The Andhra Agric. J 64 (1):176-186, 2017

Effect of Moisture Content on Physical Properties of Finger Millet(*Eleusine Coracana*)

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ABSTRACT

Physical properties of finger millet are necessary for the design of machines and analysis of the behaviour of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, processing,transporting and storage of crop. Some physical properties of finger millet (*Eleusine coracana*) of *saptagiri* variety were determined at the moisture contents of 10, 13 and 16 % (w.b). The variation of physical dimensions surface area, volume, mass of 1000 grains, bulk density, truedensity, angle of repose, static coefficient of friction and terminal velocity were measured. The values of physical properties length, width, thickness, geometric mean diameter, sphericity, surface area, volume, thousand grain weight, porosity, angle of repose, static coefficient of friction and terminal velocity were increased linearly as moisture content increased from 10 to16 % w.b. Bulk density and true density were decreased as moisture content increased from 10 to16 % w.b.

Key words: *Angle of repose, Finger millet (Eleusine coracana), Physical properties, True density.*

Finger Millet (*Eleusinecoracona*) is popularly known as Ragi. Finger millet is originally native to the Ethiopian highlands and was introduced into India approximately 4000 years ago. It is highly adaptable to higher elevations and is grown in the Himalayas up to an altitude of 2300 m. It is the most important small millet in the tropics (12% of global millet area) and is cultivated in more than 25 countries in Africa (eastern and southern) and Asia (from Near East to Far East), predominantly as a staple food grain. The major producers are Uganda, India, Nepal, and China. Finger millet has high yield potential (>10 t/ha) under optimum irrigated conditions.India contributes about 55% of total world production. In India, it is cultivated on 1.8 million ha, with an average yield of 1.3 t/ha. The major finger millet growing states are Karnataka, Andhra Pradesh and Tamil Nadu.

Finger millet is especially valuable as it contains the amino acid methionine, which is lacking in the diets of hundreds of millions of the poor who live on starchy staples such as cassava, plantain, polished rice or maize meal. Finger millet can be ground and cooked into cakes, puddings or porridge. The grain is made into a fermented drink (or beer) in Nepal and in many parts of Africa. The straw from finger millet is used as animal fodder.

Finger millet is nutritionally superior to rice and wheat. These are rich in protein, mineral and vitamins and contain higher proportion of dietary fiber than rice or wheat. It provides 1700 kcal of energy from 100 g of fingermillet(Devi*et al.,* 2011). Presence of all the required nutrients in millets makes them suitable for industrial scale utilization in manufacture of foodstuffs like baby foods, snack foods and dietary food products etc., from both grain and flour.

Physical properties of finger millet like those of other grains and seeds are essential for the design of equipment for handling, harvesting, processing and storing. Bulk density, true density and porosity can be useful in design of grain hoppers and storage facilities ; they can affect the rate of heat and mass transfer during aeration and drying processes. Flow ability of grains is usually measured using the angle of repose. 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. The objective of the present study was to assess the physical properties of finger millet of*saptagiri* variety.

MATERIALS AND METHODS

Harvested and threshed finger millet of *Saptagiri*variety was procured from Agricultural college Farm, Bapatla for conducting the research work and the initial moisture content was calculated.

Determination of physical properties

Physical properties of the grains are very important to develop and optimize various design parameters of the machine. Moisture content, Geometric mean diameter, Sphericity, 1000 grains weight, Surface area, Bulk Density, True Density, Porosity, Terminal velocity, Angle of Repose, Coefficient of Static Friction were determined using following methods.

Conditioning of the sample

A 100 g sample was taken from finger millet grains and the desired moisture content of samples were achieved by adding "Q" calculated quantity of distilled water, as per the equation given below:

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

Where Q = Weight of required water, g
Wt = Total weight of sample, g
Mf = Final moisture content (w.b), %
Mi = Initial moisture content (w.b), %

Grain samples were sealed in polyethylene bags. The samples were kept in a refrigerator maintained at 4°C for a minimum period of 7 days to equilibrate moisture content. The moisture contents of the samples were equilibrated to desired moisture contents (10, 13, 16% w.b) as per the procedures of AACC (2000). Before each experiment, samples were equilibrated at room temperature (30°C) for 2 h and the moisture was checked using the standard hot air oven-dry method (Balasubramanian and Viswanathan, 2010). All the physical properties of the grain samples were determined at the desired moisture content .

Moisture Content

Moisture content of grains was determined by Hot air oven method. The grain sample was cleaned manually to remove foreign matter like dirt, dust, stones etc., then a known weight of sample was taken and kept in oven at 130 ± 1 ^{0}C for 2 h (AOAC, 2010). After 2 h, the sample was removed from the oven and cooled. After cooling, final weight of the sample was taken and the moisture content on wet basis was determined by following formula (Sahay and Singh,1994).

$$MC\,(w.b)\% = \frac{W_w - W_d}{W_w} \times 100 \quad \text{....(2)}$$

W_w = Weight of wet grains, gW_d = Weight of dried sample, g

Physical Parameters

Physical parameters like length, width, thickness, geometric mean diameter, sphericity, surface area, volume, thousand kernel weight, bulk density, true density, and angle of repose of samples were determined as per the following procedure.

Determination of axial dimensions, geometric mean diameter, sphericity, surface area and volume

Ten finger millet grains from each sample were randomly selected and their length, width and thickness were measured with a digital vernier calipers (Aerospace Model, 0-300mm) . These values were used to calculate Geometric mean Diameter, Sphericity, Surface area and Volume using standard relationships.

Geometric mean diameter, $D_g = (LWT)^{1/3}$ **.... (3)**

Sphericity, S $= \frac{(LWT)^{\frac{1}{3}}}{L} \times 100$ **.... (4)**

Surface Area, A $= \pi Dg^2$ **....(5)**

Volume, V =
$\square 0.25[\pi/6\, L(W+T)\square^{\dagger}(2)\,]$ **....(6)**

Where,
L - Length of the grain, mm
W - Width of the grain, mm
T - Thickness of the grain, mm

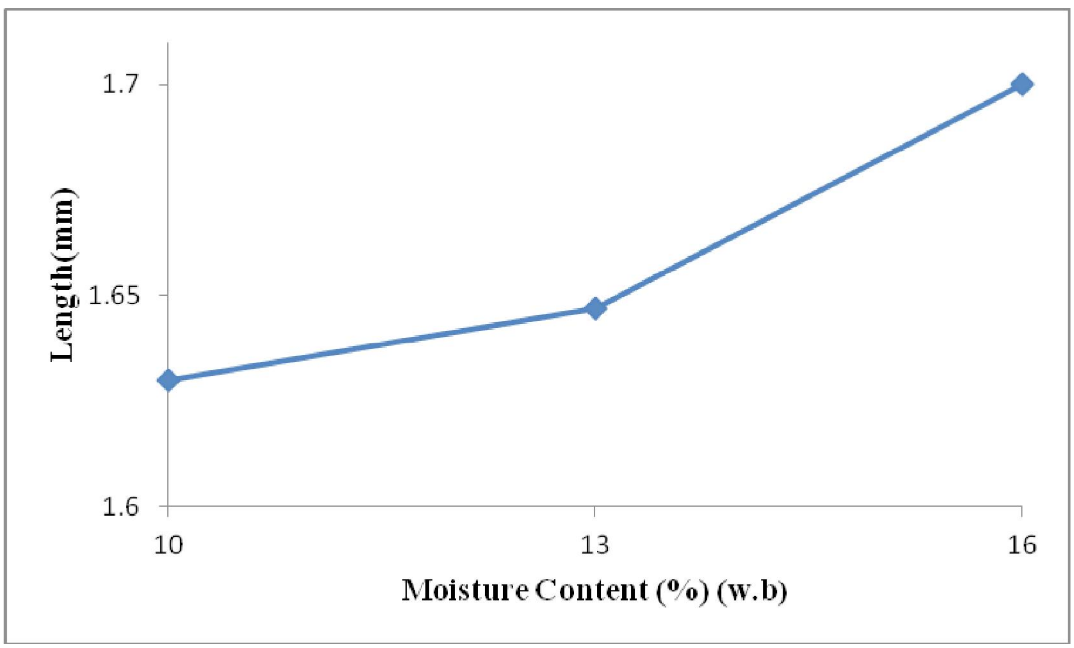
Determination of thousand grain weight

Thousand grain weight was measured by weighing the 1000 randomly selected grains in an electronic balance with an accuracy of 0.01 g. The

Table 1 Nutrient and mineral composition of finger millet.

S No	Name of the component(g)	Amount Present (per 100g of edible portion)
1	Protein	7.3
2	Fat	1.3
3	Crude Fibre	3.6
4	Ash	3.0
5	Starch	72.0
6	Total Dietary Fibre	11.5
7	Calcium	0.344
8	Phosphorus	0.283
9	Potassium	0.408
10	Sodium	0.011
11	Magnesium	0.137
12	Iron	0.0039
13	Manganese	0.00549
14	Zinc	0.0023

Fig.1. Effect of moisture content on length of finger millet grain.



measurements were replicated 10 times (Barnwal et al, 2012).

Determination of bulk density

The average bulk density of the finger millet was determined by using standard weight test procedure by filling the container of 500 ml with the sample of 100 ml from the height of 150 mm and then content is weighed (Singh and Goswami, 1996).

Bulk density, Kg/m^3 =

$$\frac{\text{Weight of the grain, Kg}}{\text{volume of the grain, m}^3} \quad \text{.... (7)}$$

Determination of true density

The average true density was expressed as the ratio of weight of grain sample to volume of toluene displaced was determined by the toluene displacement method. The volume of toluene (C_7H_8) displaced was found by immersing a weighed quantity of grain sample in the toluene (Singh and Goswami, 1996).

True density, Kg/m³ =

$$\frac{\text{Weight of the grain}}{\text{volume of the toluene displaced}}$$

ß 1000**… (8)**

Determination of porosity

The porosity was calculated from bulk and true densities by the following equation (Mohsenin, 1970).

Porosity =(1 - $\frac{\text{Bulk density}}{\text{True density}}$) ß 100 **… (9)**

Determination of angle of repose

Angle of repose of the maize grain was calculatedfrom the height and diameter of the naturally formed heap of the grains on a circular plate(Barnwal *et al.,* 2012).

Angle of repose, u= $\tan^{-1}\frac{[2Hc]}{[Dg]}$ **… (10)**

H_c = Height of the Heap, mm

D_g = Diameter of the circular plate, mm

Determination of static coefficient of friction

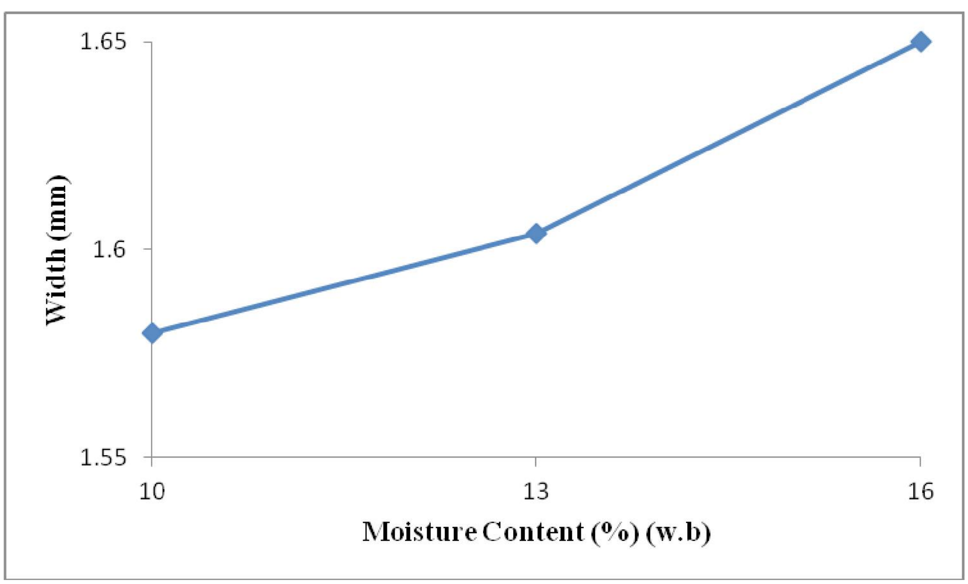
The static coefficient of friction of finger millet wasdetermined against four metallic surfacesmade of mild steel, galvanised iron and stainless steel respectively. A polyvinylchloride cylindrical pipe of 50 mm diameter and 50 mm height was placed on an adjustable tilting plate , faced with the surface, and filled with the seed sample. The cylinder was raised about 2 mm above the base of the bulk seed so as not to touch the surface. The structural surface with the cylinder resting on it was gradually raised with a screw device until the cylinder along with the sample just started to slide down and the angle of tilt ($\propto$) was read from a graduated scale. The coefficient of friction (µ) was calculated from the following relationship(Singh and Goswami, 1996).

µ = $\tan \propto$ **…. (11)**

Determination of terminal velocity

The terminal velocity of finger milletwas measured using an air column. For each experiment, a small sample was dropped into the air stream from the top of the air column, up which air was blown to suspend the material in the air stream. The air velocity near the location of the seed suspension was measured by a digital anemometer (Singh and Goswami, 1996).

Fig.2. Effect of moisture content on width of finger millet.



RESULTS AND DISCUSSION

The properties such as size, geometric mean diameter, sphericity, surface area, volume, density, mass of 1000 grains, bulk density, true density, porosity, terminal velocity, angle of repose and coefficient of friction were presented and discussed here under.

Effect of moisture content on dimensions of finger millet

The length, width and thickness of the finger millet grain of *saptagiri*variety were determined at each level of moisture contents viz., 10, 13, 16% w.b. The three axial dimensions increased with the increase of moisture content from 10 to 16% w.b. The increase in linear dimension may be due to the expansion of grains due to absorption of moisture with the increase in moisture content (Goswami*et al.,* 2015). Each dimension appeared to be linearly dependent on moisture content as shown in Fig.1, 2, 3

The length, width and thickness of finger millet grains increased with moisture content.However, the increase in length and thickness was relatively higher than that of width of grains. The average values of length were 1.63, 1.647, 1.7 mm, width were 1.58, 1.604, 1.65 mm and thickness were 1.43, 1.55, 1.54 mm at 10, 13, 16% w.b moisture content respectively.

Effect of moisture content on geometric mean diameter of finger millet

The geometric mean diameter increased with the increase of moisture content from 10 to 16% w.b due to the increase of axial dimensions. The average values of geometric mean diameter were 1.54, 1.55, 1.62 mm at 10, 13, 16 % w.b moisture content respectively. The geometric mean diameter increased linearly with respect to increase in moisture content as shown in Fig.4. The relation can be mathematically represented as (Eq No 12)

$D_g = 0.0137M + 1.393 \quad R^2 = 0.8399$ ....**(12)**

The similar type of linear trend of geometric mean diameter with moisture content has been reported for finger millet (Daploli-1 variety) (Swami and Swami, 2010).

Effect of moisture content on sphericity of finger millet

The sphericity increased with the increase of moisture content from 13 to 16 % w.b. The average values of sphericity were 0.942, 0.944, 0.955 at 10, 13, 16 % w.b moisture content respectively. The sphericity increased linearly with respect to increase in moisture content as shown in Fig.5. Similar type of linear trend of sphericity with moisture content has been reported for finger millet for Daploli-1 variety (Swami and Swami, 2010) and millets (Balasubramanian and Viswanathan, 2010).The relation can be mathematically represented as (Eq No 13)

$S = 0.0025M+0.9138 \quad R^2 = 0.9323$ .... **(13)**

Effect of moisture content on surface area and volume of finger millet

The surface area and volume of the finger millet increased linearly with the increase of moisture content from 10 to 16 % w.b as shown in Fig.6, Fig.7. respectively. The increase of the values may be due to increase in the dimensions of the grains. The average values of surface area and volume were 7.4, 7.55, 8.2 mm^2 and 1.74, 1.97,2.26 mm^3 at moisture content of 10, 13, 16 % w.b respectively. The linear relation between moisture content and surface area, moisture content and volume is given as (Eq No 14), (Eq No 15) respectively.

$A = 0.1333M + 6 \quad R^2 = 0.9231$............ **(14)**

$V = 0.0867M + 0.8633 R^2 = 0.9956$............ **(15)**

Similar type of linear trend of surface area and volume with moisture content has been reported for finger millet (Daploli-1 variety) (Swami and Swami, 2010), millets (Balasubramanian and Viswanathan, 2010).

Effect of moisture content on Thousand grain weight

The thousand grain weight of finger millet increased linearly with the increase in moisture content from 10 to 16 % w.b as shown in Fig.8. The increase in weight may be due to the absorption of moisture by the grains. The average values ofmass of 1000 grains were 2.56, 3, 3.5 g at moisture content of 10, 13, 16 % w.b respectively. The relation between thousand grain weight and moisture content can be mathematically given by (Eq No 16)

Thousand grain weight= $0.1567M + 0.9833$ $R^2 = 0.9986$......... **(16)**

Similar results were reported for finger millet (Balasubramanian and Viswanathan, 2010), cumin seeds (Singh and Goswami, 1996).

Fig.3. Effect of moisture content on thickness of finger millet.

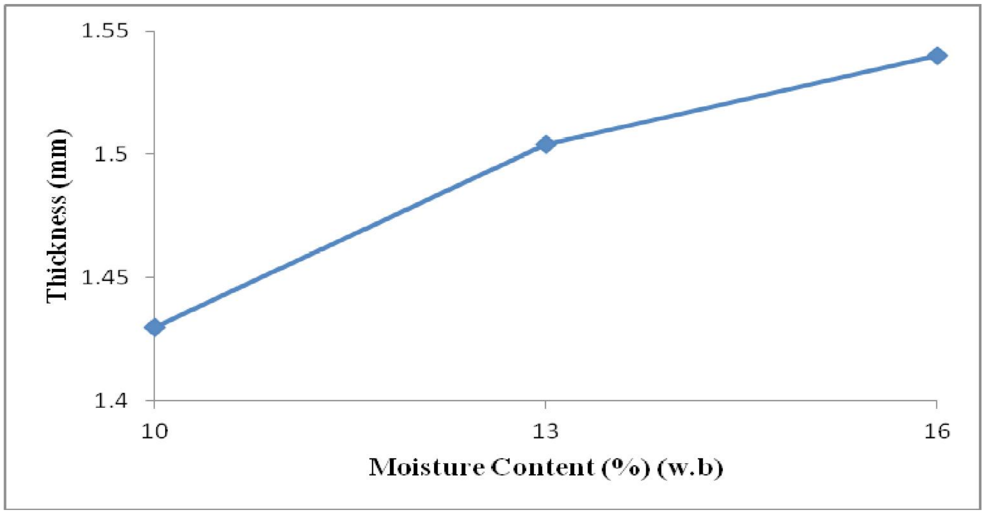


Fig.4. Effect of moisture content on geometric mean diameter of finger millet.

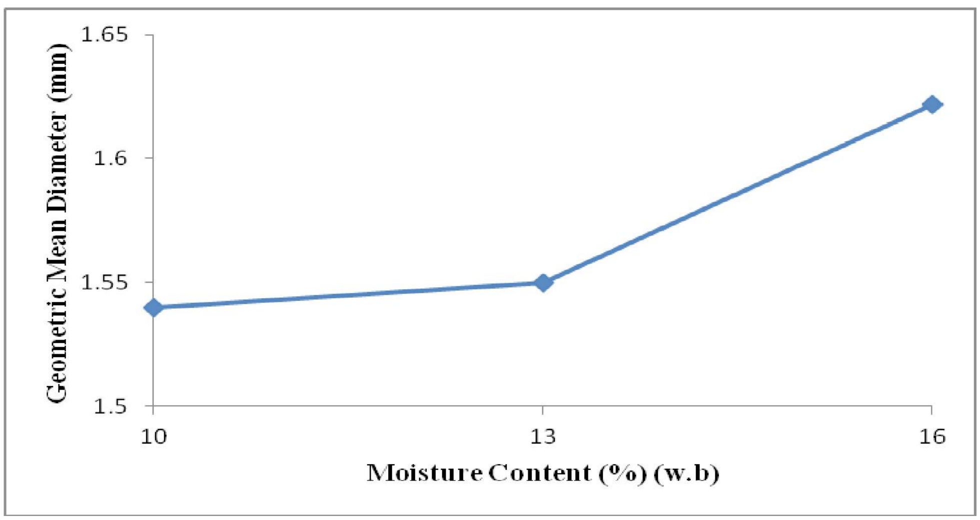


Fig.5. Effect of moisture content on sphericity of finger millet.

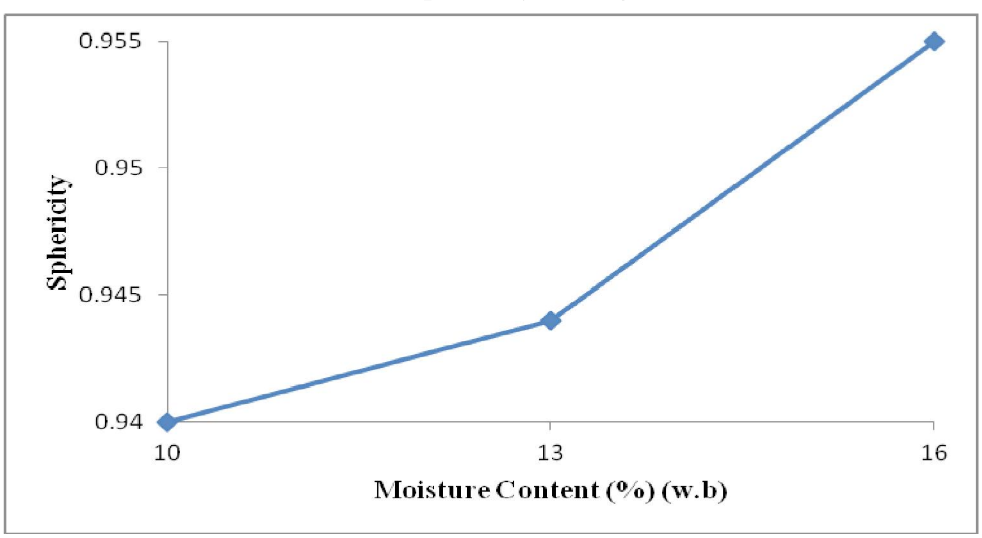


Fig.6. Effect of moisture content on surface area of finger millet.

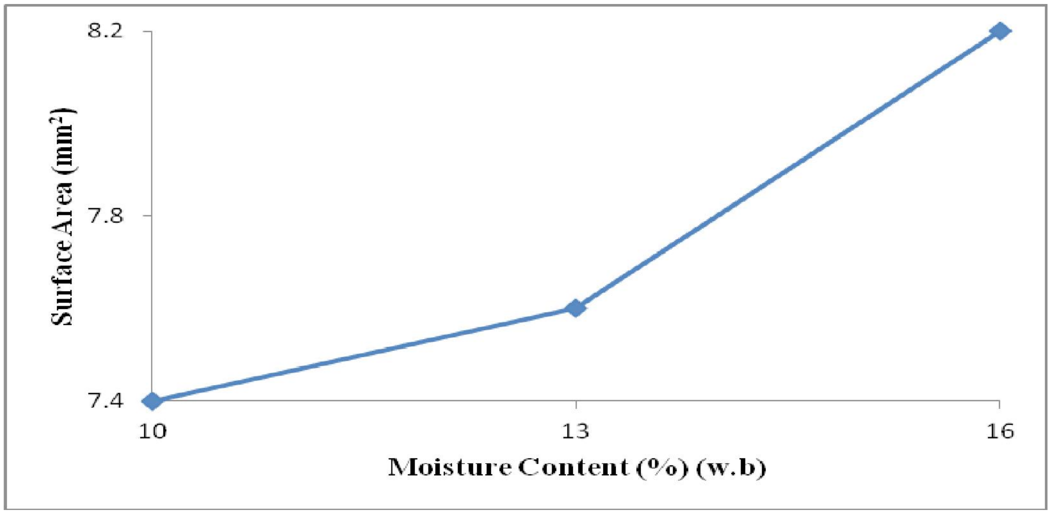


Fig.7. Effect of moisture content on volume of finger millet

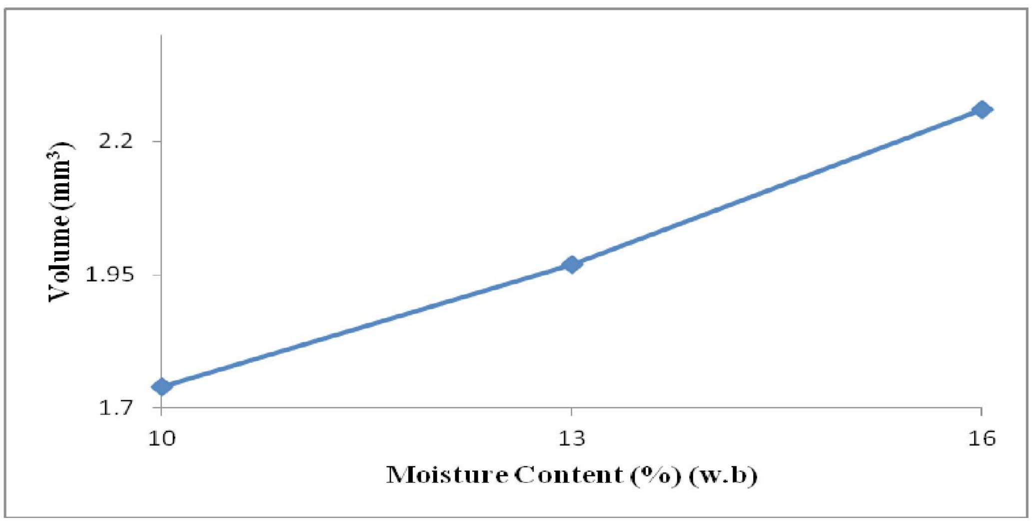


Fig.8. Effect of moisture content on mass of 1000grains of finger millet.

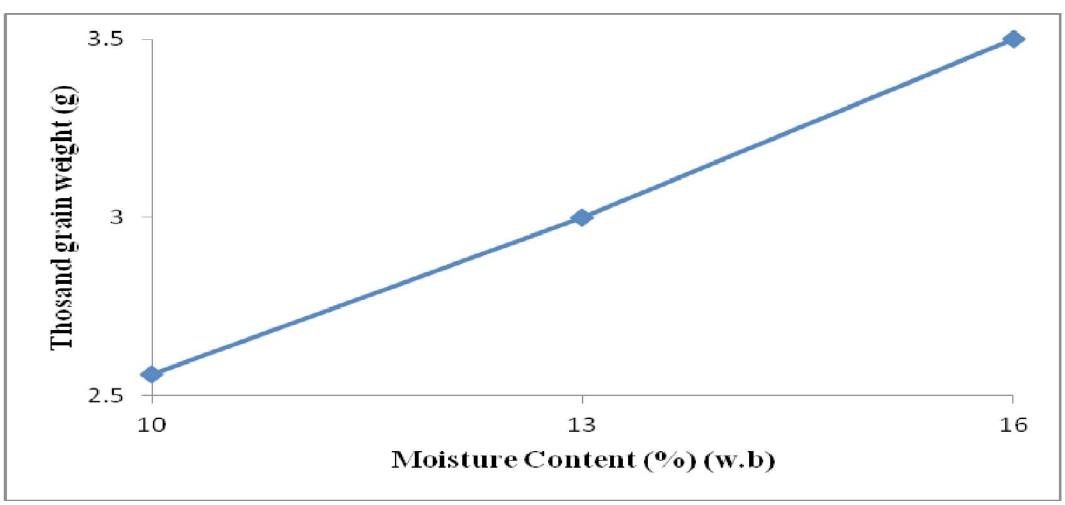


Fig.9. Effect of moisture content on bulk density of finger millet.

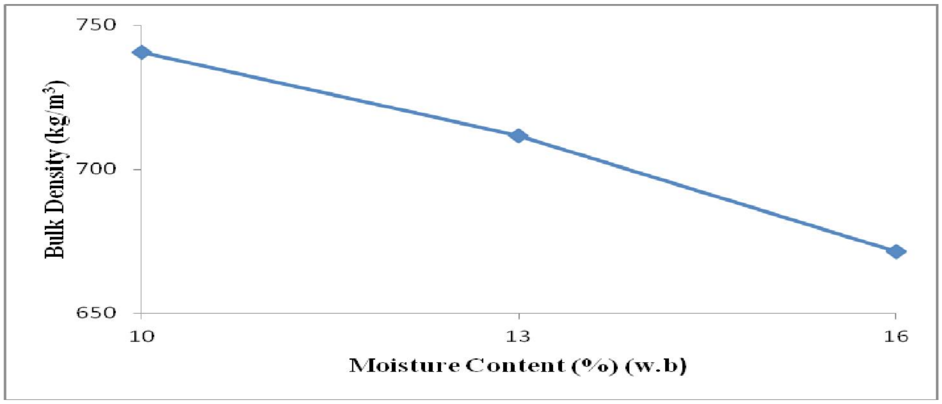


Fig.10. Effect of moisture content on true density of finger millet

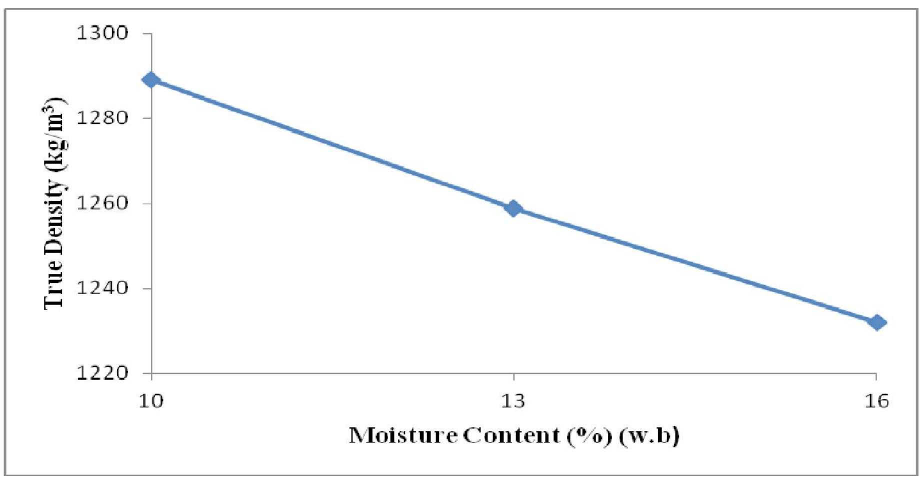


Fig.11. Effect of moisture content on porosity of finger millet.

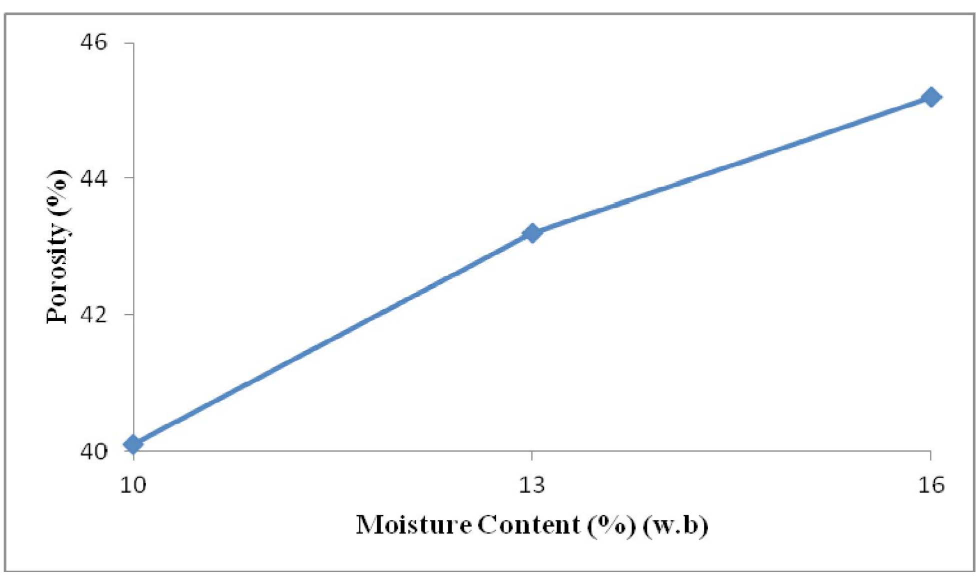


Fig.12. Effect of moisture content on terminal velocity of finger millet.

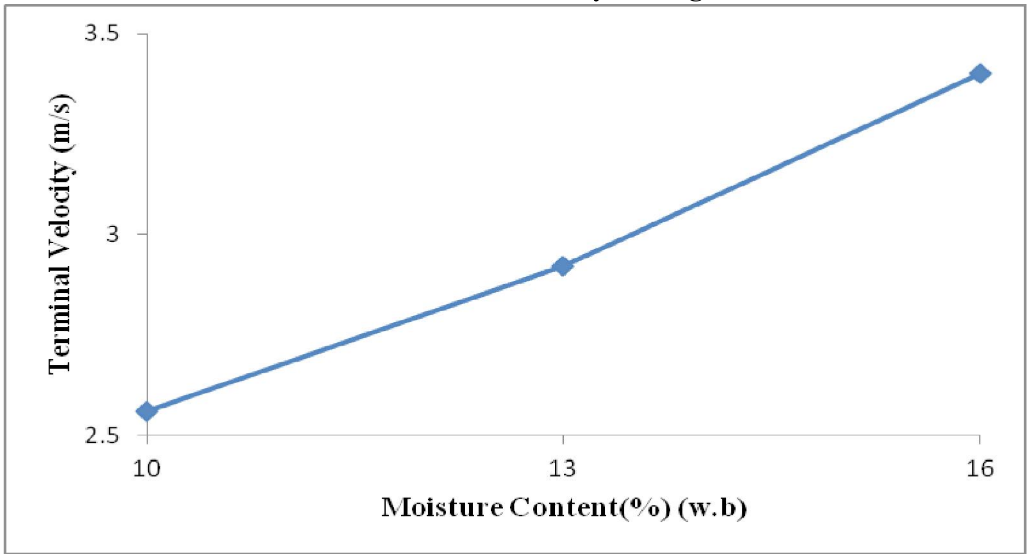


Fig.13. Effect of moisture content on angle of repose of finger millet

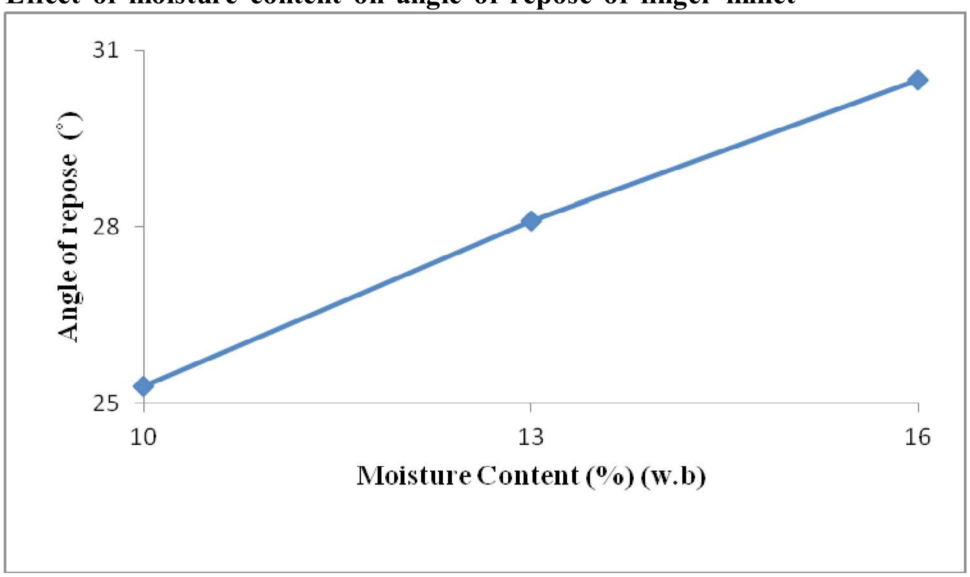
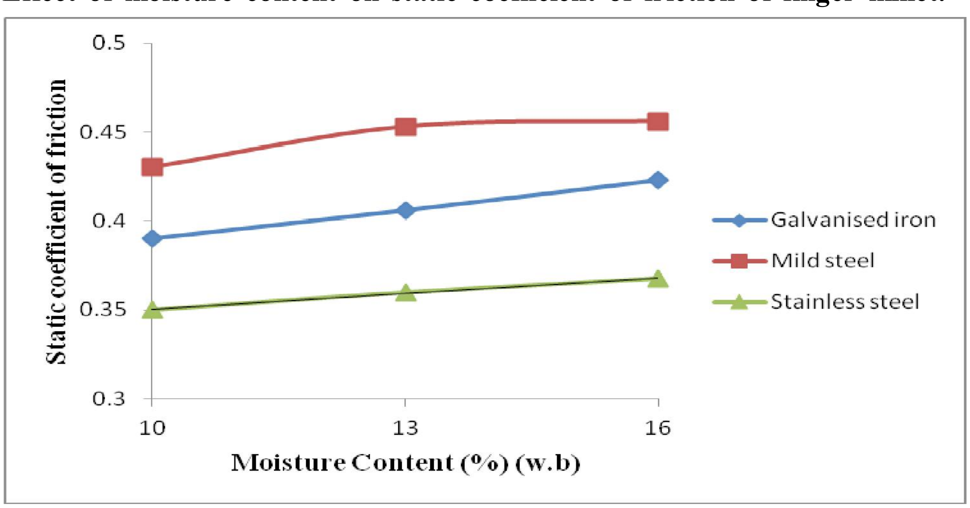


Fig.14. Effect of moisture content on static coefficient of friction of finger millet.



Effect of moisture content on bulk density

The bulk density of the grains decreased linearly with the increase of moisture content from 10 to 16 % w.b as shown in Fig.9. The decrease in bulkdensity may be attributed to the differential increase in mass andvolumetric expansion (volume) of the seeds. Itindicated that the volumetric expansion was more than that of mass increase. The average values of bulk density were 740.6, 711.5, 671.4 kg/m^3 at moisture content of 10, 13, 16 % w.b.The mathematical relation can be given as follows (Eq No 17)

Bulk density = -11.533M + 857.77 $R^2 = 0.9916$......... **(17)**

Similar results were reported for millets (Balasubramanian and Viswanathan, 2010), cumin seeds(Singh and Goswami, 1996) and finger millet (Goswami *et al.,* 2015).

Effect of moisture content on true density

The true density of the grains found decreased linearly with the increase of moisture content from 10 to 16 % w.b as shown in Fig.10.The decrease indicates thatthere is a lesser increase in grain mass compared to increase in its volume with the increase in moisture content. The average values of bulk density were 1289, 1258.7, 1232 kg/m^3 at moisture content of 10, 13, 16 % w.b and the mathematical relation can be given as follows (Eq No 18).

True density = -9.5M + 1383.4 $R^2 = 0.9987$... **(18)**

Similar results were reported for millets (Balasubramanian and Viswanathan, 2010), cumin seeds(Singh and Goswami, 1996) and finger millet (Goswami *et al.,* 2015) .

Effect of moisture content on porosity

The porosity of the grains found increased linearly with the increase of moisture content from 10 to 16 % w.b as shown in Fig.11.The average values of porosity were 40.1, 43.2, 42.2 % at moisture content of 10, 13, 16 % w.b. The mathematical relation can be given as follows (Eq No19)

Porosity = 0.85M + 31.783 $R^2 = 0.9847$....... **(19)**

Similar results were reported for cumin seeds (Singh and Goswami, 1996) and finger millet (Goswami *et al.,* 2015).

Effect of moisture content on terminal velocity

The terminal velocity of the grains increased linearly with the increase of moisture content from 10 to 16 % w.b as shown in Fig.12.The increase interminal velocity with increase in moisture content can be attributed to the increase in mass of an individual seed per unit frontal area presented to the airflow. The average values of terminal velocity were 2.56, 2.94, 3.4 m/s at moisture content of 10, 13, 16 % w.b.Similar results were reported for cumin seeds (Singh and Goswami, 1996). The mathematical relation can be given as follows (Eq No 20).

Terminal velocity = 0.14M + 1.14 $R^2 = 0.9932$.......... **(20)**

Effect of moisture content on angle of repose

The angle of repose (u) found increased with the increase of moisture content from 10 to 16 % w.b as shown in the Fig.13. The average values of the angle of repose were 25.29Ú, 28.1Ú, 30.5Ú at moisture contents 10, 13, 16 % w.b respectively. Similar results were reported for millets (Balasubramanian and Viswanathan, 2010), cumin seeds (Singh and Goswami, 1996) and finger millet (Goswami *et al.,* 2015). The mathematical relation can be given as follows (Eq No 21).

u= 0.8683M + 16.675 $R^2 = 0.9979$......... **(21)**

Effect of moisture content on static coefficient of friction

The static coefficient of friction found increased with the increase of moisture content from 10 to 16 % w.b as shown in the Fig.14. The increase in static coefficient of friction with the increase in moisture content may be due to fact that at higher moisture contents, thegrain tends to stick to the surface which resulted into increase in static coefficient of friction.The average values of thestatic coefficient of friction for galvanized iron were 0.39, 0.406, 0.423, for mild steel were 0.43, 0.453, 0.456 and stainless steel were 0.35, 0.36, 0.368 at moisture contents 10, 13, 16 % w.b respectively. Similar results were reported for millets (Balasubramanian and Viswanathan, 2010), cumin seeds (Singh and Goswami, 1996) and finger millet (Goswami *et al.,* 2015). The mathematical relation can be given as follows (Eq No 22 - 24).

For galvanized iron

$\mu = 0.0055M + 0.3348 \quad R^2 = 0.9997$……… **(22)**

For mild steel $\mu = 0.0043M + 0.39$

$R^2 = 0.8353$………. **(23)**

For stainless steel

$\mu = 0.003x + 0.3203 \quad R^2 = 0.9959$……… **(24)**

Conclusion

The average values of physical properties length ; 1.63 to 1.7 mm, width : 1.58 to1.65 mm, thickness : 1.43 to 1.54, geometric mean diameter : 1.54 to1.622mm, sphericity : 0.942 to 0.955, surface area : 7.4 to 8.2 mm^2, volume : 1.74 to 2.26 mm^3,thousand grain weight : 2.56 to 3.51g, porosity : 40.1 to 45.2, angle of repose : 25.5Ú to 30.5Ú, static coefficient of friction for galvanized iron : 0.39 to 0.423, mild steel : 0.43 to 0.456, stainless steel 0.35 to 0.356, terminal velocity : 2.56 to 3.4 m/s . All these properties increased as moisture content increased from 10 to 16 % w.b.

Bulk density and true density were decreased from 740.6 to 671.4 kg/m^3 and 1289 to 1232 kg/m^3 respectively when moisture content was increased from 10 to 16 % w.b.

LITERATURE CITED

AOAC 2010 *Official methods of analysis,18th Edition, Washington D.C.*

Balasubramanian S and Viswanathan R 2010 Influence of moisture content on physical properties of minor millets. *Journal of Food Science and Technology,* 47(3): 279–284.

Barnwal P, Kadam D M and Singh K K 2012 Influence of moisture content on physical properties of maize *International Agrophysics, 26*:331-334.

Devi P B, Vijayabharathi R, Sathyabama S, Malleshi N G and Priyadarisini V B 2011 Health benefits of finger millet (*Eleusine coracana L.*) polyphenols and dietary fiber: a review. *Journal of Food Science and Technology,* 51(6): 1021-1040.

Goswami D, Manikantan M R, Gupta R K and Vishwakarma R K 2015 Moisture dependent selected postharvest engineering properties of ragi (*Eleusine coracana*) grown in northern hills of India. *Journal of Postharvest Technology,* 3(3): 82-88.

Mohsenin N N 1970 *Physical Properties of Plant and Animal Materials*. Gordon and Breach, New York: 105-120.

Sahay K M and Singh K K 1994 *Unit Operations of Agricultural Processing.* Vikas Publishing house, New Delhi:70-75,103-110.

Singh K K, Goswami T K 1996 Physical Properties of Cumin Seed. *Journal of Agricultural Research,*64:93-98

Swami S S and Swami S B 2010 Physical Properties of Finger millet (Eleusine coracana).*International Journal of Agricultural Engineering,*3(1):156-160

(Received on 31.12.2015 and revised on 09.06.2016)