Brookshir, TX). The resulting milled rice was cooled to room temperature and then separated manually into head rice and broken rice. The paddy, brown and head-milled rice samples were kept in polyethylene bags and then stored at 5°C in refrigerator until the experiments.

One thousand grains from each sample were counted with the help of counting 1000 kernels and weighted separately in a precision electronic balance (GT2100, OHAUS, USA) reading to an accuracy of 0.01 g. To obtain the unit mass, each sample was weighted by a precision electronic balance (GT2100, OHAUS, USA) reading to an accuracy of 0.01 g.

The true volume, V (mm^3), as a function of processing and variety was determined using the liquid displacement method (Mohsenin, 1970). Toluene (C_7H_8) was used in place of water, because it is less absorbed by grains. Also, surface tension is low, so that it fills even shallows dips in a grain and its dissolution power is low (Sitkei, 1976). True density, ρ_t (kg m^{-3}), of samples was then calculated by dividing the unit mass of each sample on its true volume.

In order to determine the bulk density, a cylindrical container of 0.3 m height and 0.2 m diameter was filled with grains from a height of 0.15 m from the top surface of the container and the top was leveled. No separate or additional manual compaction was done. The electronic balance was used for weighing and apparent or bulk density, ρ_b (kg m^{-3}), of samples were then defined as the ratio of the mass of bulk sample to the volume of container (Sharma *et al.*, 1985).

The porosity, ε (%), defined as the percentage of void space in bulk grain which is not occupied by the grain and determined using the following formula (Mohsenin, 1970):

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

The static coefficient of friction for the grains was measured against five frictional surfaces, namely plywood, galvanized iron sheet, glass, rubber, and fiberglass. A topless and bottomless box of dimension 150×100×40 mm^3 was placed on adjustable sloping surface. The box surface was raised gradually with the purpose of not to touch surface. The structural surface with the box resting on it was inclined gradually with a screw device until the box just started to slide down over the surface. The angle of slop, α, was read from a graduated scale. The static coefficient of friction, μ_S, was then calculated from the following equation (Mohsenin, 1970):

$$\mu_S = \tan(\alpha). \quad (2)$$

The filling or static angle of repose, θ_f, is the angle with the horizontal at which the rice will stand when piled. This was determined using an empty cylindrical mold of 15 mm diameter and 25 mm height. The cylinder was placed at the centre of galvanized iron plate, filled with rice grains and raised gradually until it forms a cone of grain. The height of the cone was measured and the filling angle of repose was calculated by the following relationship (Ozguven and Kubilay, 2004):

$$\theta_f = \tan^{-1}\left(\frac{2H}{D}\right), \quad (3)$$

where: H and D are the height and diameter of the cone, respectively.

The terminal velocity was measured using an air column apparatus. For each test, a sample was dropped into the air stream from the top of the air column, up which air was blown to suspend material in the air stream. The air column had 41.5 mm diameter. The air velocity near the location of the grain suspension was measured by electronic anemometer having a least count of 0.1 m s^{-1} (Gezer *et al*., 2002; Joshi *et al*., 1993; Mohsenin, 1970).

All physical properties of rice varieties for different levels of processing were measured by at least in three replications. Variance analysis was performed for each treatment and means was evaluated by Duncan's Multiple Rang Test at 5% probability by MSTATC software, version 1.42. Furthermore, the chart was prepared by Microsoft Excel software (2003).

RESULTS AND DISCUSSION

In levels of processing, the thousand grain mass values of Tarom mahali, Fajr, Neda cultivars varied from 16.76 to 27.88 g (Table 1). Fajr and Tarom Mahali represented highest and lowest value of thousand grain mass in each level of processing, respectively. Thousand grain mass was found to decrease significantly for every level of processing by reason of husk, bran and germ removal from paddy and brown rice, respectively. There is similarity between these results and the studies of Singh *et al.* (2005) for twenty-three different Indian milled rice and Sujatha *et al.* (2004) for milled rice of Jaya and Kayame varieties. Thousand grain mass value of rough rice for Tarom Mahali is similar to those that reported by Ghasemi *et al*. (2008).

The range of unit mass for Tarom Mahali, Fajr and Neda at different levels of processing were 0.02031-0.02701, 0.01798-0.02343 and 0.02312-0.03054 g, respectively (Table 1). The unit mass values showed marked difference among the varieties probably due to the intrinsic characteristics of each variety. In all varieties, unit mass of rice grains was found to decreased significantly with the rice processing as a result of husk, bran and germ removal.

The average value of single grain volume of rice at different levels of processing varied from 0.342 to 0.702 mm^3 (Table 1). Neda and Fajr represented highest and lowest value of volume in each level of processing, respectively. It was also found that the volume of each variety decreased by hulling and milling, which could be due to removing the husk, bran and germ of paddy. Ghasemi *et al*. (2008) found the volume of rough rice for Sorkheh and Sazandegi cultivars were 20.27 and 21.06 mm^3, respectively, which were lower than those found in this experiment. This could be owing to the different varieties, moisture content and levels of the rice grains.

The true density of Tarom Mahali, Fajr, and Neda varieties measured at different levels of processing varied from 1172.23 to 1375.18 kg m^{-3} (Table 1). The rough rice of each variety show the least value of true density, which agrees with Araullo, De Padua, and Graham (1976), who stated that the specific gravity of paddy is lower than that of brown rice. In addition, Correa *et al*. (2007) reported similar result in the case of true density of rice by processing. The true density values found in this experiment for rough rice were close to those reported by Ghasemi *et al*. (2008). They found a true density of 1269.1 and 1193.1 kg m^{-3} for Sorkheh and Sazandegi cultivars, respectively. In this research work, the least value belonged to the rough rice of Fajr variety. On the other hand, the true density values illustrated that Neda represent the greatest value for paddy, brown rice, and milled rice, probably due to intrinsic characteristics of this variety (Table 1).

The mean value for bulk density of different paddy, brown and milled rice ranged from 563.13 to 940.34 kg m^{-3} (Table 1). It was found that the milled rice of Tarom Mahali and rough rice of Fajr had the greatest and lowest value of bulk density, respectively. The significant increase in bulk density of rice grains at different levels of processing may be attributed to husk removal and by milling for the reason that the reduction in volume is higher than the corresponding reduction in mass of the grain. In each level of processing, the bulk density indicated significant difference between three cultivars. This may due to the intrinsic characteristics of each variety. Similar trends were reported for other varieties by Correa *et al*. (2007), but the values were lower than those found in this experiment. Brooker *et al*. (1992) found that the bulk density of long type rice grain range from 541 to 579. Ghasemi *et al*. (2008), report that the mean value for bulk density of Sorkheh and Sazandegi varieties of rice were 544.34 and 471.21, respectively. The different values may due to the types, varieties, and level of moisture content. According to Muramatsu *et al*. (2007), the bulk density of brown rice varied from 775 to 910 kg m^{-3}, when the moisture content decreased from 30.1 to 14.9 kg m^{-3}. Singh *et al*. (2005), reported that the bulk density of twenty-three milled rice in the range of 0.77-0.88 g ml^{-1}, which lower than the results that we found in this paper. These disparities may be owing to the different varieties, and levels of moisture content or processing of the rice. According to Araullo *et al*. (1976), the outmost tissue of the grain is commonly known as the husk and protects grain from undesirable conditions. The distinct space between the husk and caryopsis in dried grain filled with air and allows the grain to be dehusked without any or very little abrasion to pericarp. As a result of this void space, the bulk density of paddy decreased by dehulling.

The porosity of Tarom Mahali, Fajr, and Neda varieties decreased when these varieties processed from paddy to milled rice (Table 1). For different cultivars, the effect of processing on porosity of grain indicated significant decrease with processing. The trend was found similar to the one reported for the rice grains studied by Correa *et al*. (2007). It could be attributed to the spikelet feature of the

Table 1. Average values of thousand grain mass, volume, porosity, bulk density and true density of rough rice, brown rice and milled rice of three varieties

Levels of processing	Variety		
	Tarom Mahali	Fajr	Neda
	Thousand grain mass (g)		
Rough rice	21.25 Ca	27.88 Aa	23.61 Ba
Brown rice	18.11 Cb	23.48 Ab	19.82 Bb
Milled rice	16.76 Cc	21.22 Aa	17.85 Bc
	Unit mass (g)		
Rough rice	0.02701 Bb	0.02343 Ca	0.03054 Aa
Brown rice	0.02297 Bb	0.01956 Cb	0.02508 Ab
Milled rice	0.02031 Bc	0.01798 Cc	0.02312 Ac
	Volume (mm^3)		
Rough rice	0.632 Ba	0.580 Ba	0.702 Aa
Brown rice	0.476 Ab	0.392 Bb	0.532 Ab
Milled rice	0.458 Ab	0.342 Bb	0.422 Ac
	True density (kg m^{-3})		
Rough rice	1203.99 Bc	1172.23 Bb	1252.68 Ab
Brown rice	1358.11 Aa	1360.18 Aa	1410.42 Aa
Milled rice	1282.43 Bb	1371.67 Aa	1375.18 Aa
	Bulk density (kg m^{-3})		
Rough rice	640.10 Bc	563.13 Cc	687.76 Ac
Brown rice	877.95 Ab	869.23 Bb	864.08 Bb
Milled rice	940.34 Aa	938.02 Aa	936.14 Aa
	Porosity (%)		
Rough rice	46.79 Ba	51.77 Aa	45.16 Ba
Brown rice	35.24 Ab	36.07 Ab	38.69 Ab
Milled rice	26.41 Bc	31.47 Ac	31.90 Ac

For each test, the mean followed by the same capital letter is in the row and same lower case letter in the columns, they do not differ statistically at 5% probability through the Duncan's Multiple Rang Test.

rice husk, allowing more void space in the bulk grains and when processed, the void space reduced and consequently the porosity. In every level of processing, Fajr and Tarom Mahali represented highest and lowest values of porosity, which could be owing to intrinsic characteristics of cultivars. The porosity values for paddy in this work were lower than those found by Silva and Correa (2000), Ghasemi *et al.* (2008), and Wratten *et al*. (1969), which were approximately 60% for grains with 12% (w.b.) moisture content.

The experimental results showing the effect of cultivars, level of processing, and structural surfaces on the static coefficient of friction are presented in Table 2. The static coefficient of rice grain was found to lie between 0.1929 and 0.5612. For all cultivars in every level of processing, the static coefficient of friction was greatest against rubber and the least for glass. Among rice cultivars, static coefficients of friction decreased with hulling and milling against all frictional surfaces studied, which were greatest for paddy and least for milled rice. The resemble trend of static friction with processing was also observed by Correa *et al*. (2007). This was due to the fact that the husk formed mostly of cellulosic and fibrous tissue and is covered with very hard glass-like spines. Furthermore, beneath the tegmen is a layer of tissue several cells of in thickness commonly known as aleurone layer or bran. The shape of the cells of this layer is somewhat hexagonal to spherical (Araullo *et al.*, 1976).

T a b l e 2. The static friction coefficients of rough rice, brown rice and milled rice of three varieties on different frictional materials

Variety	Level of processing	Friction material				
		Plywood	Galvanized iron	Glass	Rubber	Fiberglass
Tarom Mahali	Rough rice	0.5078 BB'a	0.3366 CC'a	0.2940 DB'a	0.2624 EA'a	0.5443 AA'a
	Brown rice	0.4561 BA'b	0.2970 CB'b	0.2579 DA'b	0.2232 EA'b	0.4986 AA'b
	Milled rice	0.4175 BB'c	0.2605 CA'c	0.2250 DB'c	0.2024 EB'c	0.4570 AA'c
Fajr	Rough rice	0.5353 BA'a	0.4093 CB'a	0.2357 EB'a	0.5612 AA'a	0.3395 DA'a
	Brown rice	0.4715 AA'b	0.2815 BB'b	0.1966 CB'b	0.4878 AA'b	0.2797 BB'b
	Milled rice	0.4440 AA'c	0.2460 BB'c	0.1929 CB'b	0.4557 AA'c	0.2380 BA'c
Neda	Rough rice	0.5403 AA'a	0.4452 BA'a	0.2654 DA'a	0.5546 AA'a	0.3541 CA'a
	Brown rice	0.4697 AA'b	0.3019 BA'b	0.2394 DA'b	0.4891 AA'b	0.2672 CA'b
	Milled rice	0.4474 AA'c	0.2739 BA'c	0.2291 CA'b	0.4630 AA'c	0.2564 BA'b

For each test, the mean followed by the same capital letter is in the row and same lower case letter is in the columns and the same (letter)', [1] among every levels of processing in three rice varieties, they do not differ statistically at 5% probability through the Duncan's Multiple Rang Test. ([1]For example, the rough rice of Fajr and Neda are the same, but the third one is difference. Hence, as it shown by the (letter)', the rough rice of Tarom Mahali (B') and others such as Neda (A'), Fajr (A') are different. It shows significant difference among these treatments).

Thus, the hulling and milling operation cause the grain surface smoother that agrees with Mohsenin (1970), who claimed that the nature and the type of surface in contact play important role in friction. It was also observed that statistically the coefficients of friction for Neda was greatest among the cultivars (except for the friction of brown rice against fiberglass), which could attributed to intrinsic characteristics of this variety.

Benedetti (1987) reported that rough rice with 11.4% (w.b.) moisture content on wood, concrete and steel surfaces showed static coefficients of friction of 0.364, 0.533 and 0.221, respectively. For the same surfaces, Brooker *et al.* (1992) (cited by Fotana, 1986) determined a friction coefficient value range of 0.4-0.45, 0.45-0.6 and 0.4-0.5 for wood, concrete and steel, respectively. Ghasemi *et al.* (2008) reported that static coefficient of paddy for Sorkheh and Sazandegi on Plywood, Glass, and Galvanized iron sheet were varied from 0.4245 to 0.4557, 0.2679 to 0.3153, 0.3153 to 0.3249, respectively.

The static coefficient values for Tarom mahali, Fajr, and Neda varieties were found to be higher than those, which reported by Benedetti (1987), Brooker *et al.* (1992), and Ghasemi *et al.* (2008) for wood. On the other hand, we obtain the similar results to those found by Ghasemi *et al.* (2008) for galvanized iron sheet. The differences in the values should be due to the fact that the roughness of the material used was different to those used in this work or due to the use of different methodologies and or apparatus for determining the friction coefficient.

The experimental values of angle of repose are given in Table 3 and it was ranging from 14.40 to 12.76, 14.76 to 12.40, and 13.60 to 11.65° for Tarom Mahali, Fajr and Neda, respectively. In all varieties, the angle of repose decreased by processing and milled rice showed the lower angle of repose values. The angle of repose for paddy, brown rice, and milled rice, practically did not present significant difference among the varieties. Similar trends have been reported by Ghasemi *et al.* (2008) for emptying angle of repose of rough rice between the Sorkhe and Sazandegi cultivars.

The experimental results for the terminal velocity of different rice cultivars at three levels of processing are shown in Table 4. The terminal velocities required suspending the rough rice, brown rice and milled rice were found to be varied from 6.00 to 7.76, 6.42 to 7.72 and 6.64 to 7.74 m s^{-1}, respectively. By dehusking and polishing, the terminal velocity was found to increase significantly for each variety. The increase in terminal velocity by hulling could be attributed to the increase in true density of an individual grain per unit frontal area presented to the air stream.

The terminal velocity of husk is higher than bran (Fig. 1). The terminal velocities of husk were greatest for Tarom Mahali and least for Fajr, respectively. On the other hand, the terminal velocities of bran were greatest for Fajr and least for Tarom Mahali. As expected, the results followed the same trend with the terminal velocity of the hull and bran being lower than for the paddy, brown rice, milled rice. The

T a b l e 3. Average values of filling angle of repose for rough rice, brown rice and milled rice of three varieties

Level of processing	Variety		
	Tarom Mahali	Fajr	Neda
Rough rice	14.40 Aa	14.76 Aa	13.60 Aa
Brown rice	13.26 Bb	13.33 Bb	13.47 Ba
Milled rice	12.76 Ca	12.40 Cb	11.65 Cb

Explanations as in Table 1.

T a b l e 4. Average values of terminal velocity of rough rice, brown rice and milled rice of three varieties

Level of processing	Variety		
	Tarom Mahali	Fajr	Neda
Rough rice	6.00 Cc	6.42 Bc	6.64 Ac
Brown rice	7.20 Cb	7.40 Bb	7.58 Ab
Milled rice	7.76 Aa	7.72 Aa	7.74 Aa

Explanations as in Table 1.

significant between the suspension air velocities for the rough rice, brown rice, milled rice, hull, and bran indicates that separa- tion of these fractions by pneumatic means is completely feasible.

Rajabipour *et al*. (2004) found the terminal velocity of paddy in the range of 5.5-5.7 m s^{-1}. Tana *et al*. (2003) reported that terminal velocity was 6.8 m s^{-1} in brown rice. The terminal velocities found in this paper were higher than those reported by Rajabipour *et al*. (2004) and Tana *et al*., (2003). This could be due to the different types and varieties of the rice grains used in these research works.

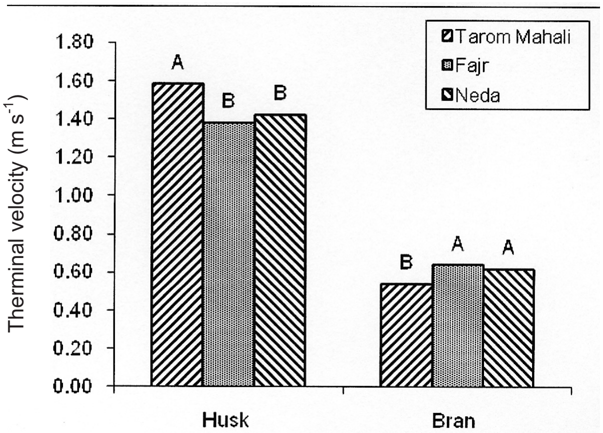

Fig. 1. Terminal velocity of husk and bran of three rice cultivars used in this study.

CONCLUSIONS

1. Thousand grain mass decreased significantly for every level of processing.

2. Unit mass and volume of single of rice decreased with the rice processing.

3. The bulk density of the rice grains increased significantly during the different steps of processing.

4. The rough rice of each variety showed the least value of true and bulk densities.

5. For different cultivars, the effect of processing on porosity of grain indicated significant decrease with the rice processing.

6. The static coefficient of friction affected by cultivars, levels of processing, and frictional materials. For all cultivars in each level of processing, the static coefficient of friction was greatest against rubber and the least for glass.

7. Among cultivars studied, static coefficients of friction decreased with hulling and milling against plywood, galvanized iron sheet, glass, rubber, and fiberglass, which were greatest for paddy and least for milled rice.

8. The filling angle of repose for all cultivars decreased by hulling and milling.

9. By husking and milling, the terminal velocity increased significantly for each variety. In addition, the terminal velocity of the hull and bran is lower than for the paddy, brown rice, milled rice.

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