Seed Res., Vol. 42(2): 201-209 December 2014

Effect of moisture content on physical properties of aged okra (*Abelmoschus esculentus*) seeds

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ABSTRACT This particular research investigation was conducted to determine selected moisture dependent physical properties of okra seed lots. Three different okra seeds lots based on their moisture content (10.98 to 16.89% d.b) and germination (80 to 50%) was chosen in this study. Average geometrical mean diameter and sphericity were in the range of 4.731 to 5.019 mm and 0.896 to 0.914, respectively. Bulk density and true density decreased from 0.622 to 0.604 g/cm^3 and 1.138 to 1.126 g/cm^3 respectively with the increase in moisture content from 10.98 to 16.89 % d.b. Porosity and angle of repose was found increasing from 45.34 to 46.35% and 24 to 29°, respectively with moisture content. Coefficient of static friction (plywood, mild steel and cast iron) increased linearly with moisture content from 0.3979 to 0.4327, 0.3878 to 0.4203 and 0.362 to 0.3959, respectively for all the three materials used. Mean peak compressive force decreased linearly from 93.70 to 81.72 N with the increase in moisture content. Terminal velocity was positively correlated with moisture content and increased from 9.2 to 9.8 m/s for the different seed lots. Outcome of this particular study were found supportive in designing seed priming prototype suitable for priming purpose of selected vegetable seeds.

Keywords: Okra seed, physical properties, moisture content, accelerated aging

Evaluation of significant physical properties of any particular crop is considered to have paramount importance for better understanding and modulation of its characteristics required for development of any pertaining prototype. Okra (*Abelmoschus esculentus*), which is also known as *'Bhindi'* belongs to family Malvaceae, is one of the important vegetables grown throughout the tropical and sub-tropical regions and also in the warmer parts of the temperate regions of India. It has a good potential as a foreign exchange earning crop and accounts for 60% of the export of fresh vegetables [1]. It is cultivated in 0.535 M ha area with production of 6.478 million MT and productivity of 12.11 MT/ha. Major okra producing states are Andhra Pradesh, West Bengal, Bihar, Gujarat and Orissa [2].

Numerous studies have been carried out by various researchers which comprises of determination of physical properties of a variety of seeds as a function of their inherent moisture content. Few among them includes, moisture-dependent physical properties of cumin (*Nigella sativa*) seeds [3], green gram (*Vigna* radiate) [4], sunflower (*Helianthus annuus*) seeds [5], canola (*Brassica napus*), sunflower pellets [6], arecanut kernels (*Areca catechu*) [7], fenugreek (*Trigonella foenum-graceum*) seeds [8], and jatropha (*Jatropha curcas* L.) seeds [9] at various levels of moisture content had been reported. The changing behaviour of seeds subjected to accelerated aging process with respect to their moisture content has not been reported previously.

Therefore, the objective of this study was to investigate relevant moisture-

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Received: May 2014 Revised: October 2014 Accepted: November 2014

dependent physical properties of three different okra seed lots obtained using accelerated aging. Seed properties, *viz.*, linear dimensions, surface area, sphericity, bulk density, true density, porosity, test weight, angle of repose, coefficient of static friction, compressive strength and terminal velocity were determined for matured seeds.

MATERIALS AND METHODS

Experimental material

In the present study, okra seed cv. Pusa A- 4 was procured from National Seeds Corporation, New Delhi for experimental purpose. Procured seeds were subjected for elimination of foreign matter such as dust, dirt, stones and chaff as well as immature, broken seeds present in it. To analyze the comprehensive effect of moisture content and germination percentage on physical properties, two more seed lots were obtained by adopting accelerated aging (AA). It was performed on approximately 250 g of seeds by keeping them covered in muslin cloth bag to be kept further in desiccator at 40 ± 1^0C, 100% RH for particular time period (regularly after 24 hours). This practice was helpful in obtaining two more lots from an existing standard germination seed lot. Further, the seed lots were subjected to quantification of moisture content and germination percentage. Germination percentage was determined through standard germination test for okra seeds [10] by wrapping the known number of seeds in wet germination towel and keeping them in germination chamber maintained at 25^0C and 80% R.H. The final germination count of all the seed samples was taken after 21st day. During accelerated aging, seed samples (150 seeds) were taken after every 24 hours and subsequently tested for moisture content and germination.

Moisture content

Initial moisture content of the seeds was determined by oven drying method at 105 $\pm1^0$C for 24 h [11]. Three different lots were selected for the determination of physical properties so as to have a comparative evaluation of moisture content dependence on physical properties.

Axial dimensions

Average size of the seed was determined by three linear dimensions specified as length (L), width (W) and thickness (T) measured by using digital Vernier callipers (least count 0.01mm). The dimensions of randomly selected twenty seeds were measured. Geometric mean diameter (Dp) and arithmetic mean diameter (Da) of the seed lots were calculated by using the relationship given by [12].

$$Dp = (L\ W\ T)\ 1/3 \quad (1)$$

$$Da = \frac{L+W+T}{3} \quad (2)$$

The sphericity of seeds was calculated by using the following relationship [12]:

$$\Phi = \frac{(LWT)\ 1/3}{3} \quad (3)$$

Surface area (S)

Surface area of okra seeds was found by analogy with a sphere of the same geometric mean diameter, using the following relationship [13-15].

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

Where S is the surface area (mm^2).

Bulk density, True density and Porosity

Bulk density of the seeds was measured using a wooden box with inside dimensions of 100× 100×100 mm. The box was filled with seeds without compaction and then weighed. This procedure was repeated five times and the average bulk density of the seeds was calculated. True density was determined using the toluene displacement method. The volume of toluene displaced was found by immersing the weighed quantity of seed in the toluene.

Porosity is the void space in the bulk of seed that is not occupied by the seeds. Porosity of the seeds was calculated using the relationship given by [12] as follows:

$$\varepsilon = 100(1\text{-}pb/\ pt) \quad (5)$$

Where ε is the porosity (%), pb is the bulk density in (g cm^{-3}) and ñt is the true density in (g cm^{-3}).

Test weight (W_{1000})

Test weight (1000) was determined by means of an electronic balance having the least count of 0.001g. To evaluate the 1000 seed weight, weight of 100 randomly selected seeds from the bulk sample was taken. The procedure was repeated five times and weights were averaged.

Terminal velocity (Vt)

The experimental setup used to measure terminal velocity (Vt) consisted of a mild steel box fitted with a long glass tube, blower and a transformer to regulate the voltage. Anemometer was used to measure the air velocity. A throttle provided with the blower and supply voltage regulated the air velocity in vertical glass tube. The seed was poured from the top of glass tube and upward air velocity required to suspend the seed was recorded. Observations were taken on five samples and mean value was computed.

Angle of repose (Φ)

The dynamic angle of repose (Φ) was measured with an apparatus consisting of a funnel with an adjustable throat opening, mounted on a stand. A circular plate, with four centering arms, was mounted in the funnel above the adjustable throat. The funnel was filled with the seed by keeping its adjustable throat closed. The throat was fully opened to allow the free flow of seed over and around the plate mounted in the funnel. At the end, a heap-cone of seed was left on the plate. The angle of cone was calculated using the base and height dimensions of the seed cone [16].

$$\Phi = \tan^{-1}(2H/D) \quad \text{.......... (6)}$$

Where, H is height of heap (mm) and D is diameter of heap (mm).

Coefficient of static friction (μ)

It was determined on three different surfaces namely plywood, mild steel and cast iron was measured for okra seed by using the inclined plane method [17]. The material was kept on the adjustable tilting plate and the slope was increased gradually. The angle at which the material just started to move downward was recorded (α). The coefficient of friction was calculated from the following relationship:

$$\mu = \tan\alpha \quad \text{.......... (7)}$$

Compressive strength (Fc)

This particular property of seed is considered to be an important mechanical property with respect to seed breakage. It was measured by using Texture Analyzer (Model: *TA+HDi*® Stable Micro Systems, UK) which was calibrated before starting the experiment. The seed was placed in the centre of the plate. The peak force was obtained and displacement was computed based on the time taken to reach peak force. Five observations were made for each seed lot.

Statistical analysis

The data was statistically analysed by using analysis of regression using Microsoft Excel.

RESULTS AND DISCUSSION

Seed Lots preparation

The seed samples of procured okra seeds was tested for its initial germination and moisture content. Germination was observed to be approximately 80% after the final seed count on 21[st] day. Having performed accelerated aging on the available seed lot, seed samples were taken on 5, 8 and 10 day, respectively and tested for their germination percentage and moisture content. This process was found to be helpful in obtaining three different lots of okra having different germination percentages and moisture content tabulated below in Table 1.

Thus, the seed lots used for further experiments on determination of physical properties were finalized to have germination percentage and moisture content as: L_1 (80% with 10.98% d.b.), L_2 (65% with 13.97 % d.b.) and L_3 (50% with 16.89 % d.b.), respectively.

Seed dimensions

Mean axial dimensions of 10 seeds of individual seed lots were found to increase with moisture content values and are reported in Table 2. Relationship between moisture content and seed dimensions is represented graphically in Fig. 1.

Higher value of correlation showed an important and positive relationship between moisture content and axial dimensions of seeds. The increase in seed dimensions was attributed to expansion as a consequence of moisture uptake in intracellular spaces within the seeds during the process of aging.

This kind of expansion in seed geometric properties as a result of moisture absorption in the intracellular spaces for different granular agro-materials have been reported by [18] for dried pomegranate seeds, [19] for niger seeds, [20] for paddy rice and [21] for kenaf seeds.

Sphericity

Sphericity values observed to follow an increasing pattern from 0.896 to 0.914 with the moisture content as shown in Fig. 1.

Table 1. Germination and moisture content of the seed lot after accelerated aging

	Available seed lot (80% Germination)		
Aging duration	After 5th day	After 8th day	After 10th day
Germination %	76	65	50
Moisture (% d.b.)	11.33	13.97	16.89

Table 2. Physical dimensions of the seed lots

Lot/ Dimensions	L_1	L_2	L_3
Length/ Width/ Thickness (mm)	5.28/4.60/4.36	5.42/4.85/4.42	5.49/5.06/4.55
Dp (mm)	4.731	4.879	5.018
Da (mm)	4.746	4.896	5.033

Following equations shows the dependence of axial dimensions on moisture content of seed lots:

$$L = 0.105M_c + 5.0186 \quad (R^2 = 0.964)$$
$$W = 0.23M_c + 4.376 \quad (R^2 = 0.997)$$
$$T = 0.095M_c + 4.253 \quad (R^2 = 0.956)$$
$$D_p = 0.143M_c + 4.588 \quad (R^2 = 0.999)$$

Relationship between sphericity and moisture content can be represented by the following equation:

$\Phi s = 0.009MC + 0.885$ .... ($R^2 = 0.906$)

Surface area

Surface area of okra seed lots increases linearly from 70.316 to 79.137 mm^2 when the moisture content increased from 10.98 to 16.89 % d.b. Variation of moisture content and surface area can be expressed mathematically as follows:

$S = 4.410MC + 65.93$ .... ($R^2 = 0.999$)

This increase might be attributed to dependence on the three principal dimensions of seed lots. A similar trend has been reported by [22] for linseed, [23] for red kidney bean grains and [9] for jatropha seeds.

Test weight

Test weight increased linearly from 63.18 to 63.86 g with increase in moisture content. Linear equation for one thousand seed weight can be formulated to be:

$W_{1000} = 0.34MC + 62.81$ .... ($R^2 = 0.986$)

A similar increasing trend in test weight with moisture content has been reported by [24] for neem nut and [13] for hemp seed. The variation in surface area and test weight with respect to moisture content is shown in fig. 2.

Bulk Density

Average bulk density of the lots was observed to decrease from 0.622 to 0.604 g/cm-3 with moisture content (Fig. 3). The decrease in bulk density with increase in seed moisture content was mainly due to the higher rate of increase in volume than weight. The negative linear relationship of bulk density with moisture content was also observed by various other research workers [25-28]. Bulk density of seed lots was found to bear the following relationship with moisture content:

$\rho b = 0.630 - 0.009MC$ .... ($R^2 = 0.995$)

True Density

True density varied from 1.138 to 1.126 g/cc when the moisture level increased from 10.98 to 16.89 % d.b. (Fig. 3). True density and the moisture content of seed can be correlated as follows:

$\rho t = 1.144 - 0.006MC$ .... ($R^2 = 0.993$)

This was due to the higher rate of increase in single seed volume than single seed weight. The density values of seeds generally used in design of storage bins and silos, separation of desirable materials from impurities, cleaning and grading and quality evaluation of the products [19]. Negative linear relationship was also observed by [25] for

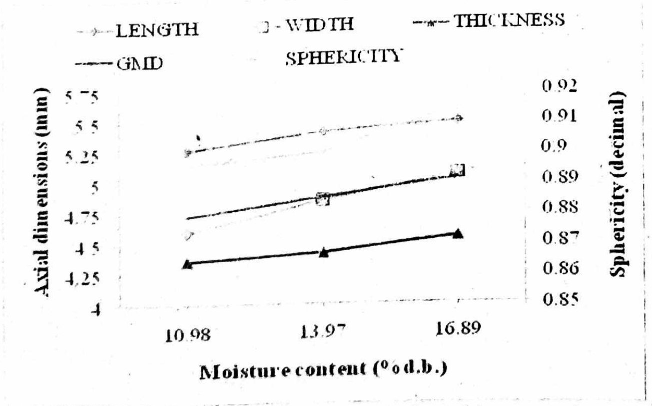

Fig. 1. Variation of axial dimensions, geometric mean diameter and sphericity with moisture content of seed lots.

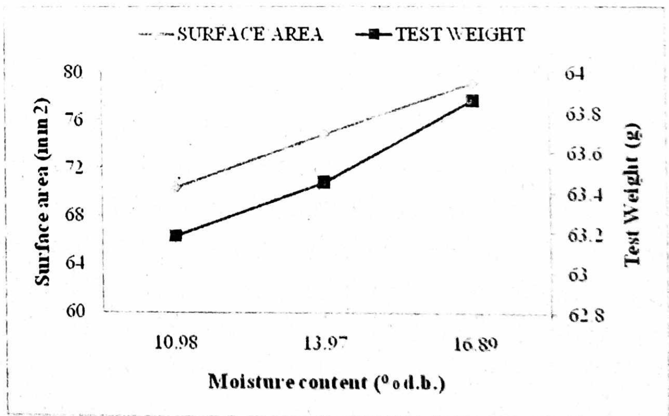

Fig. 2. Effect of moisture content on surface area and test weight.

pigeon pea, [26] for gram, [29] for soya bean, [11] for karingda seed and [17] for okra seeds.

Porosity

Porosity (ε) values of seed lots increased from 45.34% to 46.35% with the increase in moisture content from 10.98 to 16.89 % d.b (Fig. 3). Mathematical relationship between porosity and moisture content can be represented by the following equation:

ε = 0.505MC + 44.86 .... (R^2= 0.990)

Similar results have been reported by [22] for linseed, [23] for red kidney bean and [9] for jatropha seed and they stated that as the moisture content increased, the porosity values also increased. This could be attributed to the swelling and expansion of seeds that might have resulted in more void space between the seeds and increase in bulk volume. The same was exhibited in reduction of bulk density with increase in moisture content.

Terminal velocity

Terminal velocity was found to increase linearly from 9.20 to 9.80 ms^{-1} as the moisture content increased from 10.98 to 16.89 % d.b as shown in Fig. 4.

The relationship between terminal velocity and moisture content can be represented by the following equation:

Vt = 0. 3MC+8.9 .... (R^2= 0.994)

This increase in terminal velocity as moisture content increases follows the same trend of that of other seeds because the weight of the seeds increases with increase in moisture content, which also increases the air velocity needed to suspend the seeds. A linear increase in terminal velocity with an increase in moisture content has been observed by [30] for three different varieties (Pishtaz, Mahdavi and Marvdasht) of wheat and [21] for kenaf seeds.

Compressive strength

Compressive strength was measured to determine the hardness of okra seed lots. The peak compressive force at failure of seed lots decreased from 93.7 to 81.72 N at the corresponding displacement of 0.5mm with the increase in the moisture content (Fig. 4). The relationship can be represented by the following equation:

Fc=-5.59MC+101 .... (R^2= 0.873)

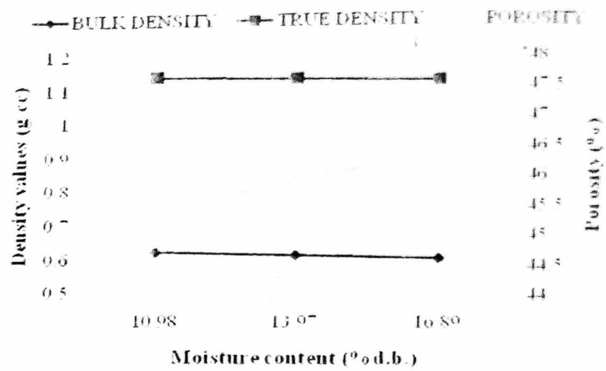

Fig. 3. Effect of moisture content variation on bulk density, true density and porosity of seed lots.

The decrease in hardness can be attributed to the seeds becoming relatively soft at increased moisture levels. Similar kind of variation has been reported by [18] for dried pomegranate seeds.

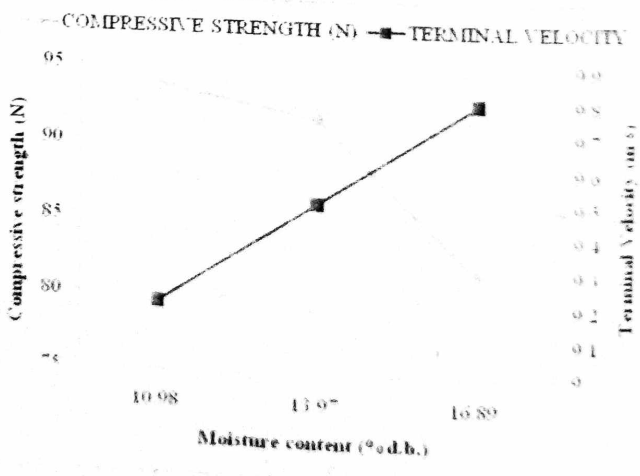

Fig. 4. Variation of compressive strength and terminal velocity with moisture content.

Angle of repose

The angle of repose is an indicator of the seed's ability to flow. The experimental result for angle of repose with respect to moisture content is shown in fig. 5. It was observed that the angle of repose increased from 24^0 to 29^0 as the moisture content increased from 10.98 to 16.89 % d.b. The relationship can be represented by the following equation:

$\Phi = 2.5MC + 21.22$ .... (R^2= 0.963)

This trend could be due to the fact that moisture present in the surface layer of the grain keeps them bound together by virtue of surface tension [31]. Similar behaviour of the angle of repose with respect to moisture has been observed for sorghum, jatropha and karanja [9, 31].

Coefficient of static friction

Plots of coefficient of static friction on three surfaces (Plywood, mild steel and cast iron) against moisture content are presented in Fig. 5. It was observed that the coefficient of static friction increased with increase in moisture content for all the surfaces. The coefficient of static friction increased from 0.3979 to 0.4327 for plywood, 0.3878 to 0.4203 for mild steel and 0.362 to 0.3979 for cast iron as the seed moisture content increased from 10.98 to 16.89 % d.b. The pertaining reason for this increase may be due to the fact that at higher moisture content, the seed lots became rough in nature and the sliding characteristics were diminished. The roughness of the plywood surface gave a higher resistance against the flow of grain than that of mild steel and cast iron, which were smoother, and thus the coefficient of friction is higher. Therefore, the coefficient of static friction increased with increase in moisture content. Relationship between moisture content and coefficients of static friction on the surfaces can be represented by the following equations:

$\mu pl = 0.017MC + 0.380$ .... (R^2= 0.998)

$\mu ms = 0.016MC + 0.371$ .... (R^2= 0.996)

$\mu ci = 0.017MC + 0.344$ .... (R^2= 0.998)

Singh and Goswami [3] reported an increase in coefficient of static friction for mild steel surface, galvanised iron, steel and aluminium in case of cumin seed with increase in moisture content.

CONCLUSION

The conclusions drawn from this investigation on moisture dependent physical properties of okra seed lots in the moisture content ranging from (10.98 to 16.89 % d.b.) are

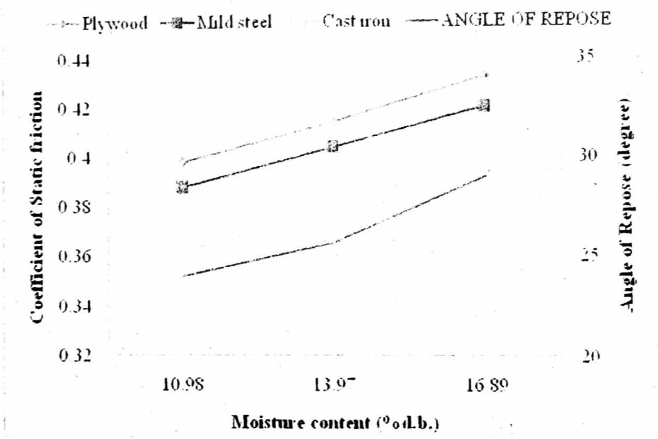

Fig. 5. Effect of moisture content on coefficient of static friction and angle of repose of seed lots.

summarized. Axial dimensions including average length, width and thickness of seed lots increased from 5.28 to 5.49, 4.60 to 5.06 and 4.36 to 4.55 mm, respectively, with moisture content. Geometric mean diameter and sphericity were both found to increase from 4.731 to 5.019 mm and 0.896 to 0.914, respectively. Test weight and surface area of seed lots are positively correlated with moisture content and hereby increased from 63.18 to 63.86 g and 70.316 to 79.137 mm^2, respectively. Bulk density and true density decreased from 0.622 to 0.604 g/cc and1.138 to 1.126 g/cc, respectively, while porosity values were increased from 45.34 to 46.35% as the moisture content increased from of 10.98

to 16.89 % d.b. Angle of repose increased from 24° to 29°, terminal velocity increased from 9.2 to 9.8 m/s as the moisture content increased from 10.98 to 16.89 % d.b. The compressive strength in terms of peak compressive force of the seed lots decreased from 93.70 to 81.72 N as the moisture content increases from 10.98 to 16.89 % d.b. Coefficient of static friction (plywood, mild steel and cast iron) increased positively from 0.3979 to 0.4327, 0.3878 to 0.4203 and 0.362 to 0.3959, respectively with the moisture content. Such information may find its applicability in adequate design and development of equipments pertaining to seed quality enhancement.

ACKNOWLEDGEMENT

The first author acknowledges University Grants Commission (UGC) for providing financial support in the form of Rajiv Gandhi Fellowship. Also, gratitude is extended to Division of Agricultural Engineering, Seed Science & Technology of IARI New Delhi for providing research infrastructure and laboratories facilities.

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