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Engineering properties of spikelets and true seeds of deenanath (*Pennisetum pedicellatum* Trin.*)* grass

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Abstract

Various engineering properties of spikelets and true seeds of deenanath grass were investigated at five levels of moisture content. As the moisture content increased from 6.88 to 19.23%, the length, width, thickness, arithmetic mean diameter, geometric mean diameter, aspect ratio, sphericity, surface area, volume, thousands seed mass and bulk density of deenanath grass spikelets varied from 5.84 to 6.56 mm, 2.53 to 2.96 mm, 1.66 to 1.91 mm, 3.34 to 3.81 mm, 2.88 to 3.25 mm, 44.98 to 46.54%, 49.68 to 50.65%, 25.44 to 33.98 mm^2, 7.95 to 12.00 mm^3, 0.512 to 0.701 g and 8.32 to 6.92 kgm^{-3}, respectively. Furthermore, in case of true seeds of deenanath grass, these values varied from 2.30 to 2.56 mm, 0.71 to 0.96 mm, 0.47 to 0.63 mm, 1.16 to 1.38 mm, 0.90 to 1.15 mm, 30.91 to 37.51%, 39.31 to 45.12%, 2.58 to 3.23 mm^2, 3.71 to 4.97 mm^3, 0.480 to 0.523 g and 652.16 to 585.78 kgm^{-3}, respectively in the experimental range of moisture content. The true density and porosity values of deenanath grass true seeds were found to decrease from 852.63 to 792.71 kgm^{-3} and 25.62 to 24.97%, respectively with the increase in moisture content. The above engineering properties of both spikelets and true seeds of deenanath grass established simple linear relationships with moisture content with correlation coefficients of more than 0.90.

Keywords: Deenanath grass, Defluffing, Engineering properties, Pelleting, Spikelets, True seeds

Introduction

Deenanath which is botanically known as *Pennisetum pedicellatum* Trin*.,* is a quick growing, high yielding, tall, erected annual tufted grass internationally known by common names like kyasuwa grass, feather pennisetum, kyasuma grass or perennial deenanath. It grows up to a height of 30-150 cm and comes with hairy leaves of length 5-25 cm long and width 4-15 cm, arranged in two rows. It has 5-15 cm long and 10-15 mm wide tight cylin--drical panicle inflorescence (Mukherjee *et al.,* 1982). Upper glume and the lower lemma are 3 lobed and 2.5-6 mm long. Upper lemma is thinly coriaceous, obtuse, and ciliolate at the apex, readily disarticulating from the rest of the spikelet. The spikelet is about 4-6 mm long usually solitary, falls at maturity with bristles, comes in clusters of 1-5 and forms a fluffy ovate involucre 0.5-1 cm in length (Schmelzer, 1997). Deenanath grass, because of its high early vigor, drought-tolerant behavior, adaptability to poor soils and high productivity becomes an important grass used for fodder purpose among all the annual range grasses. However, the light weighted and small-sized nature of its seeds leads to difficulties in handling, transportation, storage and sowing. Defluffing the deenanath seeds from its voluminous fluff is a tedious job to carry out manually by beating the fluff with a wooden rod. Reducing the unwanted volume and extracting true seeds from spikelets for efficient post-harvest handling, transportation, and various farm operations is required for large-scale utilization of deenanath grass as forage for animals (Vijay *et al.,* 2018). Seed yield of grasses is very low, while demand for seed is high for rejuvenation of grasslands (Meena and Nagar, 2019). Maity *et al.* (2017) worked on layered pelleting of nucleus seed of deenanath grass with soil and observed highest germination of 91%.

The knowledge of engineering properties of deenanath grass seeds as a function of moisture content is important in designing and developing the equipments for deenanath grass harvesting, handling, seed processing, storage, seed pelleting and uniform sowing. The importance of geometrical properties *viz.*, size, shape, surface area, density and volume etc is associated with the design of a particular machine or analysis of the behavior of the product during a process (Singh *et al.,* 2010). Different types of cleaning, grading and separation equipment can also be designed based on the moisture dependent engineering properties of deenanath grass spikelets and true seeds. However, no published work seems to have been reported on the moisture dependent engineering properties of deenanath grass spikelets as well as on its true seeds. The main objective of this investigation was, therefore, to determine and study the moisture dependent engineering properties such as moisture content, spatial dimensions, arithmetic mean diameter, geometric mean diameter, aspect ratio, thousand seed mass, sphericity, volume, surface area, bulk density, true density and porosity of deenanath grass spikelets and true seeds.

Materials and Methods

Sample preparation: Freshly harvested spikelets of deenanath grass of variety Bundel-2 were supplied by the Seed Technology Division, ICAR-IGFRI, Jhansi, India and the study was conducted in the year 2019. The spikelets were first cleaned manually to remove impurities such as chaff, straw, stone and other vegetative parts. The spikelets were then defluffed manually by beating it with the help of 1-2 meter of the wooden rod to extract true seeds. The sample spikelets and true seeds of deenanath grass (Fig 1) were randomly selected and investigated to determine the moisture dependent engineering properties.

Fig 1. Spikelets and true seeds of deenantath grass

The initial moisture content of spikelets and true seeds of deenanath grass was determined using standard oven drying method in three replications by keeping the seeds at 105 °C ± 1 °C for 24 h (Gupta and Das, 1997). The average moisture contents of both the samples were 10.21%. Physical properties of both spikelets and true seeds of deenanath grass were determined at five different moisture levels of 6.88, 10.21, 12.77, 16.19 and 19.23% dry basis (d.b.) as harvesting, defluffing, sowing and storage operations of this grass seeds are generally done in this range of moisture content. The desired moisture content of test samples was achieved by incorporating the measured quantity of distilled water based on equation 1 (Dursun and Dursun, 2005), follo-wed by proper mixing and packing in low-density polyethylene (LDPE) bags. The LDPE bags with conditioned samples were stored at 4-7 °C in a refrigerator for 7 days for moisture to distribute uniformly throughout the sample (De Figueiredo *et al.,* 2011). The required quantity of deenanath spikelets and true seeds was taken out from the refrigerator and kept at room temperature (28-35 °C) for 2 h before conducting the experiments (Deshpande *et al.,* 1993).

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

Where: Q was the mass of water to be added in kg; Wi was the initial mass of sample in kg; Mi was the initial moisture content of the sample (% d.b), and Mf was the final moisture content of the seed sample (% d.b). This technique of attending required moisture content in seeds and grains was used by many researchers (Sacilik *et al.,* 2003). The experimental parameters were determined by taking 100 observations randomly at each moisture level, and the average values with the standard error were recorded. However, the experiments were replicated five times to determine the values of thousand seed mass, bulk density, true density and porosity.

Geometrical properties: The average size of spikelets and true seeds of deenanath grass was determined by recording linear dimensions namely, length (L), width (W) and thickness (T) using a digital vernier caliper (Mitutoyo Corporation, Japan; Model No: CD-12" C; least count 0.01 mm). The arithmetic mean diameter (D_a) and geometric mean diameter (D_g) of spikelets and true seeds of deenanath grass were calculated using equations (2) and (3) respectively (Konak *et al.,* 2002). The measurement was repeated 100 times and the average values were taken as diameter.

$$D_a = \frac{(L + W + T)}{3} \tag{2}$$

$$D_g = (L \times W \times T)^{1/3} \tag{3}$$

Where: D_a was the arithmetic mean diameter in mm; D_g was the geometric mean diameter in mm; L was the length in mm; W was the width in mm, and T was the thickness of seeds of Deenanath grass in mm.

The volume (V) and surface area (A_s) of spikelets and true seeds of Deenanath grass were calculated using equations (4) and (5) respectively (Jain and Bal, 1997; Olajide and Ade-Omowaye, 1999).

$$\frac{\pi X^2 L^2}{6(2L-X)} \quad (4)$$

$$\pi D_g^{\ 2} \quad (5)$$

Where: V was the volume in mm^3, the value of X was $(WT)^{1/2}$, and A_s was the surface area in mm^2.

Shape: Sphericity (φ) and aspect ratio (Ar) were considered as the criteria to describe the shape of spikelets and true seeds of deenanath grass. The sphericity was defined as the ratio of the surface area of the sphere having the same volume as that of the spikelet/ seed to the surface area of the spikelet/seed. It was determined using equation (6) (Dursun and Dursun, 2005). The aspect ratio was calculated using equation 7 (Unal, 2009).

$$\varphi = \frac{(L \times W \times T)^{1/3}}{L} \times 100 \quad (6)$$

$$\frac{W}{L} \times 100 \quad (7)$$

Thousand seed mass: The thousand seed mass (Mt) of spikelets (Mts) and true seeds ($Mtts$) of deenanath grass was determined by picking the sample of thousand spikelets/seeds manually and randomly from the lot and the weight of each sample was measured on a precision electronic balance having an accuracy of 0.01 g (Baryeh and Mangope, 2003; Selvi *et al.,* 2006). The measurement was repeated five times and the average of replicated values was recorded.

Bulk density: The bulk density (ρ_b) of spikelets and true seeds of deenanath grass is defined as the ratio of the mass of true spikelets/seeds of deenanath grass to the total volume occupied (Deshpande *et al.,* 1993; Ghadge and Prasad, 2012). Bulk density of true seeds was measured using 500 ml cylinder filled with true seeds of deenanath grass upto a height of 15 cm. The excess seeds were removed by sweeping the surface of cylinder and the seeds were not compressed. However to determine the bulk density of deenanath spikelets, the spikelets were pressed in 500 ml cylinder manually because of its fluffy nature. The bulk density was then calculated as the ratio between the spikelet/seed weight and the total volume of the cylinder (Sacilik *et al.,* 2003). The average of five replications was taken as bulk density.

True density: The true density (ρ_t) of deenanath grass seeds is defined as the ratio of the mass of true seeds of deenanath grass to the true volume of the seeds. It was determined using liquid (toluene) displacement method. Toluene (C_7H_8) is a colorless, water-insoluble liquid with the smell associated with paint thinners. It was used instead of water to avoid the absorption during measurement and also to get the benefit of low surface tension so that it fills even shallow dips in the seeds (Ogut, 1998). Weighted quantities of deenanath grass seeds were immersed in the toluene and the volume of toluene displaced was recorded to calculate the true density (Unal, 2009).The true density of spikelets of deenanath grass was not determined because of unavailability of standard method of determination of the true density of fluffy grains. Furthermore, determining the true density of deenanath spikelets using toluene displacement method was impractical because of fluffy nature of spikelets.

Porosity: Porosity (ε) of true seeds of deenanath grass is the ratio of the volume of internal pores in between true seeds to its bulk volume. It was determined at various moisture contents from the calculated values of true density (ρ_t) and bulk density (ρ_b) using equation 8 (Pandiselvam ***et al.,*** 2014). As calculation of porosity depends on both bulk and true density values and because of unavailability of data on true density of deenanath spikelets, the porosity of spikelets was not determined.

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (8)$$

Statistical analysis: The data on recorded engineering properties of spikelets and true seeds of deenanath grass were statistically analyzed using SAS statistical software at a given range of moisture contents. The differences between the mean values of the physical properties of deenanath grass spikelets and true seed samples were tested for significance using t-test. Linear regression analysis was used to determine the relationship between moisture content and physical properties of the samples.

Results and Discussion

Axial dimensions: The mean values and standard error of engineering properties of spikelets and true seeds of deenanath grass *viz.,* length, width, thickness, arithmetic mean diameter, geometric mean diameter, sphericity, aspect ratio, surface area and volume at a selected level of moisture contents were recorded (Table 1-2). The axial dimensions (length, width, thickness, arithmetic mean diameter and geometric mean diameter) of both deena-

-nath spikelets and true seeds increased significantly (P<0.05) with moisture content in the range of 6.88 to 19.23% (d.b). The increased trend of length, width and thickness of deenanath grass spikelets and true seeds against moisture content was also recorded (Fig 2-3). The length, width and thickness of spikelets were considerably more than that of true seeds due to fluffy and hairy nature of deenanath spikelets which covers the entire true seeds. The study revealed that the deenanath grass spikelets and true seeds expanded more along its width and thickness due to increase in moisture in comparison with its length and this was in commensurate with the study of Singh *et al.* (2016) for dill seeds. This linear increase in all the dimensions of both the seeds of deenanath grass was due to the expansion resulting from moisture absorption by the sample seeds in their intercellular space. Such types of data on dimensional changing behavior of spikelets and true seeds are important in designing of conveyers, cleaners and threshers etc. Similar findings were reported for Ajwain seeds by Zewdu (2011). The variation in length, width, and thickness of spikelets and true seeds of deenanath grass over moisture content (*m*) established a linear relationship which could be expressed by regression equations (9), (10), (11), (12), (13) and (14) with coefficient of determination (R^2) of 0.992, 0.976, 0.961, 0.994, 0.994 and 0.995, respectively.

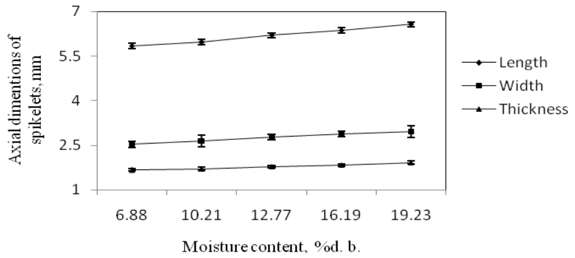

Fig 2. Effect of moisture content on axial dimensions of deenanath spikelets

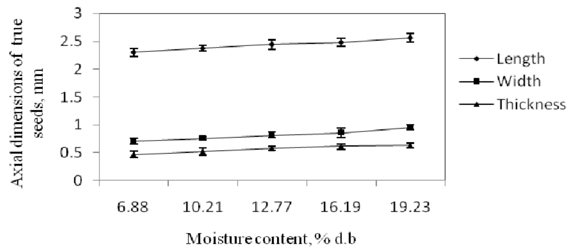

Fig 3. Effect of moisture content on axial dimensions of deenanath true seeds

Table 1. Moisture dependent engineering properties of spikelets of deenanath grass

Parameters	**Moisture content (%, dry basis)**				
	6.88	**10.21**	**12.77**	**16.19**	**19.23**
Length (mm)	5.84±1.28[c]	5.97±1.1[bc]	6.20±0.97[bc]	6.37±0.95[ab]	6.56±1.07[a]
Width (mm)	2.53±0.95[b]	2.64±0.85[ab]	2.77±0.67[ab]	2.88±0.84[a]	2.96±0.79[a]
Thickness (mm)	1.66±0.60[b]	1.71±0.61[ab]	1.77±0.50[ab]	1.84±0.53[ab]	1.91±0.58[a]
Arithmetic mean diameter (mm)	3.34±0.53[d]	3.44±0.54[cd]	3.58±0.50[bc]	3.70±0.51[ab]	3.81±0.45[a]
Geometric mean diameter (mm)	2.88±0.5[c]	2.92±0.55[bc]	3.08±0.54[ab]	3.17±0.56[a]	3.25±0.48[a]
Aspect ratio (%)	44.98±18.33[a]	45.45±17.41[a]	45.47±12.28[a]	45.89±13.86[a]	46.54±15.95[a]
Sphericity (%)	49.68±0.11[a]	49.88±0.11[a]	50.09±0.09[a]	50.39±0.09[a]	50.65±0.09[a]
Volume (mm^3)	7.95±4.93[c]	8.97±5.05[bc]	10.47±6.09[ab]	11.36±6.71[a]	12.00±5.80[a]
Surface area (mm^2)	25.44±9.38[c]	27.64±10.06[bc]	30.77±10.95[ab]	32.46±11.72[a]	33.98±9.91[a]

Table 2. Moisture dependent engineering properties of true seeds of deenanath grass

Parameters	**Moisture content (%, dry basis)**				
	6.88	**10.21**	**12.77**	**16.19**	**19.23**
Length (mm)	2.30±0.02[d]	2.37±0.02[cd]	2.44±0.02[cb]	2.48±0.02[b]	2.56±0.02[a]
Width (mm)	0.71±0.02[c]	0.76±0.02[c]	0.82±0.01[b]	0.86±0.01[b]	0.96±0.01[a]
Thickness (mm)	0.47±0.01[d]	0.52±0.01[c]	0.58±0.01[b]	0.61±0.01[ab]	0.63±0.01[a]
Arithmetic mean diameter (mm)	1.16±0.01[d]	1.22±0.01[c]	1.28±0.01[b]	1.32±0.01[b]	1.38±0.01[a]
Geometric mean diameter (mm)	0.90±0.01[d]	0.97±0.01[c]	1.05±0.01[b]	1.09±0.01[b]	1.15±0.01[a]
Aspect ratio (%)	30.91±0.99[d]	31.92±0.83[cd]	33.57±0.71[cb]	34.63±0.65[b]	37.51±0.68[a]
Sphericity (%)	39.31±0.65[c]	40.98±0.62[c]	43.01±0.61[b]	43.91±0.55[ab]	45.12±0.53[a]
Volume (mm^3)	3.71±0.19[d]	4.02±0.28[c]	4.46±0.42[b]	4.79±0.44[b]	4.97±0.35[a]
Surface area (mm^2)	2.58±0.07[d]	2.81±0.09[c]	3.01±0.11[b]	3.11±0.10[b]	3.23±0.07[a]

Figure with different superscript in a row differed significantly (P<0.05)

Ls = 5.636 + 0.184m (9) Ws = 2.426 + 0.110m (10)
Ts = 1.589 + 0.063m (11) Lts = 2.241 + 0.063m (12)
Wts = 0.642 + 0.06m (13) Tts = 0.439 + 0.041m (14)

The average diameters of deenanath spikelets calculated in terms of arithmetic mean diameter and geometric mean diameter were varied from 1.66 to 1.91 and 3.34 to 3.81 mm, respectively. In case of true seeds, these diameters were, however, in the range of 1.16 to 1.38 mm and 0.90 to 1.15 mm, respectively. The volume's and surface areas of both spikelets and true seeds of deenanath grass seeds were also increased significantly with moisture content. The ANOVA indicated that the differences among diameters, volume, and surface area of spikelets and true seeds of deenanath grass were significantly ($P<0.05$) different for the entire moisture range from 6.88% to 19.23%. The results were in agreement with the earlier findings for Onion seeds (Pandiselvam *et al.,* 2014), Vetch seeds (Yalcin and Ozarslan, 2004), proso millet (Singh *et al*., 2018) and hulled wheat (Unal, 2009)**.**

Shape: The sphericity and aspect ratio were determined as parameters of shape of deenanath grass spikelets and true seeds by using equations 6 and 7, respectively. The comparison between sphericity and aspect ratio of spikelets and true seeds of deenanath grass revealed that sphericity and aspect ratio of deenanath spikelets was more than that of its true seeds (Fig 4-5). The sphericity of the spikelets increased from 49.68 to 50.65%, whereas it increased from 39.31 to 45.12% in case of true seeds. The aspect ratio of both deenanath spikelets and true seeds varied from 44.98 to 46.54 and 30.91 to 37.51%, respectively when the moisture content increased from 6.88% to 19.23%. These findings were in confirmation with the findings of Aydin and Konak (2002) for turkish mahaleb, Dursun and Dursun (2005) for capper seeds, Altuntas *et al.* (2005) for fenugreek seeds and Nimkar *et al.* (2005) for moth gram. The data on lower values of sphericity indicated that deenanath grass true seed will not roll easily on an inclined surface and is useful in designing the feed hoppers. The closer the sphericity value to 100%, the higher will be its tendency to roll about any of the three axes (Akaaimo and Raji, 2006). The relationship between sphericity (φ_s and φ_{ts}) and aspect ratio (*Ars* and *Arts)* with moisture content (*m*) of deenanath grass spikelets and true seeds could be represented by the regression equations =(0.494 + 0.0025*m),* = (0.379 + 0.015*m), Ars* = (44.598 + 0.356*m),and Arts* = (28.935+ 1.591*m),* respectively with the respective coefficient of determination (R^2) of 0.993, 0.969, 0.925 and 0.960.

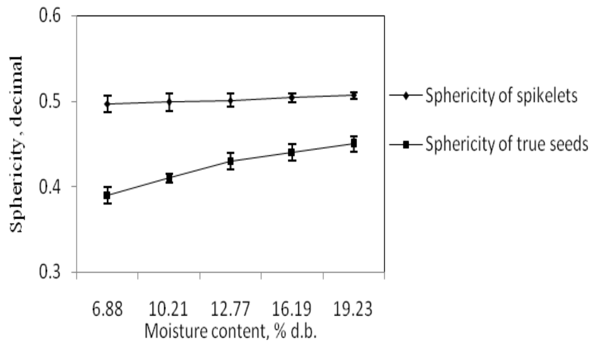

Fig 4. Effect of moisture content on sphericity of deenanath spikelets and true seeds

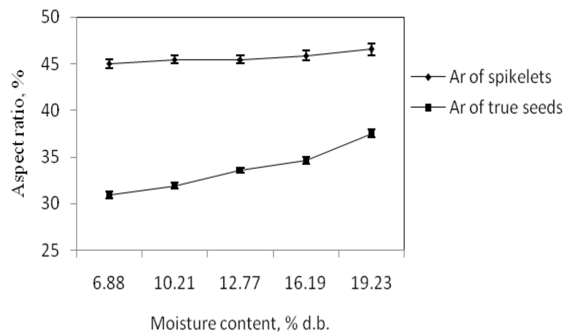

Fig 5. Effect of moisture content on aspect ratio of deenanath spikelets and true seeds

Thousand seed mass: Thousand seed mass of deenanath grass spikelets (M_{ts}) and true seeds (M_{tts}) was increased linearly from 0.512 to 0.701 g and 0.480 to 0.523 g, respectively with moisture content. It increased significantly ($P<0.05$) with the corresponding increase in moisture content from 6.88 to 19.23% which could be the result of added moisture. It was clear from the figure (Fig 6) that as moisture content increased, the mass of spikelets increased as compared to the mass of true seeds. The hairs/fluffy structure absorb more moisture as compared to true seeds and hence mass of the spikelets increased rapidly. The mass of any agricultural commodity is an important factor in designing air-cleaning and pneumatic conveying operations as it affects the acceleration of the seeds, thereby, influencing the aerodynamic force exerted on the particle (Solomon and Zewdu, 2009). Similar results were reported by Gharibzahedi *et al.,* (2010) for black cumin which had almost similar shape like true seeds of deenanath**.** The relationship between thousand seed mass of spikelets (M_{ts}) and true seeds (M_{tts}) with moisture content (*m*) could be represented by the regression equations M_{ts} = (0.4653+0.0489*m), and* M_{tts} = (0.4691 +0.0111*m)* with (R^2) of 0.993 and 0.969, respectively.

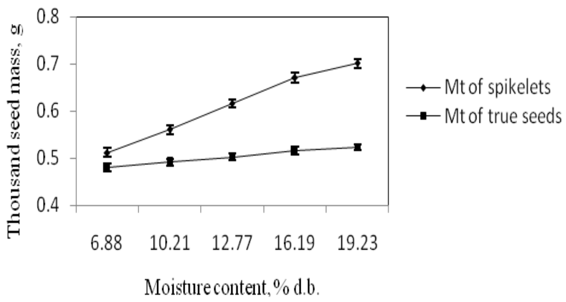

Fig 6. Effect of moisture content on thousand seed mass

Bulk density: The bulk density of spikelets and true seeds of deenanath grass at various moisture levels were also recorded (Fig 7). The bulk density of deenanath spikelets was found to decrease linearly from 8.32 to 6.92 kgm^{-3}, whereas the bulk density of true seeds decreased linearly from 652.16 to 585.78 kgm^{-3} as moisture content increased from 6.88% to 19.23%. It was observed that there was huge difference between the bulk densities of deenanath spikelets and true seeds (Fig 7). Presence of hairy structure/fluff around the seeds of deenanath grass was the main cause to increases the volume of spikelets. The decrease in the value of bulk density might be due to the higher rate of increase in volume relative to the increase in mass. These results of bulk density were in accordance with those presented for dill seeds (Singh *et al.,* 2016), turkish mahaleb (Aydin and Konak, 2002) and moth gram (Nimkar, 2005). The variation of bulk density of spikelets (ρ_{bs}) and true seeds (ρ_{bts}) with moisture content (m) could be represented by the regression equations ρ_{bs} = (8.708-0.354m), and ρ_{bts} = (667.76-16.701m) with (R^2) values of 0.992 and 0.997, respectively.

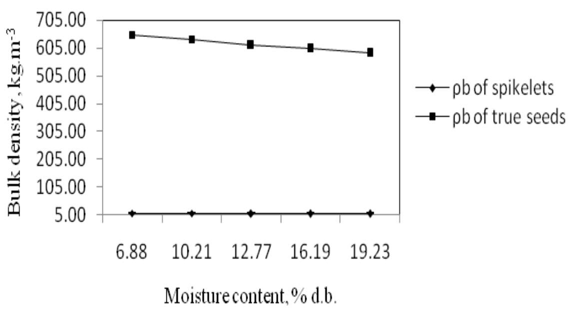

Fig 7. Effect of moisture content on bulk density

True density: The true density of true seeds of deenanath grass decreased from 852.63 to 792.71 kgm^{-3} with an increase in moisture content from 6.88 to 19.23% (Fig 8). The decreased value of true density as a function of moisture content was probably be due to a significant increase in volume, which was higher than the corresponding increase in the mass of the seeds. Zewdu (2011) for ajwain found that the true density decreased with increase in moisture content. The true density of true seeds of deenanath grass was higher by huge amount than that of its bulk density at a given range of moisture content. The relationship between true density (ρ_t) and moisture content (m) of true seeds of deenanath grass could be represented by the regression equation ρ_t = (866.62-15.154m) with a value for the coefficient of determination (R^2) of 0.996.

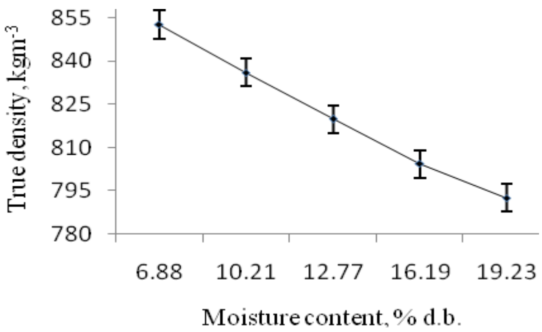

Fig 8. Effect of moisture content on true density

Porosity: Experimental data showed that the porosity of true seeds of deenanath grass decreased from 25.62 to 24.97% as the moisture content increased from 6.88 to 19.23% d.b. (Fig 9). Similar trend of decreased porosity with an increase in moisture content was reported earlier by Sacilik *et al.* (2003) for hemp seeds and Singh *et al.* (2016) for dill seeds**.** This data of porosity might be utilized for designing of aeration systems for deep bed dryer as higher porosity values provide better aeration and water vapor diffusion during deep bed drying (Singh *et al.,* 2016). The inter-relationship between porosity (**ε**) and moisture content (m) of true seeds of deenanath grass could be established by the regression equation ε = (25.76-0.158m) with (R^2) of 0.993.

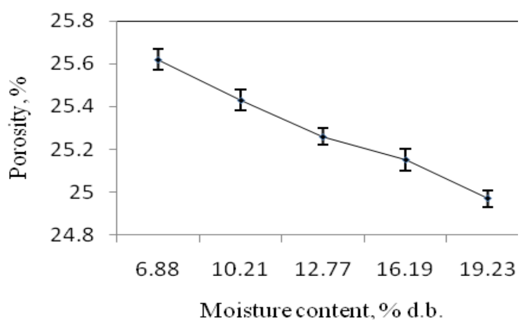

Fig 9. Effect of moisture content on porosity

Conclusion

The present investigation revealed that with the increase in moisture content from 6.88 to 19.23% (dry basis), the average length, width, thickness, arithmetic mean diameter, geometric mean diameter, aspect ratio, sphericity, surface area, volume, thousand seed mass and bulk density of deenanath grass spikelets and true seeds were varied considerably. It was also observed that all the above engineering properties of both spikelets and true seeds of deenanath grass established simple linear relationships with moisture content with correlation coefficients of more than 0.90.

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References

Akaaimo, D.I. and A.O. Raji. 2006. Some physical and engineering properties of Prosopisafricana seed. *Biosystems Engineering* 95: 197-205.

Altuntaş, E., E. Ozgoz and O.F. Taşer. 2005. Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. *Journal of Food Engineering* 71: 37-43.

Aydin, C. and M. Konak. 2002. PH- Postharvest technology: some physical properties of Turkish Mahaleb. *Biosystems Engineering* 82: 231-234.

Baryeh, E. A. and B. K. Mangope. 2003. Some physical properties of QP-38 variety pigeon pea. *Journal of Food Engineering* 56: 59-65.

De Figueiredo, A. K., E. Baumler, I. C. Riccobene and S. M. Nolasco. 2011. Moisture-dependent engineering properties of sunflower seeds with different structural characteristics. *Journal of Food Engineering* 102: 58-65.

Deshpande, S. D., S. Bal and T. P. Ojha. 1993. Physical properties of soybean. *Journal of Agricultural Engineering Research* 56: 89-98.

Dursun, E. and I. Dursun. 2005. Some physical properties of caper seed. *Biosystems Engineering* 92: 237-245.

Ghadge, P. N. and K. Prasad. 2012. Some physical properties of rice kernels: Variety PR-106. *Journal of Food Process Technology* 3: 1-5.

Gharibzahedi, S. M. T., S. M. Mousavi, A. Moayedi, A. T. Garavand and S. M. Alizadeh. 2010. Moisture-dependent engineering properties of black cumin (*Nigella sativa* L.) seed. *Agricultural Engineering International: CIGR Journal 12*: 194-202.

Gupta, R. K. and S.K. Das. 1997. Physical properties of sunflower seeds. *Journal of Agricultural Engineering Research* 66: 1-8.

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

Konak, M., K. Carman and C. Aydin. 2002. PH- Postharvest technology: physical properties of chick pea seeds. *Biosystems Engineering* 82: 73-78.

Maity, Aniruddha, D. Vijay, S. K. Singh and C. K. Gupta. 2017. Layered pelleting of seed with nutrient enriched soil enhances seed germination in Dinanath grass (*Pennisetum pedicellatum*). *Range Management and Agroforestry* 38: 70-75.

Meena, S. S. and R. P. Nagar. 2019. Effect of pelleting material on seedling emergence and growth parameters in Cenchrus species. *Range Management and Agroforestry* 40: 313-317.

Mukherjee, A. K., M. A. Roquib, S. K. Bandopadhyay and B. B. Mandal. 1982. Review of research on Deenanath grass (*Pennisetum pedicellatum* Trin.). *Forage Research* 8: 11-17.

Nimkar, P.M., D.S. Mandwe and R.M. Dudhe. 2005. Physical properties of moth gram. *Biosystems Engineering* 91: 183-189.

Ogut, H. 1998. Some physical properties of white lupin. *Journal of Agricultural Engineering Research* 69: 273-277.

Olajide, J. O. and B. I. O. Ade-Omowaye. 1999. Some physical properties of locust bean seed. *Journal of Agricultural Engineering Research* 74: 213-215.

Pandiselvam, R., M. M. Pragalyaashree, R. Kailappan, V. Thirupathi and P. Krishnakumar. 2014. Moisture dependent engineering properties of onion seeds. *Journal of Agricultural Engineering* 51: 36-43.

Sacilik, K., R. Ozturk and R. Keskin. 2003. Some physical properties of hemp seed. *Biosystems Engineering* 86: 191-198.

Schmelzer, G. H. 1997. Review of Pennisetum section Brevivalvula (Poaceae). *Euphytica* 97: 1-20.

Selvi, K. C., Y. Pinar and E. Yesiloglu. 2006. Some physical properties of linseed. *Biosystems Engineering* 95: 607-612.

Singh, K. P., N. S. Chandel, R. R. Potdar, D. Jat, K. N. Agrawal, and S. Hota. 2018. Assessment of engineering properties of proso millet (*Panicum miliaceum*). *Journal of Agricultural Engineering* 55: 42-51.

Singh, R. K., R. K. Vishwakarma, M. K.Vishal, D. Goswami and R. S. Mehta. 2016. Moisture dependent physical properties of dill. *Journal of Agricultural Engineering* 53: 33-40.

Singh, S. K., Vivak Kumar and B. R. Singh. 2010. Practical Manual: Engineering Properties of Food Materials. Department of Agricultural Engineering and Food Technology, SVPUAT, Meerut, India.

Solomon, W. K. and A. D. Zewdu. 2009. Moisture-dependent physical properties of niger (*Guizotia abyssinica* Cass.) seed. *Industrial Crops and Products* 29: 165-170.

Unal, H. G. 2009. Some physical and nutritional properties of hulled wheat. *Journal of Agricultural Sciences* 15: 58-64.

Vijay, D., C. K. Gupta and D. R. Malaviya. 2018. Innovative technologies for quality seed production and vegetative multiplication in forage grasses. *Current Science* 114: 148-154.

Yalcin, I. and C. Ozarslan. 2004. Physical properties of vetch seed. *Biosystems Engineering* 88: 507-512.

Zewdu, A. D. 2011. Moisture-dependent physical properties of ajwain (*Trachyspermum ammi L.*) seeds. *Philippine Agricultural Scientist* 94: 278-284.