Australian Journal of Crop Science
AJCS
AJCS 8(3):332-337 (2014) ISSN:1835-2707

Determination of some physical properties of common Malaysian rice MR219 seeds

Zubairu Usman Bashar[1], Aimrun Wayayok[1, 2] and Amin Mohd Soom Mohd[2]

[1]Department of Biological and Agricultural Engineering faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia
[2]Smart Farming Technology Research Centre, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia

Corresponding author: zubairug@yahoo.com

Abstract

Knowledge on physical properties of seeds is an important tool for designing agricultural machines and other equipment to handle planting, harvesting, processing, packaging and storing. The most common rice variety grown in Malaysia is MR219 but the data on its physical properties is still lacking. The aim of this study was to determine the effect of moisture content on the physical properties (basic dimensions, porosity, bulk and true densities, coefficient of friction, repose angle and sphericity) of MR219 rice variety. . These properties were evaluated as a function of moisture content at 14.26, 18.94 and 22.50% dry basis. The results revealed that length, width and thickness increased from 9.639 to 10.187, 2.266 to 2.2416 and 1.878 to 2.038mm, respectively with increasing moisture content from 14.26 to 22.50%. Similarly,1000 seed mass (M_{1000}) increased from 27.06 to 29.88g as well as arithmetic and geometric mean diameters from 4.85 to 4.88 and 3.44 to 5.68 mm. Bulk density, sphericity, and surface area have reported increase with increasing moisture content from 517.70 to 543.544kg/m^3, 0.358 to 0.362% and 37.203 to 42.596mm^{2,} respectively. A decrease was observed for true density (1244.571 to 1197.488kg/m^3) and porosity (58.403 to 54.610) as seeds rewetting increased. The static coefficient on three surfaces, namely PVC, plywood and aluminum showed increase on PVC and aluminum from 0.356 to 0.387 and 0.309 to 0.324 but a decrease on plywood from 0.372 to 0.341, respectively. This technical information is useful to design the machines for handling MR219 rice seeds.

Keywords: MR219, Porosity, Moisture Content, Axial Seed Dimension, Coefficient of Friction.
Abbreviations: ASAE_American Society of Agricultural Engineering, IRRI_International Rice Research Institute, FAO_Food and Agricultural Organization, PVC_Polyvinyl Chloride

Introduction

Rice (*Oryza Sativa* in Asia or *Oryza Glaberrima* in Africa), is classified as a monocotyledon plant because of its behavior of producing one leaf per growth development. Rice is considered by cultural geographers as the staple food for a large part of the human population especially in Asia, Africa and some parts of Europe, America, and West Indies in which the latter were predominantly dependant on other cereals such as millet, wheat and maize. According to FAO, (2004), rice stands as a grain with third highest world production after wheat and maize. Smith (1998) stated that, rice is the most important grain with regards to human nutrition and caloric intake, by providing more than $^1/_5$ of the calories consumed by human worldwide.

Information on the physical and mechanical properties of the agricultural products is an important tool for designing equipment for the purpose of planting, harvesting, dehulling, drying, handling as well as storing. Therefore, seed dimensions (width, thickness and length), 1000 seed mass (M_{1000}), surface area, porosity, sphericity, static coefficient of friction against different materials, repose angle, hardness, true and bulk densities are among the properties that are considered "physical" by researchers as per seed (Bande et al., 2012a). These variables are central in classification of seeds and in the design of machines for processing or analyzing the behavior of the product in handling or grading (Mohsenin, 1980). They are central because they give technical information to the designer on what are the basic "inputs" for their design.

All physical properties of seeds are dependent on the moisture content. They respond either in increasing or decreasing trend as the moisture content varies. The initial moisture content is determined by subjecting seeds to oven drying (either air or vacuum) at temperatures between 80^{o}C to 130^{o}C for 8hrs to 24hrs by ASAE standards (S.352.3, 1994).

The purpose of this study was to determine the effect of moisture content on the physical properties of MR219 rice which is the most common rice variety grown in Malaysia, covering almost 90% cultivated area. Therefore, machine designers and engineers can utilize this information for future design of equipment related to rice seed, specifically MR219 variety.

Results and Discussion

Effect of seed dimensions, mean diameters, 1000 mass, surface area and sphericity

The average values of axial dimensions of the seed (length, width and thickness) at varying moisture content are shown in Table 1. It was noted in Figure 1 that seed dimensions gradually increased with additional moisture level. At a moisture content of 14.26% dry basis, the mean values for

Table 1. Mean and standard error for dimensions, surface area, 1000 seed mass and sphericity.

Moisture Content (%)	Length (mm)	Width (mm)	Thickness (mm)	Surface area (mm^2)	M_{1000} (g)	Arith. Mean (mm)	Geo. Mean (mm)	Sphericty (%)
14.26	9.639± 0.214	2.266± 0.043	1.878± 0.126	37.361	27.06± 0.165	4.594	3.448	0.358
18.94	10.064 ± 0.072	2.272± 0.065	1.948± 0.013	39.471	28.61± 0.398	4.761	3.544	0.352
22.50	10.187 ± 0.025	2.416± 0.021	2.038± 0.007	42.723	29.88± 0.641	4.880	3.687	0.362

length, width and thickness were: 9.639 ± 0.214, 2.266 ± 0.043 and 1.878 ± 0.126mm, respectively. These values changed to 10.187 ± 0.025, 2.416 ± 0.021 and 2.038 ± 0.007mm for length, width and thickness, respectively, when the moisture increased to 22.50%. Similar findings were reported by (Singh, 1996; Dutta et al., 1988; Aydin and Ozean, 2004; Enoch et al., 2008)]. Furthermore, Yelcin and Ersan,(2007) also concluded in their studies on coriander seeds *(coriandrum sativum L)* seeds that the effect of moisture variation has tremendous influence on seeds dimensions. Similar observation was also reported by Solomon and Zewdu (2009) on niger seed where the dimensions increased by about 11% with the rise of moisture from 5.60 to 31.67%. The linear relationships of these values with respect to moisture content are presented in Equations [1], [2] and [3]. In conclusion, the use of these properties has a great impact on the design of separators or cleaners as well as for determining the terminal velocities or drag coefficients.

$L = 8.708 + 0.068\ MC,\quad R^2 = 0.948^{*}$ [1]
$W = 1.996 + 0.017\ MC,\quad R^2 = 0.712^{ns}$ [2]
$T = 1.598 + 0.019\ MC,\quad R^2 = 0.978^{*}$ [3]

Where, L is length (mm), W is width (mm), T is thickness (mm), MC is Moisture content (%) and R^2 represents coefficient of determination.

Effect of arithmetic and geometric mean diameters, M_{1000}, surface area and sphericity on moisture content

The average values for arithmetic and geometric mean diameters, M_{1000}, surface area and sphericity are presented in Figure 2 and Table 1. The results of the experiment indicated significant influence when moisture content increased from 14.26 to 22.5%. These values sequentially increased from 4.594 to 4.880 and 3.448 to 3.687mm for arithmetic and geometric mean diameter, respectively. Likewise, the 1000 mass also increased from 27.06 to 29.88g. Sphericity indicated similar increase from 0.358 to 0.362%. Thus, Equations [4], [5], [6], [7] and [8] represent linear relations of these values with increasing moisture. Similar findings were observed for hemp seed (Sacilik et al., 2003), wheat (Tabatabaeetar, 2003), coriander seeds (Yelcin and Ersan, 2007), cowpea (Henshaw, 2008), soybean (Davies et al., 2009), but the findings of Adejumo et al., (2007) reported a decrease in sphericity on white variety of groundnut. This report was similar to Sedat et al., (2005) on rapeseed (*Brassica napus oleifera L)*, where the sphrericity decreased with moisture from 0.93 to 0.91 within moisture range of 4.70 to 23.96%. A decreased was also reported on M_{1000} on rice grain by Razavi and Farahmandfar, (2008), where they concluded that it was due to the removal of husk, bran and germ from paddy seed.

$M_{1000} = 22.243 + 0.339\ MC,\quad R^2 = 0.999^{***}$ [4]
$S = 27.753 + 0.645\ MC,\quad R^2 = 0.964^{*}$ [5]
$\theta = 0.350 + 0.0004\ MC,\quad R^2 = 0.105^{ns}$ [6]

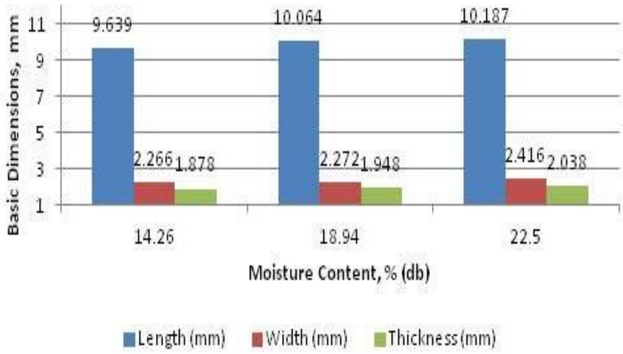

Fig 1. Influence of moisture content on Basic dimensions of the seeds.

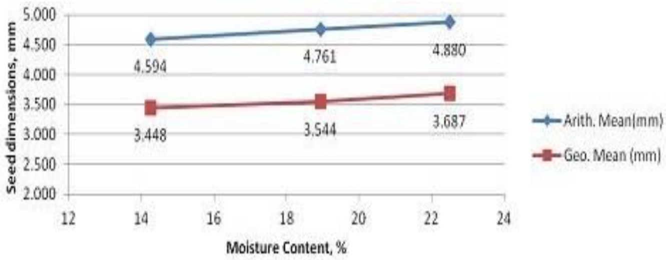

Fig 2. influence of moisture content on arithmetic and geometric means of seed dimensions.

$D_a = 4.010 + 0.035\ MC,\quad R^2 = 0.999^{***}$ [7]
$D_g = 3.029 + 0.029\ MC,\quad R^2 = 0.964^{*}$ [8]

Where, M_{1000} is 1000 seed mass (g), S is surface area (mm^2), θ is sphericity (%), D_a is arithmetic mean (mm) and D_g represents geometric mean diameter (mm). MC is Moisture content (%) and R^2 represents coefficient of determination.

Effect of bulk and true densities of MR219 rice at different moisture content

The bulk density of MR219 rice seed was measured at different moisture contents and found to increase at various levels; at 14.26% it was 517.70kg/m^3 and a significant increase was observed when the moisture content increased to 22.50% with bulk density value of 543.544kg/m^3. Similar findings were reported by Reddy and Charkraverty, 2004 with increasing values from 522 to 566kg/m^3 on raw paddy when the moisture content was increased from 7.19 to 28.28% dry basis. It was also reported an increase in bulk density from 454.8 to 537.6kg/m^3 when subjected to moisture changes of 6 to 18.13% by Kingsly et al, 2006 on dried pomegranate. This relationship between the bulk density and moisture content is presented in Equation [9].

Table 2. Moisture content with bulk and true densities, porosity, coefficients of friction, and repose angle.

Moisture Content (%)	Bulk density (kg/m^3)	True density (kg/m^3)	Porosity (%)	Coefficient of Friction PVC	Coefficient of Friction Plywood	Coefficient of Friction Alum.	Repose Angle (°)
14.26	517.700 ± 8.975	1244.571 ± 4.191	58.403	0.356	0.372	0.309	28.43
18.94	524.979 ± 3.035	1226.412 ± 1.264	57.194	0.362	0.355	0.323	29.23
22.50	543.544 ± 4.796	1197.488 ± 2.652	54.610	0.387	0.341	0.324	29.83

ρ_b = 472.017 + 3.055 MC, $R^2 = 0.896^*$ [9]

The true density was calculated at different moisture contents and observed to decrease with an increase in moisture content ranging from 1244.571 to 1197.488 kg/m^3 as moisture content increase from 14.26 to 22.50% as shown in Figure 3 and Table 2. These densities related to moisture content by equations [9 and 10]. Similar findings of various research works Dutta et al., (1988) on gram seeds; Ozarslan, (2002) on cotton seeds; Sacilik et al., (2003) on hemp seeds; Garnayak et al., (2008) on jatropha seeds (*jatropha curcas L.*) were also reported that, the mass of the seeds linearly increased with increasing moisture. But the reports of Kingsly et al., (2006) on dried pomegranate indicated an increase on true density with increasing moisture of 6 to 18.13%.

ρ_t = 1327.165 – 0.562 MC, $R^2 = 0.957^*$ [10]

Where, ρ_b is bulk density (kg/m^3) and ρ_t is true density (kg/m^3), MC is Moisture content (%) and R^2 represents coefficient of determination.

Effect of porosity (ε) on moisture content

The porosity of MR219 rice seed decreases with the increase in moisture content as shown in Table 2, Fig. 4 and Equation 11, when the moisture content increased from 14.26 to 22.50% the porosity dropped from 58.403 to 54.610. Therefore, this decrease may be attributed to the change in bulk and true densities with moisture content. Similar trends were reported for Sunflower (Gupta and Das, 2000), Cashew nut (Balasubramanian, 2001), Water melon (Koocheki et al., 2007) and Bitter melon (Bande et al., 2012b) but the findings of Mustafa (2007) on Barbunia seeds reported an increase in porosity with increasing moisture. He recorded an increase from 47.85 – 48.56% with the moisture rising from 18.33 to 32.43%.

ε = 65.091 – 0.450 MC, $R^2 = 0.921^*$ [11]

Where, ε is porosity (%), MC is Moisture content (%) and R^2 represents coefficient of determination.

Static coefficient of friction (cf) of MR219 rice variety against different surfaces

The static coefficient of friction with respect to three surfaces, namely PVC, plywood and aluminum were evaluated against the moisture content (ranged from 14.26 to 22.50% dry basis). These were found to increase linearly with increasing moisture, thus on PVC from 0.356 to 0.387 and aluminum (0.309 to 0.324), respectively. But a decrease was observed on plywood from 0.372 to 0.341 as the moisture increased. Table 2, Figure 5 and Equations [12], [13], and [14] represent a summary of the relationships between moisture content and static coefficient of friction. Similar findings were reported on the relationship between moisture content and coefficient of friction at different surfacesby Coskun et al., (2005) on sweet corn; Kingsly *et .al.*, (2006) on dried pomegranate; Razavi and Farahmandfar, (2008) on rice; Bande et al., (2012a) on egusi melon, but the findings of (Karimi et al., 2009) on wheat and (Tavakoli et al., 2009) on soybean grain revealed a linearly increased on all the surfaces with increasing moisture.. The findings of Ghasemi et al, (2008) revealed similar results with Sorkhen rice variety on plywood (0.43) at 10% moisture content.

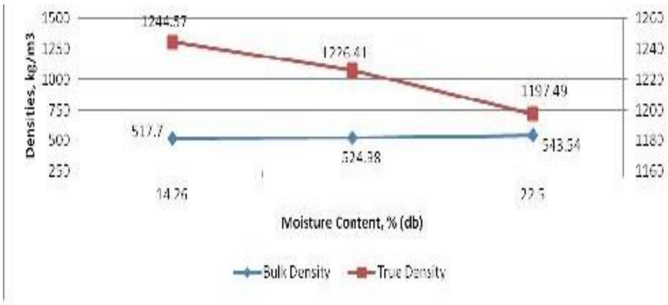

Fig 3. Influence of moisture content on bulk and true density

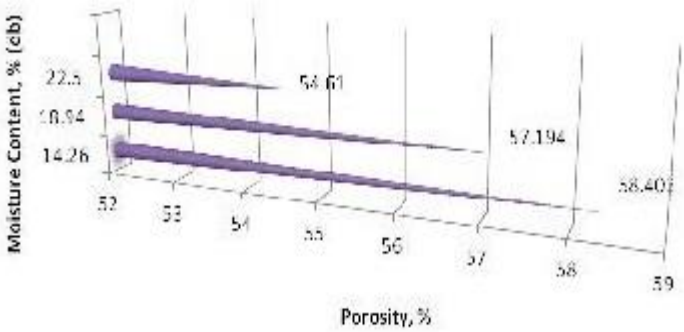

Fig 4. Influence of moisture content on porosity.

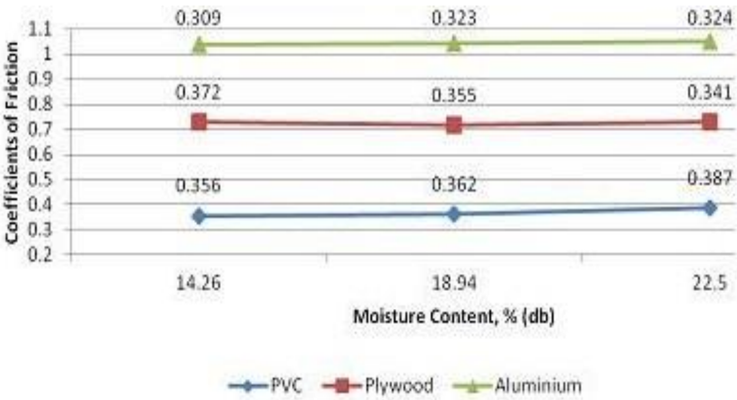

Fig 5. Influence of moisture content on coefficient of friction.

$Cf_{(PVC)}$ = 0.301 + 0.004 MC, $R^2 = 0.835^{ns}$ [12]

$Cf_{(Plywood)}$ = 0.428 – 0.004 MC, $R^2 = 0.999^{***}$ [13]

$Cf_{(Aluminum)}$ = 0.284 + 0.002 MC, $R^2 = 0.858^{ns}$ [14]

Where, $Cf_{(PVC)}$ is static coefficient of friction on PVC, $Cf_{(Plywood)}$ is static coefficient of friction on plywood while $Cf_{(Aluminum)}$ stands for static coefficient of friction on aluminum, MC is Moisture content (%) and R^2 represents coefficient of determination.

Material and Methods

Samples and sample preparation

The MR219 rice seeds for the study were obtained from Tanjong Karang rice growing area in Selangor, Malaysia. The sample seeds were manually cleaned so as to ensure that all foreign matter such as dirt, husk, immature or broken seeds, stones, weed – seeds and sand particles have been removed. The initial moisture content of the seed was then determined by oven drying method at 130±3ºC for 16 hours, following the (ASAE, 2003; IRRI Rice Knowledge Bank) standards (Coskum, et al., 2005; Yelcin and Ersan, 2007; and Jouki et al., 2012). The initial moisture content was 14.26 % dry basis. Readings were then repeated in ten replicates in order to minimize error.

MR219 rice samples were prepared by adding calculated amount of distilled water and sealed in polythene bags in order to raise the seeds moisture. These samples were refrigerated for 3 days at 5ºC to enable uniform moisture distribution. This approach of raising the moisture has been validated by many researchers such as (Mohsenin, 1980; Sacilik et al., 2003; Dursan et al., 2007; Solomon and Zewdu, 2009). Before starting the experiment, only the required quantity of seeds were removed from the refrigerator and allowed to cool to room temperature for 2 hrs. Equation [15] recommended by (Balasubramanian, 2001; Sacilik et al., 2003; Davies et al. 2010; Sharma et al., 2011) was used for calculating the amount of moisture to be added over the level of equilibrium moisture.

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \quad [15]$$

Where, Q is mass of water added (kg), W_i is initial mass of sample (kg), M_i is initial moisture content (% d.w.), and M_f is final moisture content (% d.w.)

Determination of basic dimensions

The basic dimensions of the seed (length, width and thickness) were measured using a digital micrometer screw gauge (Mitutoyo Digital Micrometer, Series - 193) with accuracy 0.001mm. Similarly, method was reportedly used by (Mohsenin, 1980; singh et al., 1996; Vilche et al., 2003; Karababa, 2006; Bande et al., 2012a) in measuring different seeds size and shape. Calculation of the average diameter of MR219 rice seeds was done by arithmetic and geometric means of the three basic seed dimensions (length, width and thickness). These values were computed using the relationship in Equations [16] and [17] suggested by (Mohsenin, 1980; kiani Deh Kiani et al., 2008; Shkelqim et al., 2010).

$$D_a = \frac{L+W+T}{3} \quad [16]$$

$$D_g = (LWT)^{1/3} \quad [17]$$

Where, D_a is Arithmetic mean *(mm),* D_g *is g*eometric mean diameter *(mm), L* is length, *(mm), W* represents Width *(mm) and T* is thickness *(mm).*

The Sphericity is defined as the ratio of the surface area of the sphere having the same volume as that of the seed. Likewise, it is regarded as the degree of closeness of seed to a sphere. Furthermore, it also describes the rolling ability of seed during processing therefore it is a function of the basic dimensions (length, width and thickness) and can be calculated using the formula in Equation [18] (Mohsenin 1980; Erica et al., (2006); Garnayak et al., 2008; Davies and Zibokere, 2011).

$$\emptyset = \frac{(LWT)^{1/3}}{L} \quad [18]$$

Where, L is the length, W as the width of the seed and T represents the seed thickness.

Determination of 1000 seed mass

Mass of 1000 seeds was determined using an electronic digital balance (Mitutoyo Digital Scale) with accuracy of 0.001g. To determine the average weight of 1000 seeds, a sample size of 100 seeds were randomly selected and weighted. This result was then multiplied by 10 so as to get mass of 1000 seeds. Similar method was reportedly used by Visvanthan et al., (1996); Ozarslan, (2002); Sacilik et al., (2003); Ibrahim (2007); Garnayak et al., (2008) and Sharma et al., (2011). Readings were repeated in five replications to reduce error.

Determination of surface area

Surface area is an important property of seed. It helps the designer in estimating the hopper, processing chamber and the chute. The surface area was found by analogy with a sphere of some geometric mean diameter using the expression in Equation [19] cited by (McCabe et al., 1986; Amin et al., 2004; Jouki and Khazaei, 2012).

$$S = \pi D_g^2 \quad [19]$$

Where; S (mm^2) represents surface area and D_g stands for geometric mean diameter (mm) respectively.

Determination of static coefficients of friction

The static coefficients of friction were found with respect to three surfaces, viz. PVC, aluminum sheet and plywood. This can be expressed as the degree of resistance of seed to flow on a given surface. The static coefficient of friction of the seed was determined by tilting on a platform of 330mm by 200mm. A hollow plastic cylinder of diameter 70mm and height as 50mm and open at both ends was used. The cylinder was filled with the seeds and placed on the material surfaces and gently lifted until the filled cylinder just started to slide down. Height at which the slide began was read as h and the distance from the base to the platform was read as d. Coefficient of tilt μ and the angle of tilt were calculated using the formula in Equation [20] (Dutta et al., 1988; Razavi and Milani 2006; Altuntas et al., 2007; Davies and Zibokere, 2011).

$$\mu = \tan \alpha \quad [20]$$

Whereas, μ is the coefficient of friction, h is the height of cone and d is the base diameter of the cone while α is the angle of inclination.

The bulk density is the ratio of the mass of seed samples to its total volume. This is determined by freely pouring the seeds in a fixed volume container of predetermined weight and re-weighted to find the mass of seed. The density is then enumerated from the mass of seeds as a function of volume of the container. The average bulk density was determined by filling 100 ml container with seed from a height of 70.90mm at a constant rate and reweighting the content with no compaction on the seeds. The volume of the beaker was calculated using Equation [22] and the bulk density as shown in Equations [21] by Mohsenin, (1986); Razavi and Milani, (2006); Karimi et al., (2009); Tavakoli et al., (2009) and Bande et al. (2012b) and it was repeated for ten replications. Furthermore, increase in mass of the seed increases or decreases the bulk density of the seed. Some researchers have presented negative trends on some seeds while some reported otherwise. It is therefore used in determination of porosity and in estimation of food fungal attack rate.

$$\rho_b = W_b / V_b \qquad [21]$$

$$V_b = \pi r^2 h \qquad [22]$$

Where, ρ_b is Bulk density, W_b is mass, V_b represents volume, r is the radius and h stands as height respectively.

The water displacement method was used to determine the true density of the seeds which has been defined as the ratio of mass of the seeds to the true volume of displaced water (Mohsenin, 1986; Deshpande et al. 1993; Omobuwajo et al., 2000; Garnayak et al., 2008). The true density was obtained by measuring 10g of MR219 seeds and filling into a 100ml of distilled water, thus the difference in liquid displacement was taken in 10 replications and average recorded.

The porosity is defined as the ratio of empty space of seeds to its total volume. This was calculated from the measured values of densities (Bulk and True) using the relationship given in Equation [23] (Mohsenin, 1986; Mustafa, 2007).

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) 100 \qquad [23]$$

Where, ρ_b is the bulk density and ρ_t is the true or grain density.

Repose angle was determined by pouring the seeds in a hollow circular plastic material of diameter 60 mm base by 80 mm height. The container was carefully filled with seeds and slowly lifted until it is free of the seeds to obtain a conical pile of seeds. The height of the cone was measured. The angle of repose was calculated using Equation [24] (Kalamullah and Gunasekar, 2002; Sirisomboon et al., 2007; Garnayak, 2008 as reported on *jatropha* to be in the range of 28 to 40. This variation of angle of repose with seed moisture is, as reported and concluded by many, that it increases linearly with the seed moisture content as the surface of the seeds become wet thereby sticking to one another. This information will help in design of storage facility also.

$$R_a = tan^{-1} (2h/d) \qquad [24]$$

Where R_a is the repose angle while h and d are the height and diameter of the cone, respectively.

Conclusion

This study concludes that 1000 seed mass, basic dimensions, sphericity, repose angle, bulk density, and static coefficient of friction on PVC and aluminum increase with the increasing moisture content (14.26 to 22.50%). But a decrease was observed in porosity, true density and static coefficient of friction on plywood surface. These data are highly essential for design and development of dehulling machine , raising rice seedling singly in nursery tray and as well as transplanter to plant seedling singly.

Acknowledgement

The authors would like to thank the Universiti Putra Malaysia for full support and grant allocated to the research through its Research University Grant Scheme (RUGS) on project number: 05 – 02 – 12 – 2199RU.

References

Adejumo OI, Alfa AA, Muhammed A (2007) Physical properties of Kano white variety of Bambara Groundnut. Nigerian Acad Forum. 12: 68 – 77.

Altuntas E, Yildiz M (2007) Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba*) grains. J Food Eng. 78: 174 – 183.

Amin MN, Hossain MA, Roy KC (2004) Effects of moisture content on some physical properties of lentil seeds. J Food Eng. 65: 83 – 87.

ASAE Standard (2003) Moisture measurement-unground grain and seed. American Society of Agricultural Engineers. Pp: 554 – 561.

Aydin C, Ozean M (2003) Some physico-mechanical properties of terebinth fruits. J Food Eng. 53: 97 – 101

Balasubramanian D (2001) Physical properties of raw cashew nut. J Agric Eng Res. 78: 291 – 297.

Bande YM, Adam NM, Azmi Y, Jamarei O (2012a) Determination of selected physical properties of Egusi melon (*Citrullus colocynthis lantus*) seed. J Basic Appl Sci. 8: 257 – 265.

Bande YM, Adam NM, Azmi Y, Jamarei O (2012b) Moisture- dependent physical and compression properties of Bitter melon (*Citrullus colocynthis lantus*) seeds. J Agric Res. 7(5): 243-254.

Coskum MB, Yalcin I, Ozarslan C (2005) Physical properties of sweet corn seed (*zea mays saccharata sturt*). J Food Eng. 74(4): 523 – 528.

Deshpande SD, Bal S, Ojha TP (1993) Physical properties of soybean. J Agric Eng Res. 56: 89 – 98.

Davies RM, El-Okene AM (2009) Moisture-dependent physical properties of Soybeans. Int Agrophysics. 23: 299 – 303.

Davies RM (2010) Some physical properties of Aroga seed. Int Agrophysics. 24: 89 – 92.

Davies RM, Zibokere DS (2011) Effect of moisture content on some physical and mechanical properties of three varieties of cowpea (*Vigna unguiculata (L) walp*). Agric Eng Int CIGR J. 13(1).

Dursun I, Tugrul KM, Dursun E (2007) Some physical properties of sugerbeet seed. J Stored Products Res. 43: 149 – 155.

Dutta SK, Nema VK, Bhardwaj RK (1988) Physical properties of gram. J Agric Eng Res. 39: 259 – 268.

Erica B, Adela C, Susana MN, Isabel CR (2006) Moisture-dependent physical and compression properties of safflower seeds. J Food Eng. 72: 134 – 140.

Enoch GA, Rose F, Hermane TA, Raymond SV, Osmane C, Adam A (2008) Importance and Practices of bitter melon crops in sociolinguistic areas in Benin. Biotech Agro Envir J. 12(4): 393 – 403.

Food and Agricultural Organisation (FAO) (2004) The state of food insecurity in the world: Monitoring progress towards the World Food summit and the Millennium Development Goals,Viale delle terme di Caracalla, 00100 Rome, Italy.

Garnayak DK, Pradhan RC, Naik SN, Bhatnager N (2008) Moisture-dependent physical properties of Jatropha seeds (*Jatropha curcas L*). Ind Crops Products, 27: 123 – 129.

Ghasemi VM, Mobli H, Jafari A, Keyhani AR, Heidari SM, Rafiee S, Kheiralipour K (2008) Som physical properties of rough rice (*Oryza sativa* L.). J Cereal Sci. 47: 496 – 501.

Gupta RK, Das SK (2000) Fracture resistance of sunflower seeds and kernels to compressive loading. J Food Eng. 86: 1 – 8.

Henshaw FO (2008) Varietal differences in physical and proximate composition of Cowpea. World J Agric Sci. 47: 496 – 501.

Ibrahim Y (2007) Physical properties of cowpea (*Vigna Sinensis* L.) seed. J Food Eng. 79, 57-62.

Jouki M, Khazaie N (2012) Some physical properties of rice seed (*Oryza sativa*). Res J App Sci Eng and Tech. 4(13): 1846 – 1849.

Kalamullah S, Gunasekar JJ (2002) Moisture-dependent physical properties of arecanut kernel. Biosystems Eng. 82(3): 331 – 338.

Karababa E (2006) Physical properties of Popcorn Kernel. J Food Eng. 72: 100 – 107.

Karimi M, heiralipur K, Tabatabaeefar A, Khoubakht GM, Naderi M, Heidarbeigi K (2009) The effect of moisture content on physical properties of Wheat. Pak J Nutr. 8(1): 90 – 95.

Kiani Deh Kiani M, Minaiei S, Maghsoudi H, Ghasemi VM (2008) Moisture-dependent physical properties of red bean (*Phaseolus vuigaris L*) grains. Int Agrophysics. 22: 231 – 237.

Kingsly ARP, Singh DB, Manikantan MR, Jain RK (2006) Moisture dependent physical properties of dried pomegranate seeds. J Food Eng. 75: 492 – 496.

Koocheki A, Razavi SMA, Milani E, Moghadam TM, Abedini M, Alamatiyan S, Izadkhan (2007) Physical properties of watermelon seed as a function of moisture content and variety. Int Agrophysics. 21: 349 – 359.

McCabe WL, Smith JC, Harriott P (1986) Unit operation of chemical engineering, McGraw- Hill, New York.

Mohsenin NN (1980) Physical properties of plant and animal materials. Gordon and Breach Science publishers, New York.

Mohsenin NN (1986) Physical properties of plant and animal materials. Gordon and Breach Science publishers, New York.

Mustafa C (2007) Physical properties of barbunia bean seed. J Food Eng, 80: 353 – 358.

Omobuwajo TO, Sanni LA, Balami YA (2000) Physical properties of sorrel (Habiscus sabdariffa) seeds. . J of Food Eng. 45: 37 – 41

Ozarslan C (2002) Physical properties of cotton seed. Biosystem Eng. 83(2): 169 – 174.

Razavi S, Milani (2006) Some physical properties of watermelon seeds. Afr J Agric Res. 13: 65 – 69.

Razavi SMA, Farahmandfar R (2008) Effect of hulling and milling on the physical properties of rice grains. Int Agrophysics. 22: 353 – 359

Reddy BS, Charkraverty A (2004) Physical properties of raw rice and parboiled paddy. Biosystems Eng. 88(4): 461 – 466.

Sacilik K, Oztruk R, Keskin R (2003) Some physical properties of hemp seed. Biosystems Eng. 86(4): 191 – 198.

Sedat C, Tamer M, Huseyin O, Ozden O (2005) Physical properties of rapeseed (*Brassica napus oleifea L)*. J Food Eng. 69: 61-66.

Solomon WK, Zewdu AD (2009) Moisture-dependent physical properties of niger seed (*Guizotia abyssinica Cass*). J Ind Crops Products. 29: 165 – 170.

Sharma V, Das L, Prandhan RC, Naik NS, Bhatnagar N, Kurell RS (2011) Physical properties of tung seed: An industrial oil yielding crop. J Ind Crops Products. 33: 440 – 444.

Shkelqim K, Joachim M (2010) Determination of physical, mechanical and chemical properties of seeds and kernels of (*Jatropha curcas L).* J Ind Crops Products. 32: 129 – 138.

Smith BD (1998) The emergence of Agriculture. Scientific American Library. A Division of HPHLP, New York. ISBN 0-7167-6030-4.

Smith RG, Gross KL, Roberson GP (2008) Effects of crop diversity on agroecosystem function: crop yield response. Ecosystem. 11: 355 – 366.

Singh KK, Goswani TK (1996) Physical properties of cumin seed. J Agric Eng. 64(2): 93 – 98.

Sirisomboon P, Kitchaiya P, Pholpho T, Mahuttanyavanitch W (2007) Physical and Mechanical properties of Jatropha Curcas L fruits, nuts and kernes. J Biosystems Eng. 97(2): 201 – 207.

Tabatabaeefar A (2003) Moisture dependent physical properties of wheat. Int Agrophysics. 17: 207 – 211.

Tavokoli H, Rajabipour A, Mohtasebi SS (2009) Moisture – dependant some engineering properties of soybean grains. Agric Eng Int CIGR J. PM 1110 Vol. XI.

Vilche C, Gely M, Santalla E (2003) Physical properties of Quinoa seeds. Biosystem Eng. 86(1): 59 – 65.

Visvanathan R, Palanisamy PT, Gothandapani L, Sreenarayanan VV (1996) Physical properties of neem nuts. J Agric Eng Res. 63: 19 – 26.

Yalcin C, Ersan K (2007) Physical properties of coriander seeds (*Coriandrum sativum L.*). J Food Eng. 80: 408 – 416.

Zewdu AD, Solomon WK (2007) Moisture-dependent physical properties of Tef seed. J Biosystem Eng. 96(1): 57-63.