J Food Sci Technol (May–June 2010) 47(3):279–284
DOI: 10.1007/s13197-010-0043-z

ORIGINAL ARTICLE

Influence of moisture content on physical properties of minor millets

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Revised: 24 August 2009 / Accepted: 29 August 2009

Abstract Physical properties including 1000 kernel weight, bulk density, true density, porosity, angle of repose, coefficient of static friction, coefficient of internal friction and grain hardness were determined for foxtail millet, little millet, kodo millet, common millet, barnyard millet and finger millet in the moisture content range of 11.1 to 25% db. Thousand kernel weight increased from 2.3 to 6.1 g and angle of repose increased from 25.0 to 38.2°. Bulk density decreased from 868.1 to 477.1 kg/m^3 and true density from 1988.7 to 884.4 kg/m^3 for all minor millets when observed in the moisture range of 11.1 to 25%. Porosity decreased from 63.7 to 32.5%. Coefficient of static friction of minor millets against mild steel surface increased from 0.253 to 0.728 and coefficient of internal friction was in the range of 1.217 and 1.964 in the moisture range studied. Grain hardness decreased from 30.7 to 12.4 for all minor millets when moisture content was increased from 11.1 to 25% db.

Keywords Foxtail millet · Little millet · Kodo millet · Common millet · Barnyard millet · Finger millet

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Introduction

Minor millets include foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*), kodo millet (*Paspalum sorobiculatum*), common millet (*Panicum miliaceum*), barnyard millet (*Echinochloa corona*) and finger millet (*Eleusine coracana*). They are robust and quick growing cereals, which are more efficient in utilization of moisture and have a high level of heat tolerance compared to sorghum or maize. They are nutritionally superior to rice and wheat, provide protein, minerals and vitamins (Rao 1986) and contain higher proportion of dietary fibre (Malleshi and Hadimani 1993). The physical properties of millet, like those of other grains and seeds are essential for design of equipment used for their handling, storing and processing. Knowledge of engineering properties of agricultural materials and their dependence on the moisture content constitute important in the design of machines, structures, processes and controls in analyzing and determining the efficiency of a machine or an operation in developing new consumer products and in evaluating and retaining the quality of the final product. Such basic information should be of value not only to engineers but also to food scientists and processors who may exploit these properties and find new uses (Mohsenin 1986).

Physical properties of pearl millet like dimension, surface area, volume, sphericity, density, angle of repose and friction were determined by Jain and Bal (1997) and Baryeh (2002) in the moisture range of 5–22.5% (db). Studies related to other millets are limited. Thermal properties including specific heat, thermal conductivity and thermal diffusivity were determined by Subramanian and Viswanathan (2003) for minor millet grains and flours. Also many researchers have determined the bulk density and friction coefficients for pigeon pea (Shepherd and Bhardwaj 1986), gram (Dutta et al. 1988), soybean (Sreenarayanan et al. 1988), green gram (Nimkar and Chattopadhyaya 2001), chick pea seeds (Konak et al. 2002) and rapeseed (Calisir et al. 2005). Manimehalai and Viswanathan (2006) determined the coefficient of internal friction for cassava flour and fuzzy cottonseeds. Though the information on physical properties for many food grains is available, the information of these properties for minor millets at various moisture levels is lacking and hence this study was undertaken.

Materials and methods

Minor millets like foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*), kodo millet (*Paspalum sorobiculatum*), common millet (*Panicum miliaceum*), barnyard millet (*Echinochloa corona*) and finger millet (*Eleusine coracana*) were obtained from the Department of Millets, Tamil Nadu Agricultural University, Coimbatore, India. The grains were cleaned by manual and mechanical means to remove all foreign matter, broken and immature grains. Physical properties for raw minor millets were investigated in the simulated moisture content range of 11.1–25% (db), since harvesting, transportation, storage and dehulling operations of minor millets are performed in this range. Grain samples of desired moisture content levels were prepared by adding calculated amount of distilled water in accordance with the following equation (Sacilink et al. 2002) and mixed thoroughly.

$$Q = W_i \left(\frac{m_f - m_i}{100 - m_f} \right) \quad (1)$$

where, Q is the weight of water to be added (g); W_i is the initial weight of grain sample (g); m_i is the initial moisture content of grain sample (% db) and m_f is the final moisture content of grain sample (% db).

Grain samples were sealed in polyethylene bags of 300 μ thickness. The samples were kept in a refrigerator maintained at 4±1°C for a minimum period of 10 days to reach uniform moisture content. The moisture contents of the samples were equilibrated to 11.1, 13.6, 16.3, 19.1, 22 and 25% db as per the procedures of AACC (2000). Before each experiment, samples were equilibrated at room temperature (30±2°C) for 2 h and the moisture was checked using the standard oven-dry method. All tests were conducted in the laboratory at an ambient temperature of about 30±2°C and relative humidity of 55–65%.

Thousand kernel weight: A grain weight of approximately 1 kg was roughly divided in to 10 equal portions and then 1000 numbers of grains were randomly picked from each portion, and weighed on a digital electronic balance. The measurement was repeated for 5 times and the mean value was taken.

Bulk density: A circular container of volume 1.482×10^{-3} m^3 was filled with the grain and gently tapped. Bulk density was calculated as the ratio of weight of millets to volume of container. Average of 5 replications was taken. Care was taken to avoid compaction of grains in the container and filled to full volume.

Porosity and true density: Porosity was determined by using the porosity apparatus (Sreenarayanan et al. 1988). True density was calculated from the measured values of bulk density and porosity using the following equation (Mohsenin 1986).

$$\varepsilon = \left(\frac{\rho_g - \rho_b}{\rho_g} \right) \times 100 \quad (2)$$

where, ε is the porosity (%), ρ_b is the bulk density of grain (kg/m^3) and ρ_g is the true density of grain (kg/m^3).

Angle of repose: The filling angle of repose was determined using the apparatus described by Sreenarayanan et al. (1988). Angle of repose was determined from the height and diameter of the naturally formed heap of grains on a circular plate.

Coefficient of static and internal friction: The coefficient of static friction apparatus consisted of a frictionless pulley fitted on a frame, a cylindrical container of negligible weight with both ends opened, loading pan and test surfaces (Visvanathan et al. 1996). The container, placed on the mild steel surface was filled with a known quantity of material and weights were added to the loading pan until the container began to slide. The experiment was performed with millets of different moisture contents. The coefficient of static friction was calculated as the ratio of weights added (frictional force) and material mass (normal force) as given below.

$$\mu_e = \frac{F_e}{N_e} \quad (3)$$

For the measurement of coefficient of internal friction, apparatus consisting of 2 cylinders, with one being a stationary and other one to slide on the stationary one (diameter:height, 50:55 mm) was used. Through a pulley-rope arrangement with a loading pan, the top cylinder was made to slide on the stationary cylinder. Both the cylinders were placed in position and sample was filled without any compaction. Grain mass sample contained in top cylinder (normal force) acts on top layer of same material in the bottom stationary cylinder and incremental load applied in loading pan to slide the top pan (frictional force). The force required to slide the empty top cylinder was subtracted from frictional force to get actual frictional force to overcome the friction due to material. Mean of 5 replications was taken. The coefficient of internal friction was calculated as the ratio of weights added (frictional force) and grain mass (normal force) as given below.

$$\mu_i = \frac{F_i}{N_i} \quad (4)$$

where, μ_e, μ_i are the coefficient of static and internal friction (dimensionless); F_i, F_e are the frictional force for static and internal friction (g) and N_i, N_e are the normal force for static and internal friction (g).

Grain hardness: A single grain hardness of minor millet at different moisture contents was measured using texture analyser (Model TA-HD, Surrey, UK). Minor millet was placed individually in its natural resting position on the platform and load was applied until the grain crushed. The measurement was repeated for 5 different samples and the mean was taken. Experimental conditions followed were load cell: 5 kg, test mode: measure force in compression, test option: return to start, pre test speed: 2 mm/sec, test speed: 0.1 mm/s, post test speed: 2 mm/sec, strain: 70% and test probe: P 4.

Statistical analysis: Results of 5 replications were statistically analysed for all physical properties of minor millets.

Results and discussion

Thousand kernel weight: The 1000 kernel weight increased linearly with increase in moisture content (Fig. 1). Singh and Goswami (1996) for cumin seeds found such linear relationship between thousand seed/kernel weight and moisture content. The weights of 1000 seeds and kernels at 6.5% db moisture content were in the range of 22–229 and 19–177 g, respectively for pumpkin seeds and kernels (Joshi et al. 1993).

Bulk density: A linear decreasing trend with in bulk density, moisture content range of 11.1–25% db was observed (Fig. 1). Higher bulk density was exhibited by barnyard millet followed by proso millet, kodo millet, finger millet, little millet and foxtail millet, at lower moisture levels. At higher moisture levels, bulk density was higher for proso millet followed by barnyard millet, finger millet, kodo millet, foxtail millet and little millet. A similar relationship was reported by Shepherd and Bhardwaj (1986) and Dutta et al. (1988) for pigeon pea and gram, respectively. However, Suthar and Das (1996) found that the bulk density increased linearly with grain moisture increase for karingada seeds. These discrepancies could be due to cell structure, volume and weight increase characteristics of grains and seeds.

True density: The true density decreased with increase of moisture content (Fig. 1). This decrease indicates that there is a lesser increase in grain mass compared to increase in its volume with its moisture content increase. These results agree with the findings of Suthar and Das (1996) with pumpkin seeds. Higher mass range of seeds, which is due to larger size of seed, also increases the volume resulting in decreased true density. True density of minor millets was found to be less than that of gram (Dutta et al. 1988). Suthar and Das (1996) noted an increase in the true density from 1010 to 1134 kg/m^3 and 1047 to 1134 kg/m^3 for karingda kernel and cumin seed for the moisture range of 5–40% db and 7–22% db, respectively (Singh and Goswami 1996). Many researchers have reported the decrease in true density with moisture content increase (4–32.6% db) for karingda seed (Suthar and Das 1996), chick pea seeds (Konak et al. 2002) and rapeseed (Calisir et al. 2005).

Porosity: Porosity values decreased with increase in moisture content (Fig. 1). Porosity value was higher

Table 1 Best fit equations for physical properties of minor millets

Properties	Foxtail millet		Little millet		Kodo millet		Common millet		Barnyard millet		Finger millet	
	mx+c	R^2	mx+c	R^2	mx+c	R^2	mx+c	R^2	mx+c	R^2	mx+c	R^2
1000 kernel wt, g	0.047X+2.126	0.968	0.033X+1.901	0.988	0.010X+3.864	0.969	0.031X+2.338	0.962	0.020X+2.873	0.961	0.049X+1.858	0.979
Bulk density, kg/m^3	-3.351X+759.9	0.990	-2.971X+758.57	0.994	-18.035X+925.18	0.996	-20.435X+1104	0.990	-15.131X+865.58	0.998	-15.143X+998.57	0.993
True density, kg/m^3	-21.608X+1738.8	0.989	-30.668X+1763.4	0.937	-78.966X+2847.9	0.989	-67.46X+2513.1	0.979	-53.842X+2468.3	0.986	-45.15X+2349.9	0.988
Porosity, %,	-0.597X+58.707	0.951	-1.203X+62.732	0.967	-1.138X+76.956	0.990	-1.404X+66.918	0.989	-0.406X+67.393	0.955	-0.397X+59.64	0.955
Angle of repose, °	0.365X+22.912	0.972	0.336X+23.645	0.855	0.495X+24.27	0.948	0.9342X+15.015	0.991	0.688X+17.494	0.987	0.2366X+27.447	0.950
Coeff. of static friction	0.015X+0.236	0.988	0.025X-0.002	0.988	0.002X+0.479	0.963	0.036X-0.140	0.992	0.004X+0.420	0.956	0.003X+0.378	0.988
Coeff. of internal friction	0.037X+0.848	0.979	0.0336X+0.919	0.971	0.038X+0.995	0.989	0.022X+1.027	0.879	0.049X+0.761	0.987	0.014X+1.122	0.978
Grain hardness, N,	-0.122X+31.577	0.996	-0.122X+21.45	0.998	-0.198X+24.66	0.998	-0.245X+31.438	0.998	-0.204X+32.967	0.999	-0.132X+15.721	0.999

X: moisture content, % db

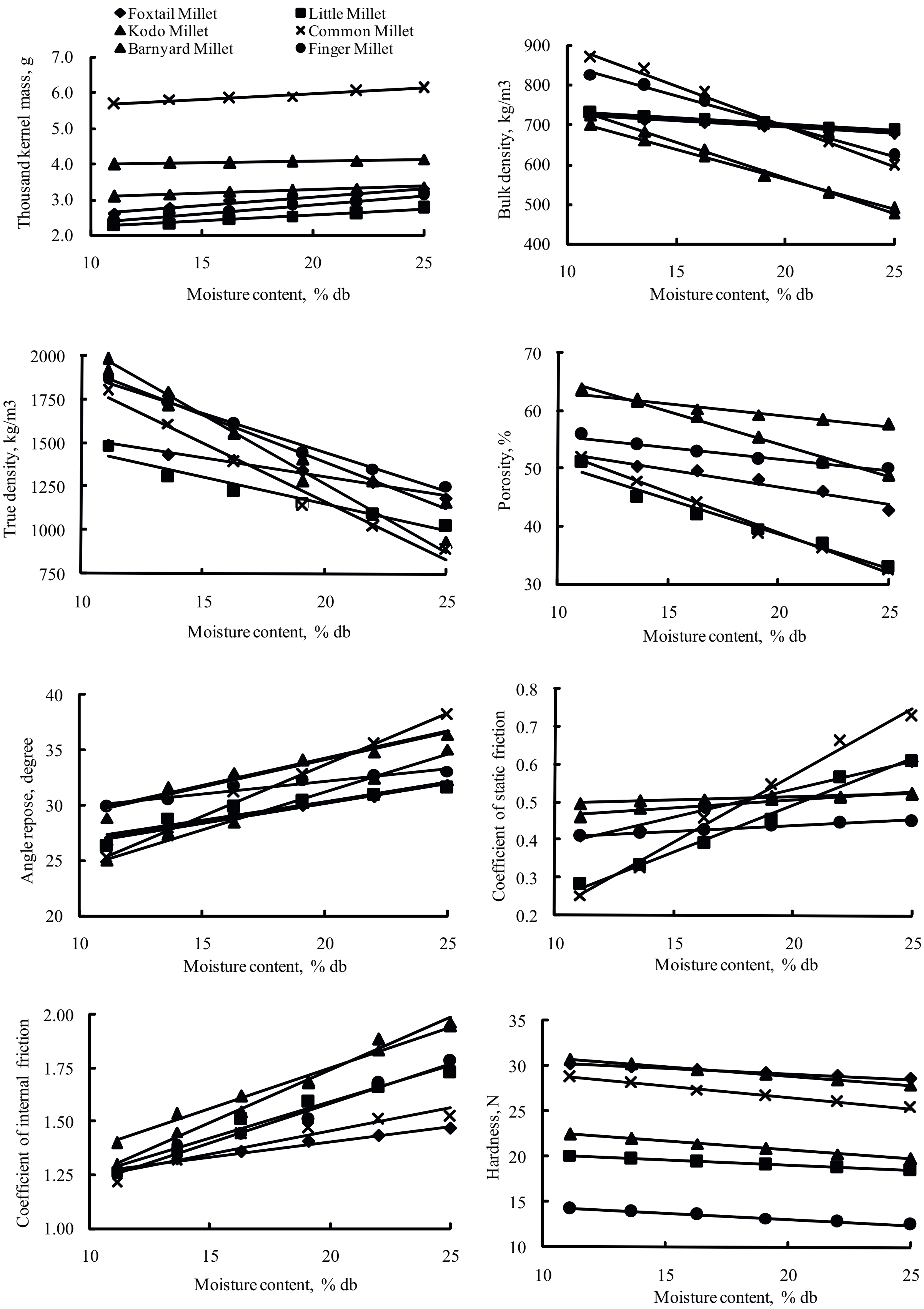

Fig. 1 Effect of moisture content on physical properties of minor millets.

for kodo millet followed by barnyard millet at all moisture contents. Joshi et al. (1993) also reported a linear decrease in porosity with increase in pumpkin seed moisture content. However, Singh and Goswami (1996) found the porosity of cumin seed to increase with grain moisture content.

Angle of repose: Angle of repose showed an increasing trend with moisture content (Fig. 1). At lower moisture content, angle of repose was higher for finger millet followed by kodo millet, little millet, foxtail millet, common millet and barnyard millet. At higher moisture content (25%, db), common millet exhibited a higher angle of repose (38.2°), followed by kodo millet, barnyard millet, finger millet, foxtail millet and little millet. Joshi et al. (1993) determined the angle of repose of pumpkin seed and kernel to vary 30–52 and 34–42.1°, respectively in the moisture range of 4.5–26.5% db. Angle of repose was determined for green gram (Nimkar and Chattopadhyaya 2001) and quinoa seeds (Vilche et al. 2003) in the moisture range of 4–32.6% db, which ranged between 18 and 31.31°.

Coefficient of static and internal friction: The coefficient of static friction for minor millet against mild steel surface increased with moisture content (Fig. 1). Little millet and common millet exhibited least coefficient of static friction at low moisture content (11.1%, db) and also exhibited a higher value of coefficient of static friction at higher moisture content (25% db) compared to other millets. Similar results were reported by Kukelko et al. (1988) for rapeseeds and by Chung and Verma (1989) for beans. The reason for increased friction coefficient at higher moisture content may be due to water present in grains offering increased adhesive force on contact surface. Among various contact surfaces, galvanised iron and mild steel offered higher coefficient of static friction as compared to stainless steel and aluminium for cumin seed (Singh and Goswami 1996) and rapeseed (Calisir et al. 2005). However, the effect of moisture content was found greater than the contact surfaces for pumpkin seed and kernel (Joshi et al. 1993). The coefficient of internal friction increased with moisture content (Fig. 1). This may be due to higher cohesion exhibited by minor millets at higher moisture content. A higher coefficient of internal friction was offered by barnyard millet followed by kodo millet, finger millet, little millet, common millet and foxtail millet.

Grain hardness: Hardness showed a decreasing trend with increase in moisture content (Fig. 1). At all moisture contents, grain hardness for foxtail and barnyard millet were almost equal. For other millets, common millet exhibited higher hardness followed by kodo, little and finger millets. The small rupturing forces at higher moisture content might have resulted from the fact that the seed became soft and more sensitive to cracking at high moisture. It indicates that greater force was necessary to rupture the seed with lower moisture. Similar trends were also reported by Kingsly et al. (2006) that the hardness of dried pomegranate seeds decreased linearly from 87 N to 50 N for the corresponding increase in moisture content from 6.0 to 18.13% (db).

Conclusion

Thousand kernel weight, angle of repose, coefficient of static and internal friction for minor millets were found to be directly proportional to moisture content. Bulk density, true density, porosity and grain hardness were found to be inversely proportional to moisture content of minor millets at the moisture range (11.1 to 25% db) studied.

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