Moisture-dependent physical properties of Plantain (Plantago major L.) seeds by image processing analysis

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Abstract: Plantain seed is a commonly used medicinal herb, which has been used in traditional medicine. Physical properties are useful information for designers of processing equipment and for industrial processing of plantain seeds. Physical properties of plantain seeds were determined as a function of moisture content by image processing method. Several properties were obtained in the moisture range from 6.44% to 19.95% dry basis. The results showed that the length, arithmetic and geometric diameter of seeds increased from 0.300 to 0.330 mm, 0.222 to 0.276 mm, and 0.231 to 0.280 mm, respectively. The thousand-unit mass increased from 0.205 to a maximum value of 0.230 g, the surface area increased from 0.282 to 0.418 mm2, the porosity increased from 50.46% to 60.30%. The value of empting angle of repose was found to increase from 36.4 °to 48.2 °and the value of filling angle of repose was decreased gently from 38.9 °to 36.8 °. As moisture content increased from 6.44% to 19.96% (d.b), the static coefficient of friction for surfaces of iron, galvanized and wood showed an increase of 29.75%, 20.99% and 48.80%, respectively. The results showed that the bulk density decreased from 666.6 to 526.9 kg/m3 and the true density decreased to a minimum value of 1310.6 kg/m3 at moisture content of 15.06% (db).

Keywords: Plantain, image processing; moisture content; physical properties

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1 Introduction

Plantago major L. belongs to the Plantagiaceae family (Chiang et al., 2002). Pharmacological properties of plantago have been demonstrated in preclinical and clinical studies as antibacterial (Parra et al., 2001).

The proper design of process equipment depends essentially on the physical and mechanical properties of agricultural products. Characteristic dimensions of various agricultural materials were reported by different researchers (Aviara et al., 2013; Garnayak et al., 2008; Sologubik et al., 2013). Size and shape are important for separator and sorter and can be used to determine the lower size limits of conveyors. Furthermore, the characteristic dimensions allow a calculation of the surface area and volume of grains, important aspects for the modeling of drying and ventilation. Porosity affects the bulk density which is also a necessary factor in the design of dryer, storage and conveyer capacity while the true density is useful to design separation equipment (Sologubik et al., 2013). The angle of repose and coefficient of friction are considered by engineers as important properties for the design of seed containers and other storage structures and accessories. The static friction coefficient limits the maximum inclination angle of conveyor and storage bin. The amount of power requirement for conveyor depends on the magnitude of frictional force. Angle of repose is a useful parameter for calculation of belt conveyor width and for designing the shape of storage. Moisture content is useful information in the drying process (Henderson and Perry, 1976; Sirisomboon et al., 2007; Fadavi et al., 2013).

The aim of this study was to investigate some physical properties of plantain seeds as a function of moisture

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content by image processing technique. The parameters included principle dimensions, thousand-unit mass, geometric mean diameter, arithmetic mean diameter, sphericity, surface area, volume, bulk density, true density, porosity, static friction coefficient on various surfaces, empting and filling angle of repose.

2 Materials and methods

2.1 Materials

Two kilograms of the dried seeds of plantain were obtained from a local market (Figure 1).

Figure 1. Plantain seeds.

2.2 Methods

The seeds were divided into three portions labeled A, B and C. The sample A was left at the market storage moisture content, while different amount of distillated water was added to B and C portion at room temperature in order to raise their moisture content to the desired different levels (Table 1). The average values of three replications were reported as moisture content for each sample.

Table 1 The list of physical properties equations

Formula	Description	Reference
$M_w = \frac{W_i(M_f - M_i)}{100 - M_f}$	M_w: mass of water added, kg; W_i: initial mass, kg; M_i: initial moisture content % (d.b); M_f: final moisture content % (d.b).	Garnayak et al., 2008; Özarslan, 2002; Gupta and Das, 1997.
$D_G = \sqrt[3]{LWT}$	*L:* length, *W:* width, *T:* thickness*	Milani et al., 2007; Garnayak et al., 2008
$D_A = \frac{L + W + T}{3}$	*L:* length, *W:* width, *T:* thickness, mm	Milani et al., 2007; Garnayak et al., 2008
$\varphi = \left(\frac{\sqrt[3]{LWT}}{L}\right) \times 100 = \frac{D_G}{L} \times 100$	*L:* length, *W:* width, *T:* thickness, mm	Aydin, 2003; Sirisomboon et al., 2007
$S = 4\pi\left[\frac{(LW)^P + (LT)^P + (WT)^P}{3}\right]^{\frac{1}{P}}$, $P \approx 1.6075$	*L:* length, *W:* width, *T:* thickness, mm	Thomsen, 2004; Ersoy, 2010
$V = \frac{\pi (D_G)^3}{6}$	D_G : Geometric mean diameter, mm	Perez et al., 2007; Burubai et al., 2007
$S_s = \frac{S\rho_b}{m}$	*m:* mass of one unit of seed, *g*	Sirisomboon et al., 2007
$\varepsilon = \left(1 - \frac{\rho_b}{\rho_s}\right) \times 100$	ρ_b: bulk density, ρ_s: true density	Sharma et al., 2011
$\mu_s = \tan(\alpha)$	α, angle	Sirisomboon et al., 2007
$\theta_F = tan^{-1}\left(\frac{h}{a}\right)$	h: height mm, a: horizontal distance, mm	Fadavi et al., 2013
$\theta_E = tan^{-1}\left(\frac{H}{A}\right)$	H: height mm, A: horizontal distance, mm	Fadavi et al., 2013

The image processing system consisted of a box dimension of 45cm×45 cm×45 cm, a camera (Canon, IXY 600F, 12.1 megapixels, USB connection, Japan), and four white-colored fluorescent lamps (32 W, 2630 lux) and a laptop computer (VAIO, VPCEG34FX, Japan) equipped with Matlab R2012a software package. Tow RGB color images were captured from top and front views of each seed. Pixels above a certain threshold value (110) were converted into white, pixels below this threshold to black, resulting in binary image (Koc, 2007). A group of black pixels adjacent to each other represented a seed, as is shown in Figure 1. The three principle dimensions of length, width and thickness were determined based on bounding box dimensions in up and front views of each seed image. The projected area of each seed (Pa) was calculated using image processing method; the obtained pixels were converted to projected area by the Equation (1):

$$\text{Projected area of the seed} = \frac{\text{Number of pixels of seed} \times \text{Projected area of the circular or squar}}{\text{Number of pixels of circular or squar}} \quad (1)$$

Equations for determination of geometric mean diameter (DG, mm), arithmetic mean diameter (DA, mm), sphericity (φ), surface area (S, mm2), volume (V, mm3), porosity (ε) and specific surface area (Ss) (mm2.mm-3) is listed in Table1.

a b c d

Figure 1 Images of a Plantain seed (a) Original RGB color image, (b) eight-bit grayscale image, (c) two-bit binary image and (d) out line image

To evaluate the unit mass and thousand-unit mass, 100 seeds selected from the bulk sample, randomly; the 100-unit mass was measured by a digital balance (Kern, Japan, accuracy of ± 0.001 g). Unit mass was calculated by dividing the 100-unit mass to 100 and thousand-unit mass was calculated by multiplying the 100-unit mass by 10.

The bulk material of seeds with different moisture content was obtained by a container with known volume (500 cm^3). The seeds were poured into the container at a height of 150 mm (Gupta and Das, 1997). The true density (ρs) is defined as the mass of sample (Ms) divided by the volume of the sample (Vs). It was determined using the toluene (C7H8) displacement method. (Milani et al., 2007; Garnayak et al., 2008; Mohsenin, 1986).

$$V_s = \frac{M_{TD}}{\rho_t} = \frac{(M_T - M_P) - (M_{PTS} - M_{PS})}{\rho_t} \quad (2)$$

$$\rho_s = \frac{M_s}{V_s} \quad (3)$$

Where， M_{TD} is the mass of displacement volume of toluene (kg), ρ_t is the density of toluene (870 kg.m-3), M_T is the mass of filled pycnometer with toluene (kg), M_P is the mass of empty pycnometer (kg), M_{PTS} is the mass of pycnometer with toluene and seeds in (kg), and M_{PS} is the mass of pycnometer and seeds (kg).

The coefficients of static friction of the seeds were determined using inclined plane method on surfaces of iron, galvanized and plywood. A topless and bottomless cylinder of 100 mm diameter and 50 mm height was filled with the samples. The filling and emptying angle of repose were measured by a device consists of two boxes, upper and down box, of dimensions 120 mm length, 120 mm height, and 60 mm width (Fadavi et al., 2013).

2.3 Statistical analysis

Data were subjected to ANOVA procedures of SAS, PC version 6.12 (1999), appropriate for completely randomized designs. The effect of moisture treatments on physical properties data at $p<0.05$ significant level were analyzed with Duncan's multiple range tests (Duncan, 1955).

3 Results and discussion

3.1 The mean value of different physical properties of the plantain seed at different moisture content

The mean value of different physical properties of the plantain seed, including length, width, thickness, arithmetic mean diameter, geometric mean diameter, unit mass, sphericity, surface area, specific surface area, volume and project area at different moisture content are given in Table 2. With increasing moisture content from 6.44 to 19.95% (d.b), the length, width, thickness, the arithmetic mean diameter and the geometric mean diameter of seeds increased significantly from 0.300 to 0.330 mm, 0.243 to 0.287 mm, 0.151 mm to 0.224 mm, 0.222 to 0.276 mm and 0.231 to 0.280 mm, respectively. The principle dimensions increased from 10% to 48.3% that the thickness had the largest percentage increase with increase in moisture content. The same result was reported for sorghum seed (Mwithiga and Sifuna, 2006). The increase in size could be attributed to the expansion of the grain as a result of moisture absorption in the intracellular spaces inside the seeds (Sologubik et al., 2013).

The product shape can be determined in terms of its sphericity which affects the flow characteristics. The results obtained are presented in Table 2. The sphericity had a slight increment to 75.929 at moisture content of 15.06 % (d.b) then reaches to a value of 84.543% at moisture content of 19.95 % (d.b). The reason can be due to more increase of width (18%) and thickness (48%) relative to that of length (10%) with increase moisture content (Table 2). The seeds considered as spherical when the sphericity value was more than 70%. In this study, plantain seed should be treated as an equivalent sphere for calculation of the surface area (Garnayak et al., 2008).

Table 2 Basic and complex geometric characteristic of plantain seeds[1]

Parameter	Moisture content , % (d.b)		
	6.44	15.06	19.95
	Mean ± σ[2]	Mean ± σ	Mean ± σ
L ,mm	0.300 ±0.023	0.325 ±0.047	0.330 ±0.050
W ,mm	0.243 [b] ±0.030	0.227 [b] ±0.018	0.287 [a] ±0.021
T ,mm	0.151 [c] ±0.014	0.199 [b] ±0.017	0.224 [a] ±0.018
D_G ,mm	0.222 [c] ±0.016	0.244 [b] ±0.018	0.276 [a] ±0.022
D_A,mm	0.231 [c] ±0.017	0.250 [b] ±0.021	0.280 [a] ±0.025
φ	74.148 [b] ±3.805	75.929 [b] ±6.120	84.543 [a] ±6.508
S ,mm^2	0.282 [b] ±0.042	0.330 [b] ±0.052	0.418 [a] ±0.074
S_S ,mm^{-1}	0.911[b] ±0.136[a]	0.850 [b] ±0.134	1.000 [a] ±0.176
V ,mm^3	0.006 [b] ±0.001	0.008 [b] ±0.002	0.011 [a] ±0.003
Pa ,mm^2	0.011 ±0.001	0.011 ±0.001	0.009 ±0.001

1.The value of each characteristic obtained from fifty seeds

2 Standard deviation

Different trends have been reported for moisture dependence of sphericity. The sphericity of seeds can be relatively constant within a moisture range (Mwithiga and Sifuna, 2006). Sologubik et al. (2013) reported an initial increase followed by a decrease in sphericity for barley. An initial decrease in the sphericity with increase in moisture content was also reported for Tef Seed (Zewdu and Solomon, 2007).

The surface area, *S*, increased from 0.282 to 0.418 (an increase of 48.2%) and the specific surface, S_s, increased from 0.911 to 1.000 (an increase of 9.8%) when the moisture content increased from 6.44 to 19.95% (d.b). A linear increase has been reported for barely seed (Sologubik et al., 2013).

With increasing moisture content from 6.44 to 19.95 % (d.b) volume of the seeds increased from 0.006 to 0.011 mm^3 (80.95% increase) and projected area from 0.009 to 0.0107 mm^2 (Table 2).

3.2 The thousand-unit mass of the plantain seeds at different moisture levels

The thousand-unit mass of the plantain seeds was measured at different moisture levels. The Figure 2 indicates that the seed mass increases polynomial with increase in seed moisture content. It varies from 0.206 to 0.230 g when the moisture content increased from 6.44 to 15.06 % (d.b); then with increasing moisture content from 15.06 to 19.95 % (d.b), the thousand-unit mass value decreased from 0.230 to 0.220 g (Figure 2).

At higher moisture content, the more free water formed on the surface of grains. A possible reason for this variation can be due to the ease lost of free water during the experiment that was time consuming due to small geometry of grains. This caused an experimental error. There are many literatures on moisture dependency of thousand-unit mass; results indicated that in most cases with increasing moisture content, thousand-unit mass increased (Visvanathan et al., 1996; Özarslan, 2002; Sacilik et al., 2003).

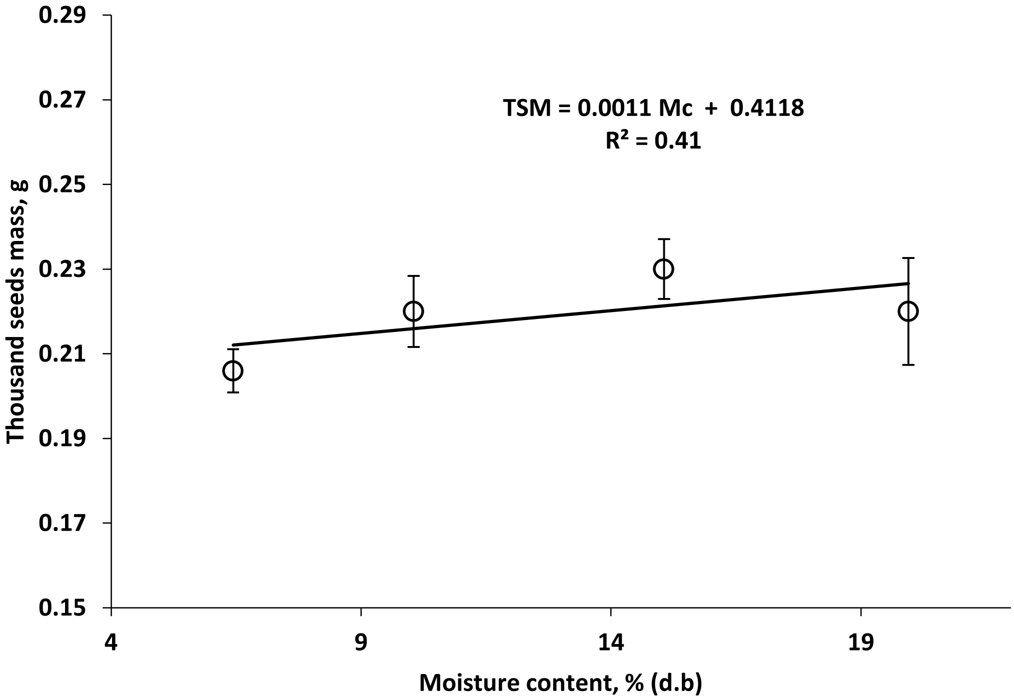

Figure 2 Thousand seeds mass of plantain seeds with moisture content

3.3 The bulk density of plantain seed at different moisture contents

The bulk density of plantain seed decreased linearly with moisture content from 666.556 to 526.912 kg/m^3 in the moisture ranges of 6.44 to19.95 % dry basis (Figure 3). The bulk density of seed was significantly affected by moisture content at 5% level of significance. The reason of this reduction can be explained as follows: while the seeds absorb moisture, their individual volume increases, especially due to the increment of their thickness which grows more rapidly than the width and length (Table 2); the shape of the seeds changes, and consequently the bulk volume of the seeds increased. This behavior caused the number of seeds occupying a fixed volume decreased, and this resulted the reduction of the bulk density. The negative relationship of bulk density with moisture content was also observed by other researchers (Pradhan et al., 2009; Mendoza et al., 2008; Garnayak et al., 2008; Zewdu and Solomon, et al., 2007; Fadavi et al., 2013).

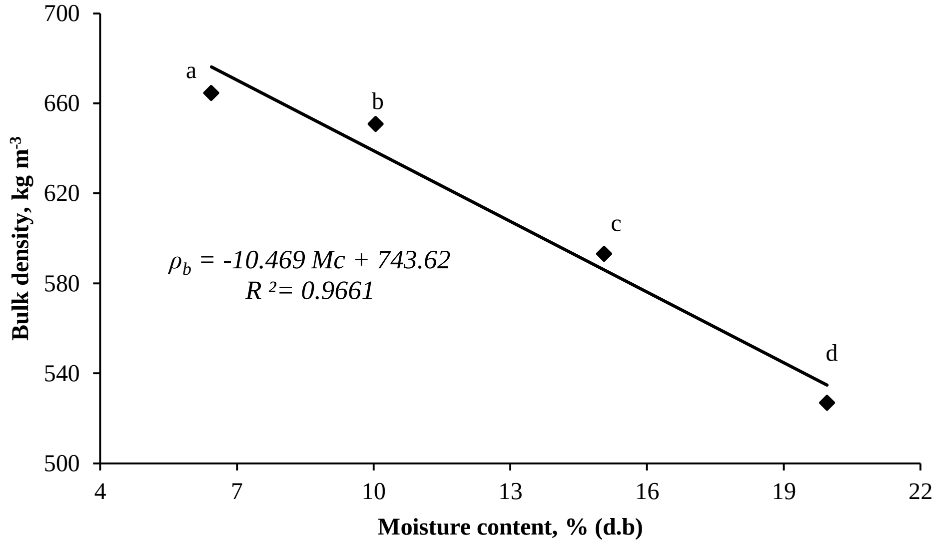

Figure 3 Variation of bulk density of plantain seeds with moisture content

3.4 The true density of the plantain seeds at different moisture levels

The true density of the plantain seeds was measured at different moisture levels. It had an initial decrease from 1341.579 to 1310.619 kg/m^3 when the moisture content increased from 6.44 to 15.06 % (d.b); then with increasing moisture content from 15.06 to 19.95% (d.b) the value of true density increased from 1310.619 to 1327.143 kg/m^3 (Figure 4). The observed reduction of true density could be explained due to the fact that the increment of grain weight caused by the moisture seed resulted lower than the volume expansion experimented by grains (Pradhan et al., 2009; Sologubik et al., 2013).

Rehydration was applied to reach specified moisture content. During the rehydration process, the dry porous material undergoes several simultaneous changes (e.g., porosity, textural properties, volume, etc.). In dehydration process, reconstitution of material cannot be achieved thus the properties of the raw material cannot be restored completely (Górnicki et al., 2013).

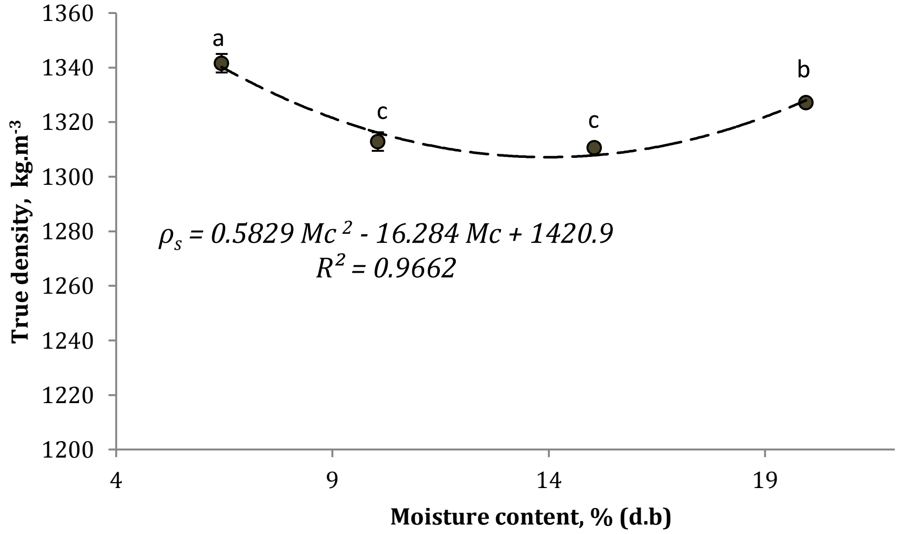

Figure 4 Variation of true density of plantain seeds with moisture content

At the first stage, capillary imbibition is very important, leading to an almost instantaneous uptake of water thus the increase volume rate is possibly more than the excess mass, consequently the density decreased during the early stages. A further increase of moisture increased the free water on the surface of grain without any significant change of volume.

The reports of true density with moisture content showed often contradictorily; the results sometimes indicated an increase of the true density with increase moisture content (Aydin, 2003; Bart-Plange and Baryeh, 2003; Milani et al., 2007; Mirzabe et al., 2013; Garnayak et al., 2008), but in some cases with increasing moisture content, the true density decreased (Dutta et al., 1988; Deshpande et al., 1993; Zewdu and Solomon, 2007; Pradhan et al., 2009; Sologubik et al., 2013).

The porosity was calculated using the average values of bulk density and true density of each batch (Table 1). It was observed that when moisture content increased from 6.44 to 19.95% (d.b),

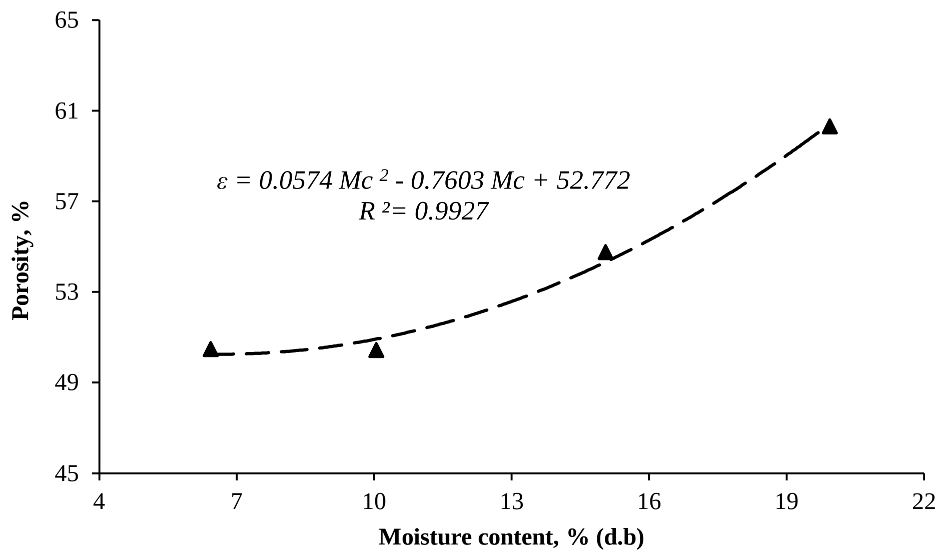

Figure 5 Variation of porosity of plantain seeds with moisture content

porosity increased from 50.465% to 60.297% as shown in Figure 5. For a given mass of seed, an increase in the moisture content leads to higher bulk volume and the addition of water to the seeds structure affects principle dimensions of seed differently, altering mainly the thickness and width, it influences more on the bulk density than on the true density of seed, resulting a rise of porosity (Sologubik et al., 2013). Aviara et al. (2013) for moringa oleifera seed and Sologubik (2013) for bareley, Zewdu and Solomon for tef seed and Mendoza et al. (2008) for roselle seeds stated that as the moisture content increased, the porosity value increased, but Pradhan et al. (2009) for jatropha fruit and Mwithiga and Sifuna (2006) for sorghum seeds reported a decreasing trend of porosity with moisture content.

3.5 The static coefficient of friction of plantain seed

The static coefficient of friction of plantain seed on three surfaces (iron, galvanized and wood sheet) against moisture content was shown in Figure 6. It is observed that the static coefficient of friction of seeds increased linearly with increase in moisture content for all contact surfaces. The reason for the increased of friction coefficient at higher moisture content may be owing to the water present in the seed, offering an adhesive force on the surface of contact (Pradhan et al., 2009). The coefficient of friction increased from 22.35 to 29°, 26.77 to 32.39° and 19.65 to 29.24° for iron, wood and galvanized, respectively, as the moisture content increases from 6.44 % to 19.95 % (d.b).

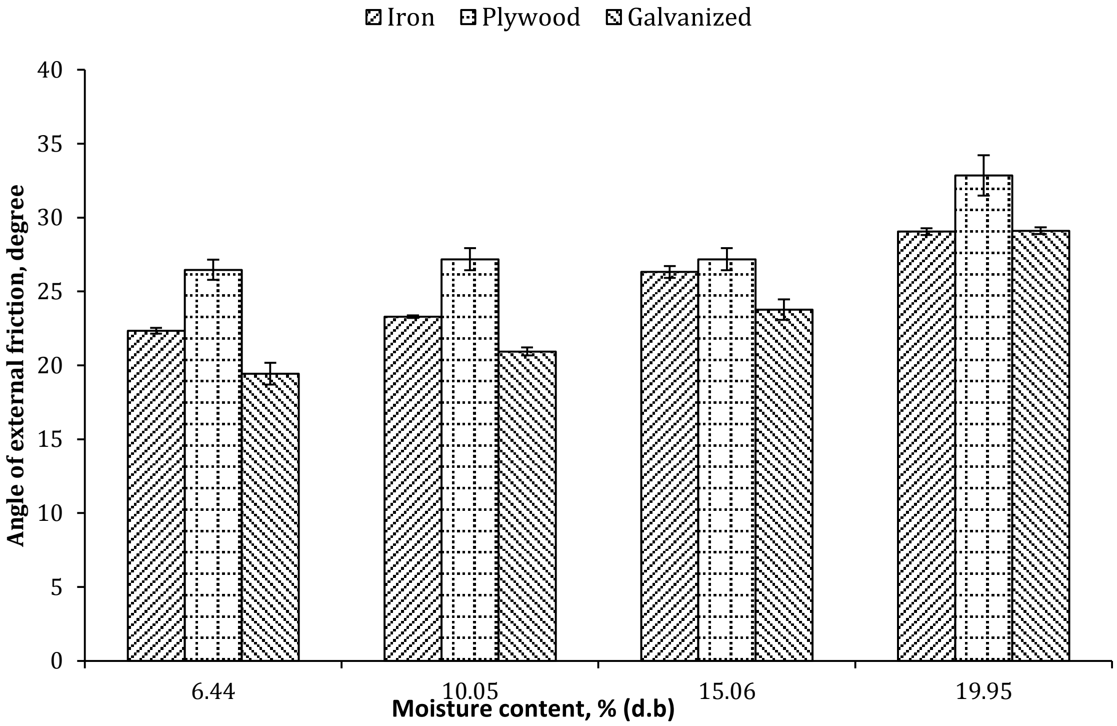

Figure 6 Variation of angle of external friction of plantain seeds for iron, galvanized and wood

At all moisture contents, the maximum friction is offered by wood, followed by the iron and galvanized surfaces. The least static coefficient of friction may be owing to the smoother and more polished surface of the galvanized sheet than the other materials used. Wood also offered the maximum friction for tef seed (Zewdu and Solomon, 2007), jatrofa fruit (Pradhan et al., 2009) and for almond (Mirzabe et al., 2013), but the galvanized iron had higher coefficient of friction than plywood for Roselle seeds (Mendoza et al., 2008) and lentil seeds (Amin et al., 2004).

3.6 The angle of repose of the plantain seeds at different moisture levels

The angle of repose is an indicator of the product's flow ability. The results for the angle of repose with respect to moisture content are shown in Figure 7. The value of empting angle of repose was found to increase from 36.43° to 48.19° in the moisture range of 6.44 to 19.95% (d.b). This variation of angle of repose with moisture content occurs because the surface layer of moisture surrounding the particle holds the aggregate of seeds together by the surface tension. These results were similar to those reported for other agricultural crops (Visvanathan et al., 1996;

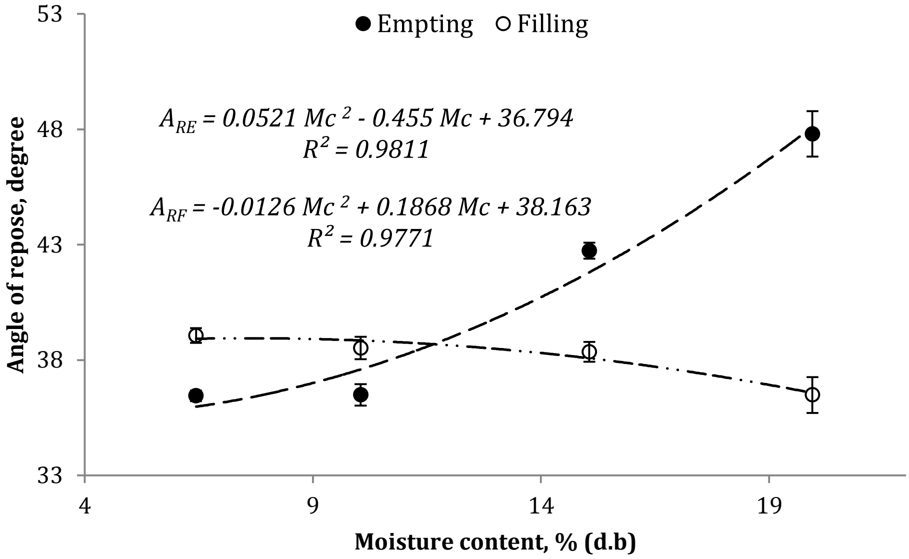

Figure 7 Variation of filling and empting angle of repose of plantain seeds with moisture content

Sacilik et al., 2003; Pradhan et al., 2009; Bart-Plange and Baryeh, 2003). But the value of filling angle of repose was found to decrease gently from 38.91° to 36.81° in the moisture range of 6.44 to 19.95 % (d.b). Different behavior for emptying and filling angle of repose have been reported for agricultural materials, the emptying angle of repose was greater than that of filling for wild pistachio (Fadavi et al., 2013), but the reverse results were shown for jatropha (Karaj and Müller, 2010, Sirisomboon et al., 2007).

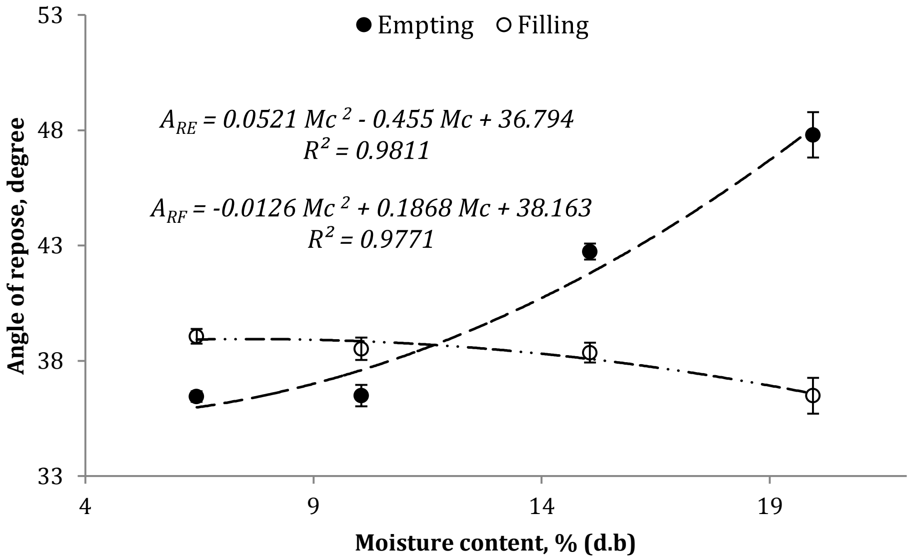

Figure 7 Variation of filling and empting angle of repose of plantain seeds with moisture content

4 Conclusions

The following conclusions are drawn from the investigation on moisture-dependent physical properties of plantain seed with moisture contents ranging from 6.44% to 19.95% (d.b). As moisture content increases from 6.44% to 19.96% (d.b), the physical properties varied in different ways. The three principle dimensions had different increase, which caused the sphericity had a maximum value of 84.543% at moisture content of 19.95%.

One thousand seeds mass had a maximum value of 0.230 g. Bulk density and porosity of the seeds varied from 664.556 to 526.912 kg.m^{-3} and 50.464 to 60.297%, respectively. The true density of the plantain seeds was found to be negatively correlated and varies from 1341.579 to a minimum value of 1310.619 kg/m^3 when the moisture content increased from 6.44 to 15.06% (d.b); then it increased to 1327.143 kg/m^3 at moisture content of 19.95% (d.b).

The empting angle of repose increased from 36.43° to 48.19° and filling angle of repose decreased from 38.9° to 36.81° as the moisture content increased. The static coefficient of friction increased for all three surfaces, namely, iron (22.35 to 29°), galvanized (19.65 to 29.24°) and wood (26.77 to 32.39°) as the moisture content increased from of 6.44% to 19.95% (d.b). At all moisture contents, the maximum friction is offered by wood, followed by the iron and galvanized surfaces.

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