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Moisture-Dependent Physical Properties of Finger Millet Grain and Kernel (*Eleusine coracana* (L.) *Gaertn*)

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The physical properties of finger millet grain and kernel are necessary for design of processing equipments, handling and storage. The physical properties of finger millet grain and kernel were studied in the moisture range of 7 to 25% db. With the increase in moisture content, the geometric mean diameter, sphericity, volume, surface area and thousand grain weight, angle of repose, terminal velocity and static coefficient of friction for grain were increased from 1.41 to 1.58 mm, 0.91 to 0.95, 1.62 to 2.20 mm^3, 6.31 to 7.88 mm^2, 2.30 to 2.92 g, 21 to 30°, 4.1 to 5.9 m s^{-1} and 0.38 to 0.43 (steel), 0.38 to 0.42 (plywood), 0.36 to 0.40 (glass), respectively. The bulk density, true density and porosity decreased from 749 to 665 kg m^{-3}, 1515 to 1000 kg m^{-3}, 50.59 to 33.33%, respectively for the finger millet grain in the moisture range of 7 to 25% db. Similar trend was observed for finger millet kernel also.

(***Key words:*** *Grain, Kernel, Physical properties, Moisture content)*

Finger millet (*Eleusine Coracana (L.) Gaertn*) commonly known as *Ragi*, is one of the important small millet crop grown in hilly areas of India. It popularly called as '*Nachni*', which means dancer in the state of Maharashtra (Kumar *et al.,* 2013; Pradhan *et al.*, 2010). In India, it's commonly grown in the hilly rainfed areas, having well-drained red soil. Karnataka is leading state for production of finger millet, contributed the highest share in terms of area and production, and followed by Tamil Nadu, Uttrakhand, Maharashtra, Andhra Pradesh and Odisha (Anonymous, 2010). The popularity for finger millet is due to its high nutritional and medicinal value. The high fiber content in finger millet permitting slow digestion is very popular food for diabetic patients.

The harvesting of finger millet is generally carried in the moisture range 16 to 20 % db and is allowed for sun drying to reduce its moisture content in between 10 to 12 % db. Thereafter, the panicles of the crop were stacked for 1 to 1.5 months. Due to this practice the internal heat is generated in the stack that reduces bonding between grains, panicles and glumes resulting loosening the grains and glumes from the panicles (Singh *et al.,* 2015). Ultimately, it reduces human efforts required for manually threshing and pearling. The all field operations from sowing to threshing of finger millet are performed manually. It characterized as labour intensive, drudgery, time and energy consuming (Joshi *et al.,* 2015; Pradhan *et al.,* 2010). The size and shape of seed are essential properties in designing of the threshing sieve, pearling sieve and cleaning sieve in finger millet thresher cum pearler (Wandkar *et al.,* 2012; Gupta *et al.,* 2007). Bulk density and porosity have an effect on the structural loads and are important to decide the size of hopper and capacity of the machine. The angle of repose is useful in designing of the hopper, storage and transport. Terminal velocity of grains, kernel and husk are useful in the design of pneumatic conveying and cleaning system of grains. The coefficient of friction of the grain against the various surfaces is also necessary in designing of conveying, transporting and storing structures (Chavoshgoli *et al.,* 2014; Aghajani *et al.,* 2012; Subramanian and Viswanathan, 2007). Many researchers have determined the physical properties of different agricultural produces like minor millet (Subramanium and Viswanathan, 2007; Baryeh, 2002), faba bean (Altuntas and Yildiz, 2007), caper seed (Dursun and Dursun, 2005), sunflower seed (Gupta *et al.,* 2007), tef grain (Zewdu, 2007), guar seeds (Vishwakarma *et al.,* 2012) and pea seed (Yalcin *et al.,* 2007). Subramanium and Viswanathan, (2007) studied some physical properties finger millet grains; however they did not consider other physical, aerodynamic and mechanical properties of finger millet kernel. It is evident from the literature that there was not much

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published work available relating to physical properties of finger millet grain and kernel. Hence, study was undertaken to find out moisture dependent physical properties of finger millet grain and kernel in moisture range 7 to 25% db.

MATERIALS AND METHODS

Finger millet grain and kernel

The finger millet grain has a pericarp or so called glumes on its outer periphery. This outer pericarp is hard to digest and decrease the quality of product. Therefore, it removed by applying gentle rubbing force. The grain without outer glumes is called as kernel (Ushakumari, 2009).

Preparation of samples

Finger millet grains for the study were procured from the Department of Agronomy; Dr. Balasaheb Sawant Kokan Krishi Vidyapeeth Dapoli, Maharashtra, India. The sample was cleaned manually to remove all foreign materials such as dust, husk, small branches and immature seeds. Fifteen (15) grams of each sample were placed in a hot air oven at 105±1°C for 24h to determine the initial moisture content of the grain and kernel (Sessiz *et al.,* 2007; Sacilik *et al.,* 2003). The initial moisture content of the seed was 10.1% db. To obtain different moisture contents in range 7 to 25% db., the seed samples were conditioned in the refrigerator. The Eq. (1) was used to determine the amount of water needed to add or subtract from the sample to achieve the desired moisture content (Garnayaka *et al.,* 2008).

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

The cleaned and graded samples of finger millet grain and kernel were transferred to tightly sealed polyethylene bags. The bags were put in the refrigerator at 5°C temperature for a week to distribute moisture uniformly throughout the sample (Sonawane *et al.,* 2014; Garnayak *et al.,* 2008, Sessiz *et al.,* 2007). Before determining the properties, the required quantities of samples were taken out from the refrigerator and allowed to warm to the room temperature for about 2h (Singh *et al.,* 2010; Tavakoli *et al.,* 2009). All physical and aerodynamic, properties were assessed at five levels of the moisture content viz. 7.15, 10.73, 15.33, 20.31 and 25.11% db for kernel and 7.05, 10.21, 15.44, 20.99 and 25.03% for grain. The experiments were replicated thrice.

Geometric mean diameter

The mean geometrical diameter 'D_{ge}' of the finger millet grain and kernels were determined by measuring their three linear dimensions of 100 randomly selected grains and kernels, using vernier caliper with least count 0.001 mm. Eq. (2) was used to determine the geometric mean diameter of grains and kernel (Mohsenin, 1970).

$$D_{ge} = (LWT)^{1/3} \quad ...(2)$$

Sphericity

The sphericity ϕ of the grain and kernels were calculated using Eq. (3) (Mohsenin, 1970).

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

Surface area

The surface area 'S' of the finger millet grain and kernel was assessed by analogy with a sphere of same mean diameter, using Eq. (4) (Singh *et al.*, 2010, Coşkuner and Karababa, 2007).

$$S = D^2_{ge} \quad ...(4)$$

Volume

The volume 'V' of the finger millet grain and kernel was calculated by analogy with following Eq. (5) (Mohsenin, 1970).

$$V = \frac{\pi B^2 L^2}{6(2L - B)} \quad ...(5)$$

$$B = (W_d T)^{0.5}$$

Thousand grain and kernel mass

Thousand grain and kernel weight 'M_t' was determined by counting 1000 seeds and weighing with an electronic balance. Electronic balance with least count 0.001g was used for measurement (Coskuner and Karababa, 2007).

Bulk density

The bulk density 'δ_{bd}' is the ratio of the mass of the seed to the volume of the container. Bulk densities of finger millet grain and kernels at five different moisture levels were determined by filling a circular jar of 500 mL capacity with grains and kernels without manual compaction (Singh *et al.,* 2010) and then the weight (W) of 500 mL grains of all samples were recorded. The bulk density was assessed using Eq. (6)

$$\delta_{bd} = \frac{W}{500} \text{ x } 106 \quad ...(6)$$

True density

True density 'δ_{td}' of finger millet was determined by toluene displacement method. True density is the ratio of the mass of the sample to the volume of displaced toluene. A graduated cylinder of 100 mL filled with 50 mL of toluene and 5 g seeds were immersed in it (Singh *et al*., 2010; Coskuner and Karababa, 2007). The grain and kernel have less affinity with toluene as compared with water, therefore the actual volume of toluene displaced equal to the actual volume of the grain (Vishwakarma *et al.*, 2012; Mohsenin, 1970). The true density was calculated by using Eq. (7)

$$\delta_{td} = \frac{W}{V_{td}} \quad ...(7)$$

Porosity

The porosity 'P' is the ratio of pore space in the bulk to its bulk volume. The porosity of finger millet grain and kernels was calculated by analogy using Eq. (8) (Singh *et al*., 2010; Mohsenin, 1970).

$$P = 1 - \frac{\delta_{bd}}{\delta_{td}} \text{ x } 100 \quad ...(8)$$

Terminal velocity

Terminal velocity was determined by the air column experimental device. (Chavoshgoli *et al.*, 2014; Singh *et al*., 2010). It was the transparent plastic made hollow cylindrical air column. A sample of 100 g was fed into air column and airflow rate was adjusted so that the seeds suspended in the air column for 30 s. The air velocity was measured using vane anemometer and noted as terminal velocity of the grain. Three replications of each sample were taken.

Angle of repose

The apparatus consists of conical shape funnel with sliding and removable opening at one end. The funnel was filled with grain/kernel and the sliding side was quickly removed and allowing the grains to free flow to their natural slope. The angle of repose was determined by measuring the height of hemp (H) and diameter of the hemp (D), it was calculated by Eq. (9) (Singh *et al.,* 2010).

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \quad ...(9)$$

Static coefficient of friction

The static coefficient of friction of finger millet grain and kernel against three different surfaces namely mild steel, plywood and glass surfaces were determined.

Abbreviations

Q	mass of water added/removed, kg	V	volume, mm^3
W_i	initial mass of the sample, kg,	μ_s	coefficient of static friction
M_i	initial moisture content of the sample. % db	α	tilt angle in degree
M_f	final moisture content of the sample, % db.	yg	regression equation for finger millet grain
D_{ge}	geometric mean diameter, mm	FMG	finger millet grain
L	length, mm	FMK	finger millet kernel
W_d	width, mm	yk	regression equation for finger millet kernel
T	thickness, mm	db	dry basis
ϕ	sphericity	Ygs	regression equation for static coefficient of friction for steel surface
S	surface area, mm^2	Ygp	regression equation for static coefficient of friction for plywood surface
M_t	thousand mass, g	Ygg	regression equation for static coefficient of friction for glass surface
δ_{bd}	bulk density, kg m^{-3}	FMGSCFS	finger millet grain static coefficient of friction for steel
W	mass of grain $kernel^{-1}$, g	FMGSCFP	finger millet grain static coefficient of friction for plywood
δ_{td}	true density, kg m^{-3}	FMGSCFG	finger millet grain static coefficient of friction for glass
P	porosity	FMKSCFS	finger millet kernel static coefficient of friction for steel
H	height of hemp, mm	FMKSCFP	finger millet kernel static coefficient of friction for plywood
D	diameter of hemp, mm	FMKSCFG	finger millet kernel static coefficient of friction for glass
V_{td}	Volume of toluene displaced		

A plastic rectangular box of 50 mm length and 55 mm width was taken to determine the static coefficient of friction. The box filled with grain was placed on an adjustable inclined surface. With help of screw devices adjust surface inclination slowly until grain filled box start to slide with help of this angle the static coefficient of friction was determined (Singh *et al.*, 2010). The coefficient of friction was calculated using Eq. (10)

$$\mu_s = \tan\alpha \qquad ...(10)$$

RESULT AND DISCUSSIONS

Geometric mean diameter

Fig. 1a shows the effect of the moisture content on the geometric mean diameter of grain and kernel. The geometric mean diameter ranged from 1.41 to 1.58 mm for grain and 1.38 to 1.54 mm for the kernel respectively within the moisture content range from 7 to 25% db. It evident that the geometric mean diameter of grain and kernel increased with the increase in the moisture content and it followed a linear relationship. The relationship between diameter and moisture content for grain and kernel are given in the Eqs. (11) and (12), respectively. The geometric mean diameter of grain and kernel increased with increase in moisture content, it happened due to increasing the respective dimensions of seed (Singh *et al.*, 2010). The similar results were observed by Vishwakarma *et al.* (2012) for guar seed, Dursun and Dursun (2005) for caper seed, Al-Mahasneh and Rababah (2007) for green wheat, Sacilik *et al.* (2003) for hemp seed and Singh *et al.* (2010) for barnyard millet grain and kernel.

Sphericity

It was found that, the sphericity of the finger millet grain and kernel increased from 0.91 to 0.95 and 0.92 to 0.96 respectively, with the increase in moisture content from 7 to 25 % db (Fig. 1b). The Fig. 1b represents the effect of moisture content on sphericity of grain and kernel. The variation of sphericity with moisture content for finger millet grain and kernel has been expressed by the linear relationship in Eqs. (13) and (14). The sphericity of grain and kernel increased with increase in moisture content, it happened due to increases the respective dimensions of seed (Singh *et al.*, 2010). The increase in sphericity after addition of moisture have been reported for hemp seed (Sacilik *et al.,* 2003), for guar seed (Vishwakarma *et al.,* 2012), for green wheat (Al-Mahasneh and Rababah, 2007) and for barnyard millet grain and kernel (Singh *et al.,* 2010).

Volume

It was observed from Fig. 1c that, the volume of finger millet grain increased from 1.62 to 2.20 mm^3 and that of the kernel was increased from 1.40 to 2.10 mm^3, as moisture content increased from 7 to 25 % db. It happened due to increasing the respective dimensions of seed (Singh *et al.*, 2010). The mathematical relation between variations of moisture content and volume of the grain was given by Eqs. (15) and (16) for the grain and kernel, respectively. A similar trend of the result was observed by Al-Mahasneh and Rababah, (2007) for green wheat, Sonawane *et al.* (2014) for kokum seed and Ndirika and Oyeleke (2006) for millet.

Surface area

As the moisture content of the finger millet increased from the 7 to 25% db, the surface area of the grain was increased from 6.31 to 7.88 mm^2 and that of kernel 5.70 to 7.50 mm^2. It happened due to increasing the respective dimensions of seed (Singh *et al.*, 2010). The effect of moisture content and surface area was shown in the Fig. 1. The mathematical relation between variation of moisture content with surface area of grain and kernel is shown in Eqs. (17) and (18). Similar trends have been reported by Singh *et al.* (2010) for barnyard millet grain and kernel, Al-Mahasneh and Rababah, (2007) for green wheat and Vishwakarma *et al.* (2012) for guar seed.

Thousand grain weight

The mass of 1000 grain and kernel was found to increase from 2.297 to 2.918 and from 2.171 to 2.79 g, for millet grain and kernel, respectively with an increase in moisture content from 7 to 25% db. as shown in Fig. 1e and Eqs. (19) and (20). A similar increasing trend has been reported by Singh *et al.* (2010) for barnyard millet grain and kernel, Dursun and Dursun (2005) for caper seed and Sacilik *et al.* (2003) for hemp seed.

Bulk density

The bulk density of finger millet grain was decreased from 749 to 665 kg m^{-3} and that of the kernel decreased from 890 to 781 kg m^{-3}, as moisture content increased from 7 to 25% db. The linear relationship (Eq. 21 and 22) between moisture content and bulk density is shown in Fig. 1f. A similar relationship was reported by Balasubramanian and Viswanathan, (2009) for minor millet, Singh *et al.* (2010) for barnyard millet grain and kernel, Al-Mahasneh and Rababah, (2007) for green wheat, Aghajani *et al.* (2012) for barly seed and Sacilik *et al.* (2003) for hemp seed.

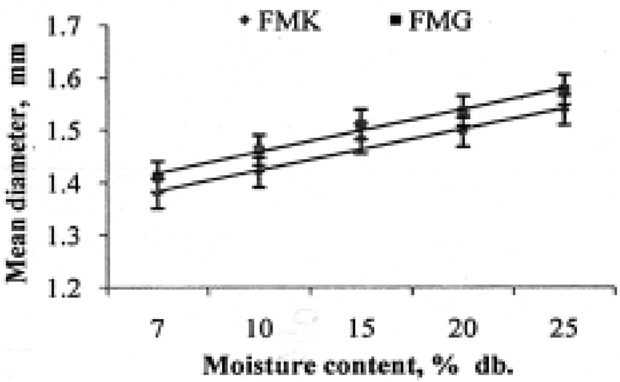

Fig. 1a. *Effect of moisture content on mean diameter of FMG and FMK*

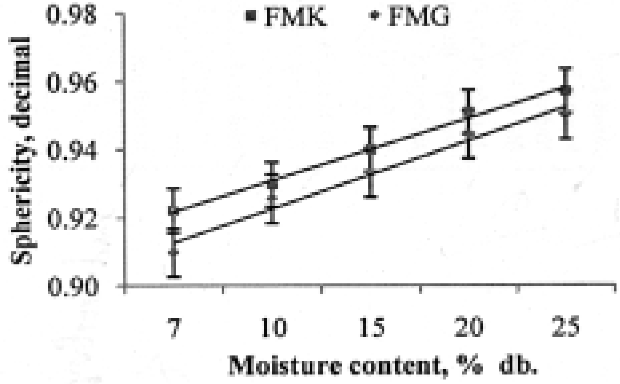

Fig. 1b. *Effect of moisture content on sphercity of FMG and FMK*

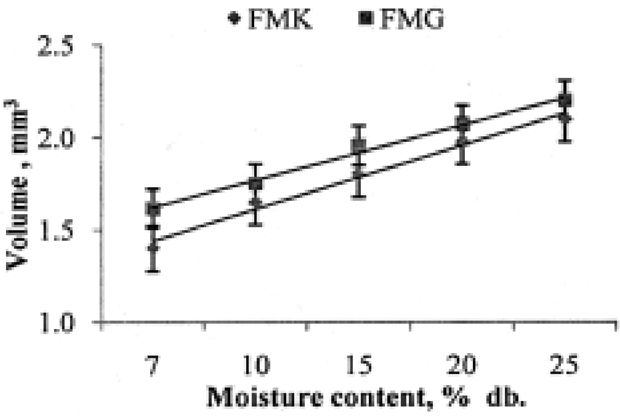

Fig. 1c. *Effect of moisture content on volume of FMG and FMK*

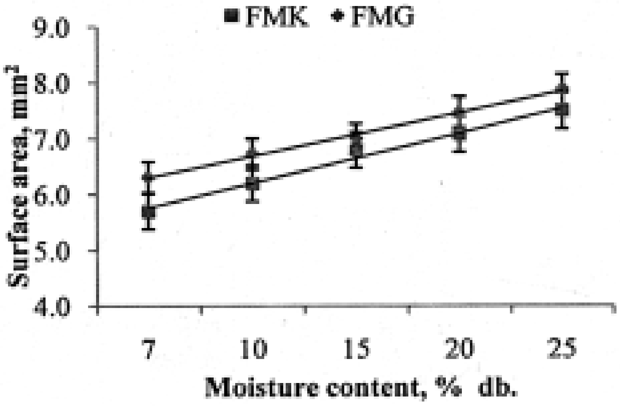

Fig. 1d. *Effect of moisture content on surface area of FMG and FMK*

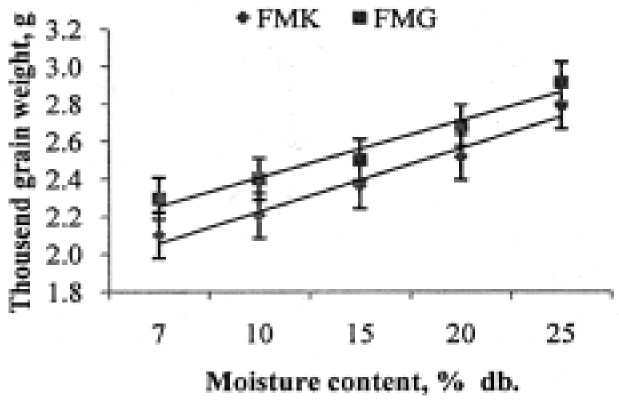

Fig. 1e. *Effect of moisture content on thousand grain weight of FMG and FMK*

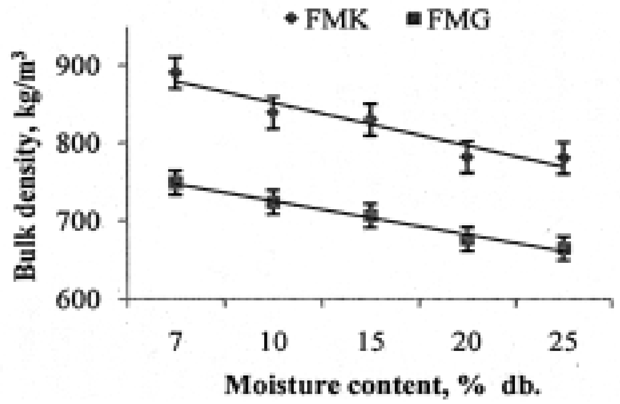

Fig. 1f. *Effect of moisture content on bulk density of FMG and FMK*

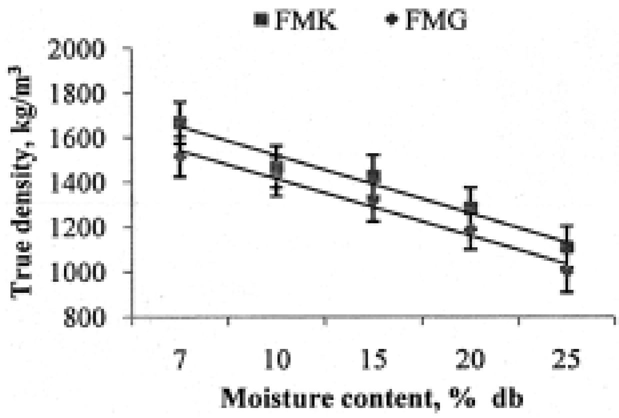

Fig. 1g. *Effect of moisture content on true density of FMG and FMK*

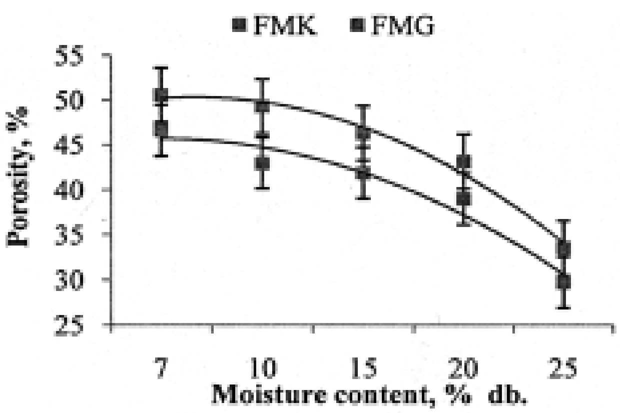

Fig. 1h. *Effect of moisture content on porosity of FMG and FMK*

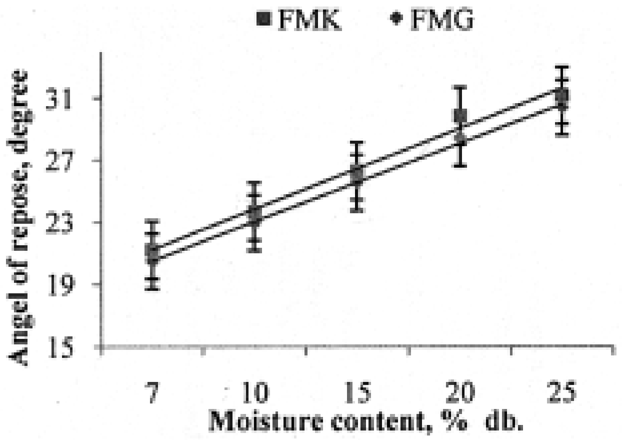

Fig. 1i. Effect of moisture content on angle of repose of FMG and FMK

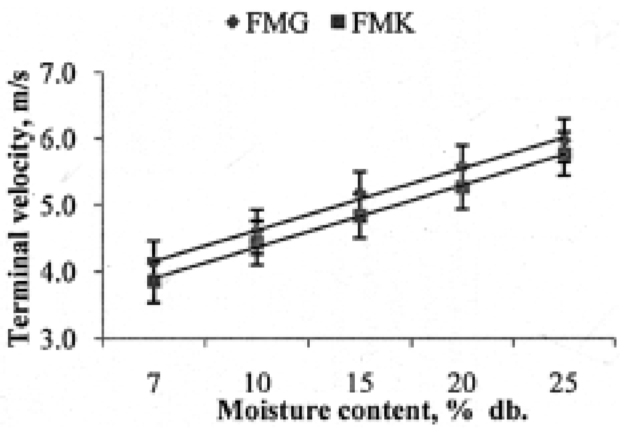

Fig. 1j. Effect of moisture content on terminal velocity of FMG and FMK

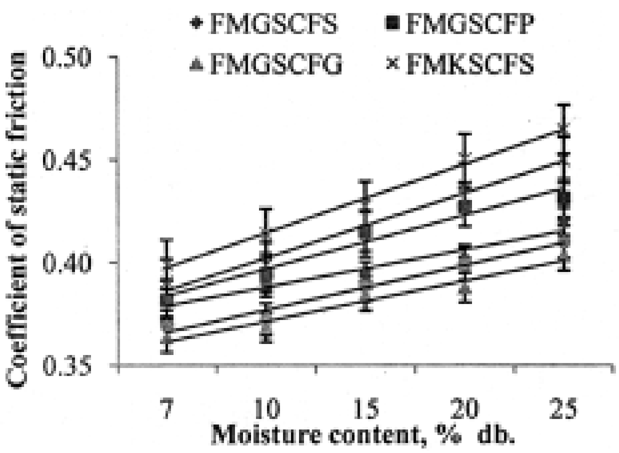

Fig. 1k. Effect of moisture content on coefficent of static frction of FMG and FMK

True density

It was observed from the Fig. 1g, the true density of the finger millet grain decreased from 1515 to 1000 kg m^{-3} and kernel 1667 to 1111 kg m^{-3}, as moisture content increased from 7 to 25% db., respectively. The relationship existing between moisture content and true density shows was linear and represented by the regression Eqs. (22) and (24). The decreasing trend of true density with increase in moisture content of grain indicates that the increase in grain and kernel mass was less as compared to increase in volume (Singh *et al*., 2010). These results agree with the findings Balasubramanian and Viswanathan, (2009) for minor millet, Al-Mahasneh and Rababah, (2007) for green wheat, Sacilik *et al.* (2003) for hemp seed, Aghajani *et al.* (2012) for barley seed and Dursun and Dursun (2005) for caper seed.

Porosity

It was found that, the porosity of finger millet grain and kernel had an inverse relation with moisture content, as the moisture content increases porosity was decreased. The porosity depends on the bulk density and true density of the grain and kernel, it was calculated by using Eq. (7). The effect of moisture content on porosity was shown in Fig. 1h. It was noted that, the porosity of finger millet grain decreases from 51 to 34 %, 47 to 30%, for grain and kernel, respectively. The relationship existing between moisture content and true density was polynomial and represented by the regression Eqs. (25) and (26). A similar trends of result was observed by Balasubramanian and Viswanathan, (2009) for minor millet, Sacilik *et al.* (2003) for hemp seed, Aghajani *et al.* (2012) for barly seed, Gupta *et al.* (2007) for sunflower seed, Al-Mahasneh and Rababah (2007) for green wheat and Dursun and Dursun (2005) for caper seed.

Angle of repose

The experimental results for the angle of repose of finger millet grain and kernel at various moisture levels are shown in Fig. 1i. The figure indicates that the angle of repose of grain (21-30 degree) and kernel (21-32 degree) increased linearly with increase in seed moisture content from 7 to 25% db. The variation of moisture content and angle of repose can be expressed mathematically by Eqs. (27) and (28), for grain and kernel, respectively. Similar linear relation was also found by Altuntaş and Yildiz, (2007) for fababean grain, Aghajani *et al.* (2012) for barely seed, Balasubramanian and Viswanathan, (2009) for minor millet, Sacilik *et al.* (2003) for hemp seed, Aghajani *et al.* (2012) for barley seed, Gupta *et al.* (2007) for sunflower seed, Al-Mahasneh and Rababah (2007) for green wheat and Dursun and Dursun (2005) for caper seed.

Terminal velocity

The terminal velocity of finger millet grain and kernel (Fig. 1j) increased from 4.13 to 5.97 and 3.87 to 5.8 m/s respectively, as the moisture level was increased from 7 to 25% db. The increase in terminal velocity with an increase in moisture content of grain and kernel can be attributed to the increase in mass of an individual seed per unit surface area (Singh *et al.*, 2010). Similar linear trends were observed by Vishwakarma *et al.* (2012) for guar seed, Al-Mahasneh and Rababah (2007) for green wheat, Dursun and Dursun (2005) for caper seed, Sacilik *et al.* (2003) for hemp seed and Singh *et al.* (2010) for barnyard millet grain and kernel. The variation in terminal velocity of finger millet grain and kernel followed a linear relationship with moisture content as shown in Eqs. (29) and (30).

Static coefficient of friction

It is evident from the Fig. 1k that static coefficient of friction of grain and kernel increased with the increase of moisture content from 7-25% db. At all moisture contents, the static coefficient of friction for finger millet

Table 1. *Relationship between various physical properties and moisture content of finger millet grain and kernel*

Sr. No	Properties	Specification		Regression equation	R^2	Eq. No.
1	Geometric mean diameter	Grain		$yg= 0.040x + 1.378$	0.98	11
		Kernel		$yk = 0.039x + 1.345$	0.96	12
2	Sphericity	Grain		$yg = 0.009x + 0.912$	0.99	13
		Kernel		$yk = 0.009x + 0.912$	0.99	14
3	Volume	Grain		$yg = 0.148x + 1.472$	0.99	15
		Kernel		$yk = 0.173x + 1.267$	0.99	16
4	Surface area	Grain		$yg = 0.388x + 5.913$	0.99	17
		Kernel		$yk = 0.448x + 5.312$	0.98	18
5	Thousand grain weight	Grain		$yg = -0.152x + 2.102$	0.96	19
		Kernel		$yk = 0.169x + 1.888$	0.97	20
6	Bulk density	Grain		$yg = -21.53x + 768.7$	0.91	21
		Kernel		$yk = -27.53x + 906.8$	0.98	22
7	True density	Grain		$yg = -126.8x + 1670$	0.97	23
		Kernel		$yk = -129.9x + 1781$	0.97	24
8	Porosity	Grain		$yg = -1.201x^2 + 3.183x + 48.24$	0.98	25
		Kernel		$yk = -1.080x^2 + 2.510x + 44.80$	0.98	26
9	Angle of repose	Grain		$yg = 2.518x + 17.99$	0.99	27
		Kernel		$yk = 2.600x + 18.63$	0.98	28
10	Terminal velocity	Grain		$yg = 0.463x + 3.696$	0.99	29
		Kernel		$yk = 0.463x + 3.443$	0.99	30
11	Static coefficient of friction	Grain	Steel	$ygs = 0.009x + 0.368$	0.94	31
			Plywood	$ygp = 0.013x + 0.370$	0.95	32
			Glass	$ygg = 0.009x + 0.351$	0.96	33
		Kernel	Steel	$yks = 0.015x + 0.370$	0.97	34
			Plywood	$ykp = 0.016x + 0.381$	0.99	35
			Glass	$ykg = 0.010x + 0.355$	0.97	36

grain was highest against plywood (0.38 to 0.43) followed by mild steel (0.38-0.42) and least for glass (0.36 to 0.40). The linear equations for static coefficient of friction (μ) for finger millet grain for different test surfaces with moisture range 7-25% have been shown in Eqs. (31), (32) and (33). Similar, trends were also found for finger millet kernel (Fig.1k). At all moisture contents, the static coefficient of friction for finger millet grain were highest against plywood (0.40 to 0.46), followed by steel (0.39-0.45) and least for glass (0.37 to 0.41). The linear equations for static coefficient of friction (μ) for finger millet grain on all test surfaces with moisture range 7-25 % db can be represented in Eqs. (34), (35) and (36). The increase in static coefficient of friction with an increase in moisture content may be due to increased cohesive force between wet seeds and the structural surface, since the surface became sticky at higher moisture contents (Sacilik *et al.* 2003). Similar linear trends were also observed by Vishwakarma *et al.* (2012) for guar seed, Al-Mahasneh and Rababah, (2007) for green wheat, Dursun and Dursun (2005) for caper seed, Sacilik *et al.* (2003) for hemp seed and Singh *et al.* (2010) for barnyard millet grain and kernel.

The physical properties of finger millet grain and kernel are useful for the design of agricultural processing machines such as design of thresher, pearler, blower, cleaning unit, etc. The geometric mean diameter, sphericity, grain volume, surface area, thousand grain weight, angle of repose, terminal velocity and static coefficient of friction increased with increase in moisture content of grain as well as the kernel. True density, bulk density and porosity of grain as well as kernel decreased with the increase of moisture content.

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