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Moisture Dependent Selected Postharvest Engineering Properties of Ragi (*Eleusine coracana*) Grown in Northern Hills of India

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Abstract

The machines and systems for processing and value addition of ragi are totally dependent on its postharvest engineering properties. These properties are further, greatly affected by the moisture content of the grains. As ragi processing and value addition requires different set of moisture contents, the present study was aimed at assesment of selceted postharvest engineering properties of ragi (cv. VL Mandua -315), grown in Himalayan regions of India as a function of its moisture content (8- 40%, wb). The spatial dimensions, geometric mean diameter, thousand grain mass, angle of repose, sphericity, surface area and porosity increased with increasing moisture content of the grains. The bulk density and true density decreased linearly from 777.50 to 684.99 kg/m^3 and from 1270.44 kg/m^3 to 1236.48 kg/m^3, respectively with the moisture content. The values of static coefficient of friction of ragi against plywood, mild steel, galvanized iron and glass increased from 0.57, 0.52, 0.35 and 0.30 to 0.83, 0.72, 0.79 and 0.70, respectively. The hardness decreased with moisture (67.95 N to 37.51 N) whereas toughness first increased from 5.17 Nmm (8% moisture) to 6.91 Nmm (24% moisture) followed by decrease to 3.97 Nmm at 40% moisture content.

INTRODUCTION

Ragi or finger millet (*Eleusine coracana*) is an important staple food of the people belonging to the lower socio-economic strata in the Indian subcontinent and also in some of the African countries. In the Indian subcontinent, the major ragi growing states are Karnataka, Uttarakhand, Tamilnadu and Maharashtra. Nutritionally, ragi is a rich source of calcium (344 mg/100 g), phosphorous (283 mg/100 g) (Gopalan et al., 1989) and crude fibre (3.7 percent) (Joshi and Katoch, 1990). It is easily digestible, does not cause acidity, least allergic and has a warming effect. Food grains has to undergo different unit operations like cleaning , grading, drying, soaking, pearling, grinding, mixing, extrusion, baking, packaging, transportation, storage etc. Most of these operations are dependent on physico-mechanical properties of food grains.

The size and shape are important in designing of separating, harvesting, sizing and grinding machines (Hauhouot-O'Hara et al., 2000). Cereal grain kernel densities and hardness are important in determining breakage susceptibility (Chang, 1988). The angle of repose is important in determining the inclination angle of the machine hopper tank (Kaleem et al., 1993) during storage, processing and transportation (Soliman, 1994). The operations viz. conveying, cleaning, loading and unloading are influenced by the friction between grain and a surface (Helmy, 1995 and Varnamkhasti et al., 2008).

One of the important factors that govern these properties is the moisture content of the food grains. Effect of moisture content on postharvest engineering properties of numerous food grains and oilseeds has been reported elsewhere in literature. There was no literature available on the postharvest engineering properties of hill area grown ragi. Ragi processing and value addition requires different set of moisture contents viz 8-9% for medium term conservation, 18% for popping (Malleshi and Desikachar, 1981), 35% for decortication purpose (Malleshi, 2006) and 40% for expanded millet (Ushakumari et al., 2007). The present study was therefore undertaken with the objective- to study the effect of moisture content (8 – 40%, generally

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utilized in ragi processing) on postharvest engineering properties of ragi (cv. VL Mandua – 315) grown in northern hills of India.

MATERIALS AND METHODS

Materials

Ragi (cv. VL Mandua -315), grown in rainfed conditions of Uttarakhand hills was procured from Vivekananda Parvatiya Krishi Anusandhan Ssansthan (VPKAS), Almora. This variety gives an average grain and fodder yield of 23 q/ha and 78 q/ha, respectively. The seeds of this variety are of light copper color and surface is smooth. The grains were cleaned and graded to remove the foreign materials and immature kernels. Moisture content of the grain was determined by the standard oven-drying method (AOAC, 1980). To achieve moisture content level of 8%, the grains were dried in a cabinet drier (Macro Scientific Works, Delhi) at 60°C for 8 h (Singh & Sethi, 2003). The samples of higher moisture content (16, 24, 32 and 40%, wb) were prepared by adding the calculated amount of distilled water (Visvanathan et al., 1996):

$$Q = \frac{A(b-a)}{(100-b)} \quad (1)$$

where: Q is mass of water to be added, A is initial mass of the sample, a and b are initial and final moisture content of sample (%, wet basis), respectively. After thorough mixing, the moistened samples were sealed in polyethylene bags and kept in a refrigerator at 5°C. To achieve the desired moisture level and uniformity the grains were equilibrated for 1 week with in-between shaking. Before each experiment, the samples were kept at room temperature for 2 h to equilibrate the temperature. Minimum five replications were done for each experiment (except 1000 grain mass). For 1000 grain mass study, 100 sound seeds were taken.

METHODS

Hundred sound grains were randomly selected and their linear dimensions length (L), width (W) and thickness (T) were measured in three mutually perpendicular directions (Singh and Goswami, 1996) using vernier caliper (Model No. CD-8"CSX, Mitutoyo Corporation, Kawasaki, Japan, least count 0.01 mm). The mean geometric diameter (D_{ge}), sphericity ($\emptyset$) and surface area (S) was then calculated using the following equations (Jain and Bal, 1997):

$$Dge = (LWT)^{1/3} \quad (2)$$

$$\emptyset = Dge/L \quad (3)$$

$$S = \pi Dge^2 \quad (4)$$

The thousand grain mass was determined by randomly selecting 100 sound grains and weighing in an electronic balance of 0.001 g sensitivity. The weight was then converted into 1000 grain mass (W_{1000}).

To determine bulk density (ρ_b), the mass of ragi seeds, filled in a cylinder of known volume (100 ml) was measured in an electronic balance (least count 0.001g). The bulk density was then calculated as the ratio of mass of the seeds and volume of container.
The true density (ρ_t) was determined using toluene displacement method (Singh and Goswami, 1996). The porosity (ε) was calculated from the obtained bulk density and true density using the following equation (Jain and Bal, 1997):

$$\varepsilon = \frac{(\rho t - \rho b) \times 100}{\rho t} \quad (5)$$

For the determination of angle of repose (θ), the conditioned samples were filled in a hopper, placed 15 cm above a circular plate of 10 cm diameter (D). The aperture of the hopper was opened quickly and the sample was allowed to fall on the circular plate for a natural heap formation. The angle of repose was then calculated as follows (Joshi et al., 1993):

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \quad (6)$$

where: H is the height of the heap.

To determine the static coefficient of friction (μ) of the samples, the apparatus consisted of a frictionless pulley fitted on a frame, a bottomless cylindrical wooden container, loading pan and four test surfaces (plywood, galvanized iron (GI), mild steel (MS) and glass). The container placed on the test surface was filled with a known quantity of material and weights were added to the loading pan until the container began to slide (Chandrasekar and Visvanathan, 1999). The static coefficient of friction was calculated as the ratio of weight added (frictional force, F) and mass of the material (normal force, N) as follows:

$$\mu = \frac{F}{N} \quad (7)$$

The hardness (F_r) of ragi seeds was determined using texture analyzer (Model TA-XT2i, Stable Micro System Ltd, UK) with 5 mm diameter alluminium alloy probe. The test conditions of the texture analyzer were- pre-test speed: 2.00 mm/s, test speed: 0.10 mm/s, post-test speed: 2.00 mm/s and trigger force: 0.10 N. The energy (N mm) required to crush the seeds completely was measured using the texture analyzer, and is being reported as toughness (E_r) (Sajeev et al., 2004). The probe and operating conditions were kept same as during determination of hardness.

The colour of ragi seeds was determined using HunterLab miniScan XE Plus colorimeter (Model 45/0-L, HAL, USA). The L, a and b values of the samples was recorded. The statistical analysis was done using Statistica 6.0 software. The mathematical relationships between moisture content and properties under study were established using regression analysis.

RESULTS AND DISCUSSION

The average values of spatial dimensions, geometric mean diameter, spehricity and surface area of ragi seeds at different moisture contents are reported in Table 1. The length, width and thickness of ragi seeds increased significantly with moisture content however, the increase in length and thickness was relatively higher than that of width of ragi seeds. The geometric mean diameter of ragi increased significantly ($p<0.05$) with moisture which can be attributed to the expansion of seed upon absorption of moisture. The findings were in agreement with the earlier reported observations for barnyard millet grain and kernel (Singh et al., 2010), Dapoli-1 variety ragi (Swami and Swami, 2010) and rough rice (Araghi et al., 2010). The relationship of geometric mean diameter with moisture content (m) can be represented as follows:

$$D_{ge} = 1.16E\text{-}04 M_C^2 - 4.02E\text{-}04\, M_C + 1.795 \quad (8)$$

($R^2 = 0.998$)

where M_C is the moisture content.

Table 1. Effect of moisture content on dimensional properties of ragi

Particulars	Moisture content (% w.b.)				
	8	16	24	32	40
Length, mm	1.95±0.07^a	1.96±0.05^a	1.99±0.09^{a,b}	2.04±0.07^{b,c}	2.12±0.20^c
Width, mm	1.77±0.11^a	1.80±0.05^a	1.83±0.09^{a,b}	1.89±0.05^b	1.89±0.11^b
Thickness, mm	1.69±0.08^a	1.71±0.04^a	1.74±0.09^{a,b}	1.79±0.05^b	1.91±0.07^c
Geometric mean diameter, mm	1.80±0.07^a	1.82±0.01^a	1.85±0.08^{a,b}	1.90±0.02^b	1.97±0.03^c
Sphericity	0.92±0.03^a	0.93±0.02^a	0.93±0.01^a	0.93±0.03^a	0.93±0.07^a
Surface area, mm^2	10.18±0.81^a	10.43±0.16^a	10.77±0.94^{a,b}	11.37±0.28^b	12.14±0.39^c

Values are mean±SD at 5% significance level. Values in row with different superscripts differ significantly at 5% level.

The sphericity of ragi increased with moisture content however, the change was not significant (Table 1). Swami and Swami (2010) and Singh et al. (2010) reported increase in sphericity of ragi (Variety Dapoli-1) and barnyard millet grain and kernel, respectively with moisture content. However, a decrease in sphericity with moisture content is reported for lathyrus (Zewdu and Solomon, 2008) and red bean (Kiani et al., 2008). The relation of sphericity of ragi seeds with moisture contents (m) can be represented by the following equation:

$$\varnothing = -1.06E\text{-}05\, M_C^2 + 8.24E\text{-}04\, M_C + 0.917 \quad (9)$$

($R^2 = 0.998$)

Surface area of the ragi grain increased significantly ($p<0.05$) with moisture content (Table 1). Increase in surface area with moisture content is also reported by Coskuner and Karababa (2007) for coriander seed. All spatial of ragi increased with moisture content (Table 1) and, therefore the surface area increased. Relationship between the moisture content (m) and surface area of ragi seeds can be represented by:

$$S = 0.001\, M_C^2 - 0.008\, M_C + 10.16 \quad (10)$$

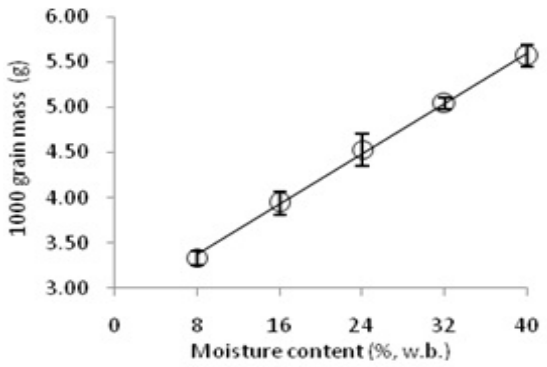
($R^2 = 0.999$)

The 1000 grain mass of ragi increased linearly with moisture content from 3.34 g to 5.57 g when moisture content increased from 8% to 40% (Fig. 1). The relationship between moisture content and 1000 grain mass of ragi seed can be represented as:

$$W_{1000} = 2.814 + 0.069\, M_C \quad (11)$$

($R^2 = 0.998$)

Fig. 1. Effect of moisture content on 1000-grain mass of ragi seeds



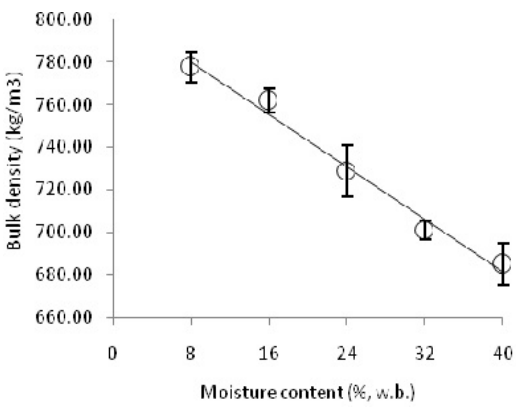
Similar results have been reported for barnyard millet grain and kernel (Singh et al., 2010), rough rice (Araghi et al., 2010), red bean (Kiani et al., 2008) and guar seeds (Vishwakarma et al., 2010). However, Sahoo and Srivastava (2002) found logarithmic relationship between the 1000 seed mass and moisture content in okra seeds.

The bulk density of the ragi seeds decreased linearly from 777.50 kg/m^3 at 8% moisture to 684.99 kg/m^3 at 40 % moisture content (Fig. 2). The decrease in bulk density was significant ((p<0.05) and may be attributed to the differential increase in mass and volumetric expansion (volume) of the seeds. It indicated that the volumetric expansion was more than that of mass increase. The change in bulk density of ragi seeds with moisture content can be described as:

$$\rho_b = 804.5 - 3.069\, M_C \quad (12)$$

($R^2 = 0.985$)

Fig. 2. Effect of moisture content on bulk density of ragi seeds

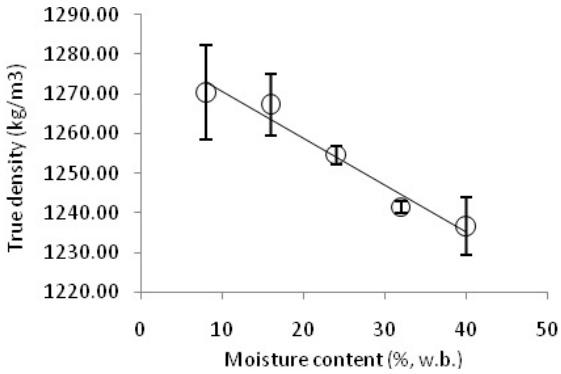


The true density of ragi decreased significantly (p<0.05) from 1270.44 kg/m^3 to 1236.48 kg/m^3 in moisture range under study (Fig. 3). It showed that the increase in seed volume was higher corresponding to the increase in grain mass due to increase in water content. The relationship between moisture content and true density can be represented as:

$$\rho_t = 1282 - 1.173\, M_C \quad (13)$$

($R^2 = 0.963$)

Fig. 3. Effect of moisture content on true density of ragi seeds



The results are in agreement with the findings of Balasubramanian and Visvanathan (2010) for minor millets, Singh et al. (2010) for barnyard millet grain and kernel and Zewdu and Solomon (2007) for tef seed. However Swami and Swami (2010) reported increase in true density & bulk density of ragi (Variety Dapoli-1) with moisture content.

The porosity of ragi increased linearly from 38.80% to 44.60% with moisture content (Table 2) and the increase was significant (p<0.05). The relationship between porosity and moisture content of ragi seeds is represented as:

$$\varepsilon = 37.17 + 0.190\, M_C \quad (14)$$

($R^2 = 0.989$)

Linear significant increase in angle of repose of ragi from 13.5^o to 24.4^o was observed for ragi seeds with moisture content (Table 2). Similar increase in angle of repose with moisture content is reported by Subramanian and Visvanathan (2007) for minor millets, Singh et al. (2010) for barnyard millet grain and kernel, Zewdu and Solomon (2007) for tef seed and Vishwakarma et al. (2010) for guar seeds. Variation in angle of repose of ragi seeds with moisture content can be expressed as:

$$\theta = 11.10 + 0.344\, M_C \quad (15)$$

($R^2 = 0.991$)

Table 2. Effect of moisture content on porosity and angle of repose of ragi

Particulars	Moisture content (% w.b.)				
	8	16	24	32	40
Porosity	38.80±0.82[a]	39.89±0.37[a]	41.89±0.45[b]	43.51±0.95[c]	44.60±0.15[c]
Angle of repose	13.49±0.54[a]	16.70±0.53[b]	19.80±0.28[c]	22.45±1.12[d]	24.39±0.27[e]

Values are mean±SD at 5% significance level. Values in row with different superscripts differ significantly at 5% level.

The seeds tend to stick together at higher moisture content resulting into better stability and lower flowability and consequently a higher pile is made.

The effect of moisture content on static friction coefficient of ragi against plywood (μ_{pb}), galvanized iron (μ_{gi}), mild steel (μ_{ms}) and glass (μ_g) are presented in Fig. 4. Significant increase in coefficient of friction with moisture content was observed for the all surfaces under study. At higher moisture contents, the grain tends to stick to the surface which resulted into increase in coefficient of friction. The change in coefficient of friction of ragi seeds against various surfaces at different moisture can be expressed as:

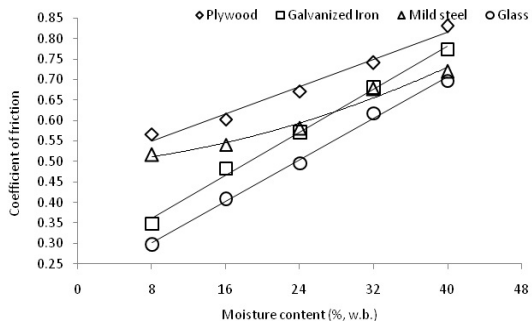
$$\mu_{pb} = 0.483 + 0.008\, M_C \quad (16)$$
$(R^2 = 0.981)$

$$\mu_{gi} = 0.257 + 0.013\, M_C \quad (17)$$
$(R^2 = 0.995)$

$$\mu_{ms} = 1.69E\text{-}04\, M_C^{\,2} - 0.002\, M_C + 0.525 \quad (18)$$
$(R^2 = 0.988)$

$$\mu_g = 0.201 + 0.012\, M_C \quad (19)$$
$(R^2 = 0.997)$

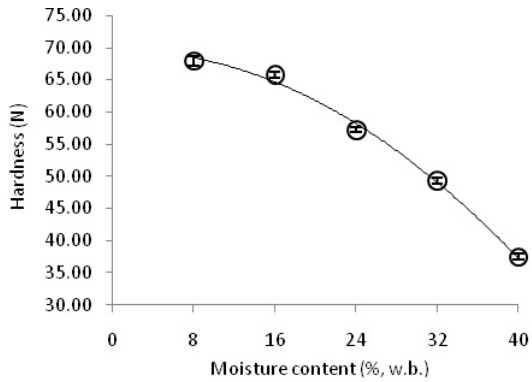
Fig. 4. Effect of moisture content on static friction coefficient of ragi seeds on different surfaces



Similar result was reported for barnyard millet (Singh et al., 2010), minor millets (Subramanian and Visvanathan, 2007). Plywood exerted highest friction followed by mild steel, galvanized iron and glass. Zewdu and Solomon (2008) also reported highest coefficient of friction of plywood followed by mild steel and glass for grass pea. The hardness of ragi decreased from 67.95 N at 8% moisture content to 37.51 N at 40 % moisture content (Fig. 5). The following equation represented the relationship between moisture content and hardness:

$$F_r = -0.020\, M_C^{\,2} + 0.034\, M_C + 69.41 \quad (20)$$
$(R^2 = 0.995)$

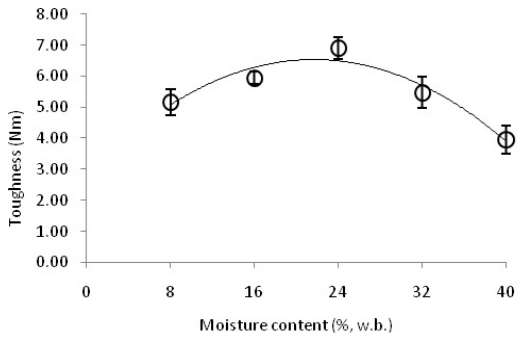
Fig. 5. Effect of moisture content on hardness of ragi seeds



Similar results were reported by Subramanian and Visvanathan (2007) for minor millets and Singh et al. (2010) for barnyard millet. The toughness of the ragi sample first increased from 5.17 Nmm at 8% moisture content to 6.91 Nmm at 24 % moisture (Fig. 6). Thereafter it decreased to 3.97 Nmm at 40% moisture content. The relationship of the toughness of ragi seeds with moisture content can be presented as:

$$E_r = -0.007\, M_C^{\,2} + 0.337\, M_C + 2.874 \quad (21)$$
$(R^2 = 0.925)$

Fig. 6. Effect of moisture content on toughness of ragi seeds



Singh et al. (2010) reported a decrease in the toughness of barnyard millet.

The instrumental colour values for L, a, b of ragi seeds with moisture content is given in Table 3. The 'L', 'a' and 'b' value increased significantly ($p<0.05$)

in the range of 38.22 - 43.65, 14.56- 16.65 and 16.15-20.09, respectively with moisture content.

Table 3. Effect of moisture content on colour values of ragi

Particulars	Moisture content (% w.b.)				
	8	16	24	32	40
L Value	38.22±0.48[a]	41.74±0.50[b]	42.89±0.33[c]	43.60±0.40[d]	43.65±0.46[d]
a value	14.56±0.37[a]	15.14±0.34[b]	15.70±0.33[c]	16.42±0.35[d]	16.65±0.48[d]
b value	16.15±0.49[a]	17.05±0.46[b]	18.34±0.49[c]	20.05±0.46[d]	20.09±0.89[d]

Values are mean±SD at 5% significance level. Values in row with different superscripts differ significantly at 5% level.

CONCLUSION

Ragi is one of the important staple food grains of northern hills region of India. Due to small land holdings, the processing machines of small capacity are required. The postharvest engineering properties viz. Grain size, sphericity, surface area, 1000 grain mass, bulk density, true density, porosity, angle of repose, static coefficient of friction, colour, hardness and toughness were studied in the moisture content range of 8- 40 %. The present study provides some basic useful data about postharvest engineering properties of ragi grown in hill region for designing of small scale machines.

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REFERENCES

AOAC, 1980. Official methods of analysis. 13th ed. Association of Official Analytical Chemists, Washington, D.C.

Araghi, H.A., Sadeghi, M. and Hemmat, A. 2010. Physical properties of two rough rice varieties affected by moisture content. International Agrophysics, 24: 205-207.

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

Chandrasekar, V. and Visvanathan, R. 1999. Physical and thermal properties of coffee. Journal of Agricultural Engineering Research, 73: 227–234.

Chang, C.S. 1988. Measuring density and porosity of grain kernels using a gas pycnometer. Cereal Chemistry, 65: 13-15.

Coskuner, Y. and Karababa, E. 2007. Physical properties of coriander seeds (*Coriandrum sativum* L.). Journal of Food Engineering, 80: 408–416.

Gopalan, C., Rama Sastri, B.V. and Balasubramanian, S.C. 1989. Nutritive value of Indian foods. National Institute of Nutrition. ICMR, Hyderabad. 156p.

Hauhouot-O'Hara, M., Criner, B.R., Brusewitz, G.H. and Solie, J.B. 2000. Selected physical characteristics and aerodynamic properties of cheat seed for the separation of wheat. Agricultural Engineering International: the CIGR E-journal, 2: 1-14.

Helmy, M.A. 1995. Determination of static friction coefficient of some Egyptian agricultural products on various surface. Misr Journal of Agricultural Engineering, 12: 267-281.

Jain, R.K. and Bal, S. 1997. Properties of pearl millet. Journal of Agricultural Engineering Research, 66: 85–91.

Joshi, H.C. and Katoch, K.K. 1990. Nutritive value of millets: A comparison with cereals and pseudocereals. Himalayan Research and Development, 9: 26-28.

Joshi, D.C., Das, S.K. and Mukherjee, R.K. 1993. Physical properties of pumpkin seed. Journal of Agricultural Engineering Research, 54: 219–229.

Kaleem, F.H., Ismail, Z.E. and Abd Hakim, G.R. 1993. Factors affecting grain cleaning efficiency (Part 1): Grain straw mixture and blower characteristics. Misr Journal of Agricultural Engineering, 10: 369-382.

Kiani, M.K.D., Minaei, S., Maghsoudi, H. and Varnamkhasti, M.G. 2008. Moisture

dependent physical properties of red bean (*Phaseolus vulgaris* L.) grains. International Agrophysics, 22: 231-237.

Malleshi, N.G. and Desikachar, H.S.R. 1981. Studies on the suitability of roller flourmill, hammer mill and plate grinder for obtaining refined flour from malted ragi (*Eleusine coracana*). Journal of Food Science and Technology, 18: 37-39.

Malleshi, N.G. 2006. Decorticated finger millet (*Eleusine coracana*) and a process for preparing the decorticated finger millet. US Patent No.7029720 B2.

Sahoo, P.K. and Srivastava, A.P. 2002. Physical properties of okra seed. Biosystems Engineering, 83: 441–448.

Sajeev, M.S., Manikantan, M.R., Kingsly, A.R.P., Moorthy, S.N. and Sreekumar, J. 2004. Texture analysis of taro (*Colocasia esculenta L. Schott*) cormels during storage and cooking. Journal of Food Science, 69: 315–321.

Singh, K K. and Goswami, T.K. 1996. Physical properties of cumin seed. Journal of Agricultural Engineering Research, 64: 93–98.

Singh, K.P., Mishra, H.N. and Saha, S. 2010. Moisture-dependent properties of barnyard millet grain and kernel. Journal of Food Engineering, 96: 598–606.

Soliman, N.S. 1994. Effect of moisture content on angle of repose of paddy rice and its products. Misr Journal of Agricultural Engineering, 11: 163-173.

Subramanian, S. and Visvanathan, R. 2007. Bulk density and friction coefficient of selected minor millet grains and flours. Journal of Food Engineering, 81: 118–126.

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

Ushakumari, S.R., Rastogi, N.K. and Malleshi, N.G. 2007. Optimization of process variables for the preparation of expanded finger millet using response surface methodology. Journal of Food Engineering, 82: 35-42.

Varnamkhasti, M.G., Mobli, H., Jafari, A., Keyhani, A.R., Soltanabadi, M.H., Rafiee, S. and Kheiralipour, K. 2008. Some physical properties of rough rice (*Oryza sativa* L.) grain. Journal of Cereal Science, 47: 496-501.

Vishwakarma, R.K., Shivhare, U.S. and Nanda, S.K. 2011. Physical properties of guar seeds. Food and Bioprocess Technology, 5(4):1364-1371.

Visvanathan, R., Palanisamy, P.T., Gothandapani, L. and Sreenarayanan, V.V. 1996. Physical properties of neem nut. Journal of Agricultural Engineering Research, 63: 19–25.

Zewdu, A.D. and Solomon, W.K. 2007. Moisture-dependent physical properties of tef seed. Biosystems Engineering, 96(1):57-63.

Zewdu, A.D. and Solomon, W.K. 2008. Moisture dependent physical properties of grass pea (*lathyrus sativus.* L.) seeds. Agricultural Engineering International: the CIGR Ejournal, 10: FP 06-027.