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Mechanical properties of onion seeds (*Allium cepa* variety *aggregatum* L.) under compression loading

M.M. Pragalyaashree[1*], R. Kailappan[2] and Z. John Kennedy[2]

[1]Department of Food and Agricultural Process Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641004, India.
[2]Tamil Nadu Agricultural University, Coimbatore-641003, Tamil Nadu, India.

Corresponding author: shreepragalyaa@gmail.com

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Abstract

Some mechanical properties of onion seeds were investigated in this study. These properties are often required for the design of transportation, storage and grading/sorting machines and other post harvest machines for onion seeds. The seeds were compressed along three mutually perpendicular axes and the properties studied were initial rupture force, rupture force, deformation at rupture and energy consumed at rupture. The ranges of moisture content investigated were 7, 9, 11, 13 and 15% (db), respectively. The tests were carried out at a deformation rate of 70% strain energy. Onion seeds were compressed along major axes (length), intermediate axes (Breadth) and minor axes (thickness), respectively. Physical properties like dimensions, geometric mean diameter, sphericity and mass were also evaluated. It was observed from the results that rupture force, Peak force and energy consumed at rupture decreased with increase in moisture content and the deformation at rupture increased with increase moisture content.

Highlights

- used in the design and development of thresher parts
- study at different m.c helps to know optimum range with minimum damage to seeds

Keywords: Rupture force, peak force, sphericity, deformation etc.,

Onion (*Allium cepa* L. var. aggregatum) is an important commercial horticultural crop and belongs to the "Liliaceae" family. It is used as vegetable and spice all over the world and is rich in sulfur-containing compounds that are responsible for their pungent odours and for many of their health-promoting effects. India is the second largest producer of onion in the world with a production of 16.81MT/ha (NHB, 2013). Onion is mainly raised through seeds. Seed production is widely adapted to temperate and subtropical regions.

There are two methods of seed production. Seed to seed and bulbs to seed methods and both the methods are in practice for onion seed production. Mostly the bulb to seed method is followed for seed production because it permits selections of "true-to-type" and healthy bulbs for seed production and seed yields are comparatively very high. The seed to seed method, however, can be practiced for varieties having poor keeping quality (Agarwal, 2008).

Moisture content is one of the most important characteristics of biological materials. Moisture content of agricultural materials affects the physical and mechanical properties (Sitkei 1986). It also affects the storability, handling and processing of biological materials. Many researchers have reported the physical and mechanical properties of bio materials (Kaleemullah and Gunasekar, 2002; Aydin, 2003; Koyuncu *et al.* 2004; Aviara *et al.* 2005; Chandrasekar and Kailappan, 2007; Dash *et al.* 2008; Altuntas and Ozkan, 2008; Altuntas and Erkol, 2010; Singh *et al.* 2010).

The physical properties of agricultural materials are essential is in the design and development of specific equipment and structures for transporting, handling, processing and storage and also for assessing the behaviour of product quality (Kashaninejad *et al.* 2005). Physical properties of onion seeds are essential in the design of components of equipment for threshing, cleaning, grading and storage. Moisture content relationship is useful information in the threshing process. The dimensions and shape are important in designing separating, harvesting, sizing and size reduction machines (Dash *et al.* 2008).

The main objective of the study was to determine the effect of moisture content on compression loading (mechanical properties) of onion seeds. The parameters studied were rupture force, deformation at rupture and energy consumed at rupture. These properties were analyzed under different moisture contents.

Materials and Methods

Freshly harvested onion umbels were procured from the farmer at J.Krishnapuram, Palladam Taluk, Tirupur Dt., Tamil Nadu, India. Fresh umbels were dried on cement concrete floor to attain optimum moisture level for threshing. Seeds were obtained by threshing the onion umbels using onion umbel thresher. After threshing the seeds were cleaned to get good quality seeds. Experiments were carried out to determine some physical and mechanical properties of onion seeds at five different moisture levels.

Sample preparation and moisture content determination of onion seed

Moisture content of onion seed is one of the most important factors in the maintenance of seed quality. The seed were cleaned manually to remove all foreign materials such as broken flower parts, dust, dirt, chaff as well as immature and damaged seed. The initial moisture content of the onion seed was determined using hot air oven method at 105 ± 2˚C until a constant weight was reached (ISTA 1996). The initial moisture content of seed was found to be 9.3% (db). For varying moisture content in the lower end of range, a predetermined quantity of seed was dried to the desire moisture content. In order to achieve the desired moisture levels for the study, onion seed samples were conditioned by adding calculated quantity of water based on Equation (1) (Dursun and Dursun, 2005) followed by a thorough mixing, sealing it in plastic bags and kept in a refrigerator at 4±1°C for a minimum period of 7 days for the moisture to distribute uniformly throughout the seed.

$$Q=\frac{W_i\left(M_f-M_i\right)}{100-M_f} \qquad \dots (1)$$

Where,

Q - mass of water to be added, kg

Wi - initial mass of the sample, kg

M_i - initial moisture content of the sample,% (db) and

M_f - final moisture content required,% (db)

The moisture contents of the samples were equilibrated to 7.4, 9.3, 11.2, 13.4, and 15.1 (db) as per the procedures of AACC (2000). The required amount of sample was withdrawn from the refrigerator and reconditioned at room temperature (30±2°C) before conducting tests on it. Each test was repeated three times to determine mean values.

Physical properties of onion seeds

Physical properties such as size, shape, Geometric Mean Diameter and mass of 1000 seeds were determined. The methods followed to determine these properties are detailed below.

Size of onion seeds

Size of onion seeds was determined by randomly selecting twenty seeds separately for each moisture content from the bulk sample. The three principal dimensions along major (length), intermediate (width) and minor (thickness) axes (MJD, ITD and MND), respectively were measured using a vernier calipers having accuracy of 0.01 mm.

Geometric mean diameter of onion seeds

The Geometric mean diameter Dg, of onion seed was determined using standard formula Moshenin (1970).

$$Dg = (abc)^{1/3} \qquad \text{-------- (2)}$$

where,

Dg = Geometric mean diameter (mm),

a = major diameter (mm),

b = intermediate diameter (mm), and

c = minor diameter (mm).

2.2.3. Sphericity of onion seeds

The sphericity of onion seed is also calculated using the following formula (Mohsenin 1986).

$$\Phi = \frac{(abc)^{1/3}}{a} \qquad \text{-------------- (3)}$$

Where,

Φ – sphericity, decimal

a – length, mm

b – breadth, mm

c – thickness, mm.

2.2.4. Mass of one thousand seeds

In order to determine one thousand onion seed mass (m_{1000}), a seed mass of approximately 1 kg was roughly divided in to 10 equal portions and then 1000 numbers of seed were randomly picked from each portion and weighed on a digital electronic balance with an accuracy of 0.01 g. The measurement was repeated for 3 times and the mean value was taken.

Mechanical properties

During compression loading mechanical properties like rupture force, deformation at rupture and the amount of energy required for the deformation were determined for onion seeds at different moisture ranges. Three replicates were used for each size, loading position and moisture content.

Mechanical tests were carried out in the Food engineering Laboratory of Tamil Nadu Agricultural University (TNAU), Coimbatore, India. The average room temperature throughout the test was 32°C. The Texture analyzer, manufactured by Stable Microsystem, TA-HDi was used to perform the test. Before carrying out the test the seeds were analyzed for cracks and any other damages. It was ensured that the best seeds were selected for the test.

Experimental procedure

Texture analyzer was switched on to run the tests. Exact probe (P25/l, 25 mm dia. Cylinder LAP perspecx) for conducting compression test was selected. Each seed was placed in between the compression plates and the personal computer (PC) was switched on to respond to the behavior of the seed under loading. Other information like name of the test, type of material, test speed, size, moisture content, loading position and so on were also fed in to the PC. The parameters needed from the test like rupture force (peak load), deformation at rupture (deformation at peak), amount of energy required to cause deformation (energy at peak) were recorded.

The start bottom was then pressed to commence the test. As the test proceeded, the graph of the force–deformation was plotted automatically and displayed by the PC as the seed responds to compression. When the test sample cracked, the test stopped automatically. This was the point of rupture and was observed as a sharp or continuous decrease of the load on the graph of the load–deformation. The rupture force and deformation were easily read on the graph. Then the machine was stopped to end the test. The crosshead was then raised up to remove the crushed seed. This procedure was followed unit all the seeds were tested. The texture analyzer gave the actual values of rupture force, deformation and energy at rupture including their units.

Statistical analysis

Data collected were subjected to regression analysis using Excel analysis software (Excel 2007) to determine the effects of moisture content on rupture, deformation and energy at rupture.

Results and Discussion

Dimension and mass of onion seeds at different moisture contents

The changes in the seed length, breadth and thickness are shown in the Figure 1 (Table 1). It is observed from the graph that the average length, breadth and thickness of the onion seeds varied from 2.677 to 2.91, 1.929 – 2.244 and 1.408 – 1.538 mm, respectively as the moisture content increased from 7 – 15% d.b. Very high value of correlation was observed between the three principal dimensions (length, breadth and thickness) and moisture content indicating that upon moisture absorption, the onion seed expands in length, width and thickness within the moisture range indicated above. From the figure it was observed that there exists a linear relationship between moisture content and principal dimensions and the regression equation of the forms are presented as

$L = 0.029x + 2.4762$ ($R^2 = 0.9874$)

$B= 0.036x + 1.6942$ ($R^2 = 0.9652$)

$T = 0.0147x + 1.3207$ ($R^2 = 0.9278$)

Where,

L = length of the onion seeds

B = breadth of the onion seeds

T = thickness of the onion seeds

X = moisture content of the onion seeds

Similar results were obtained by Altunas (2005) and Garnayak (2008) for fenugreek and jatropa seeds, respectively.

Effect of moisture content on Geometric Mean Diameter (GMD) and Sphericity of onion seeds

Changes in the geometric mean diameter of the onion seeds with respect to moisture content is shown in the Figure 2. It is observed from the figure that the GMD increases as there is an increase in the moisture content. The figure shows direct and linear relationship between moisture content and GMD and established a high R^2 value.

$GMD = 0.0263x + 1.7621$ ($R^2 = 0.9825$)

Where,

GMD = geometric mean diameter, mm

x = moisture content,% (d.b)

The sphericity of the onion seeds were calculated with the Eq. 3 using the data used for geometric mean diameter and are presented in the Table 1. It is noticed from the table that the sphericity value increased with increase in moisture content. It is also evident from the table that the mean sphericity value ranging from 0.726 – 0.745. Pandiselvam *et al.* (2014) and Chhina and Sharma (2010) have reported the sphericity value ranges between 0.72 -0.78 and 0.68-0.74 respectively. The relationship between moisture content and sphericity is represented by the following equation

$\phi = 0.0023x + 0.7105$ ($R^2 = 0.9944$)

Similar results have been reported by Aydin, Ogut, and Konak (2002), Gupta and Das (1997), Sacilik *et al.* (2003), Baumler *et al.* (2006) and Dursun and Dursun (2005) for Turkish mahaleb, sunflower, hemp seed, safflower and caper seed.

Mass of thousand seeds

Mass of 1000 onion seeds M_{1000} increased linearly from 2.91 to 5.52 g as the moisture content increased from 7 to 15%, (d.b) (Table 1). The relationship between moisture content and M_{1000} (Figure 3) is represented by the following equation with a value for the coefficient of determination of $R^2 = 0.9783$

$M_{1000} = 0.3225x + 0.5145$ ($R^2 = 0.9783$)

A similar increasing trend has been reported by Pandiselvam *et al.* (2014) for onion seeds, Visvanathan *et al.* (1996) for neem nut, Sacilik *et al.* (2003) for hemp seed, Singh and Goswami (1996) for cumin, Vilche *et al.* (2003) for quinoa and Yalcın and Ozarslan (2004) for vetch.

Mechanical properties of onion seeds

The mechanical properties like initial rupture force, peak force required for deformation, energy absorbed during rupture and distance moved at rupture are determined as per the procedures mentioned in Materials and Methods and the results are represented as follows

Dimension and mass of onion seeds at different moisture contents

Properties	Moisture content,% (db)				
	7	9	11	13	15
Major axes (mm)	2.677	2.731	2.813	2.845	2.91
Minor axes (mm)	1.929	2.048	2.092	2.138	2.244
Intermediate axes (mm)	1.408	1.471	1.488	1.504	1.538
GMD (mm)	1.937	2.01	2.06	2.09	2.16
Sphericity, (ϕ)	0.726	0.732	0.736	0.740	0.745
M_{1000}, g	2.91	3.30	4.05	4.53	5.52

Rupture force

The seed rupture observed at different moisture content levels along three mutually perpendicular directions are represented as shown in the Figure 1. The figure clearly indicates the force required to initiate the rupture is highly dependent on moisture content as it increases from 7 -15%, (db). The initial rupture force value ranged from 5.28 to 0.93, 9.65 to 3.82 and 8.04 to 1.38 N along length, breadth and thickness, respectively. It is evident from the figure that much force is required to initiate the rupture at lower moisture content. The maximum force required to initiate the rupture is along the breadth and the minimum value is recorded along length. The least rupture forces at higher moisture content might have resulted from the fact that the onion seed seemed to be very soft texture at high moisture content. Similar results were reported by Aydin (2002), Altunas and Yildiz (2007) and Altunas and Erkol (2010) for walnuts and pistachio nuts, respectively.

Mathematical correlations were established between moisture content and rupture force of onion seeds compressed along length, breadth and thickness are represented as follows:

$L = 628.57x^2 - 166.74x + 12.033$ $R^2 = 0.9974$

$B = 1525x^2 - 339.9x + 22.499$ $R^2 = 0.9579$

$T = 544.64x^2 - 174.39x + 15.155$ $R^2 = 0.9661$

It is observed from the figure that highest rupture force is required when the seed is kept along breadth wise. At a moisture content of 7%, it has recorded a maximum rupture force of 9.65 N and a minimum of 3.82 N at 15% m.c (db). The initial rupture force is minimum when the seed sample is loaded along length wise when compared to compression along breadth and thickness wise. The value of 5.82 and 0.93 N were recorded at a moisture content of 7 and 15% m.c (db), respectively. This result is highly dependent on the structure of the seed sample.

Peak force at deformation

The mean value for the deformation at peak force is represented in the Table 2 and Figure 5. It is seen from the table that deformation occurred at peak force is highest (77.81N) along breadth wise and least (35.61N) along length wise. The highest and lowest values were obtained at lowest and highest moisture contents. It is also evident from the figure that the peak force decreases as the moisture content increases along all the three axes. The values along length, breadth and thickness decreased from 35.61 to 22.85, 77.18 to 48.01 and 74.23 to 42.79 N as the moisture increased from 7 to 15%, m.c (db). Mathematical relationship between moisture content and peak force at deformation is expressed in terms of regression equation as follows

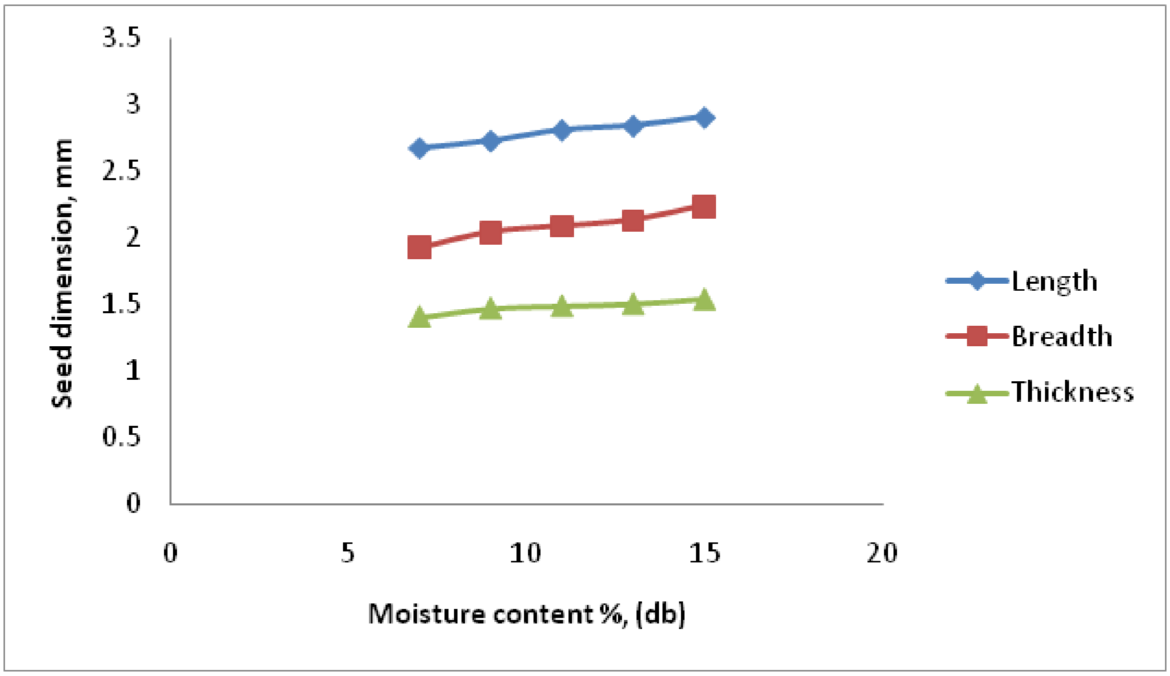

Figure 1. Effect of moisture content on Dimensions of onion seeds

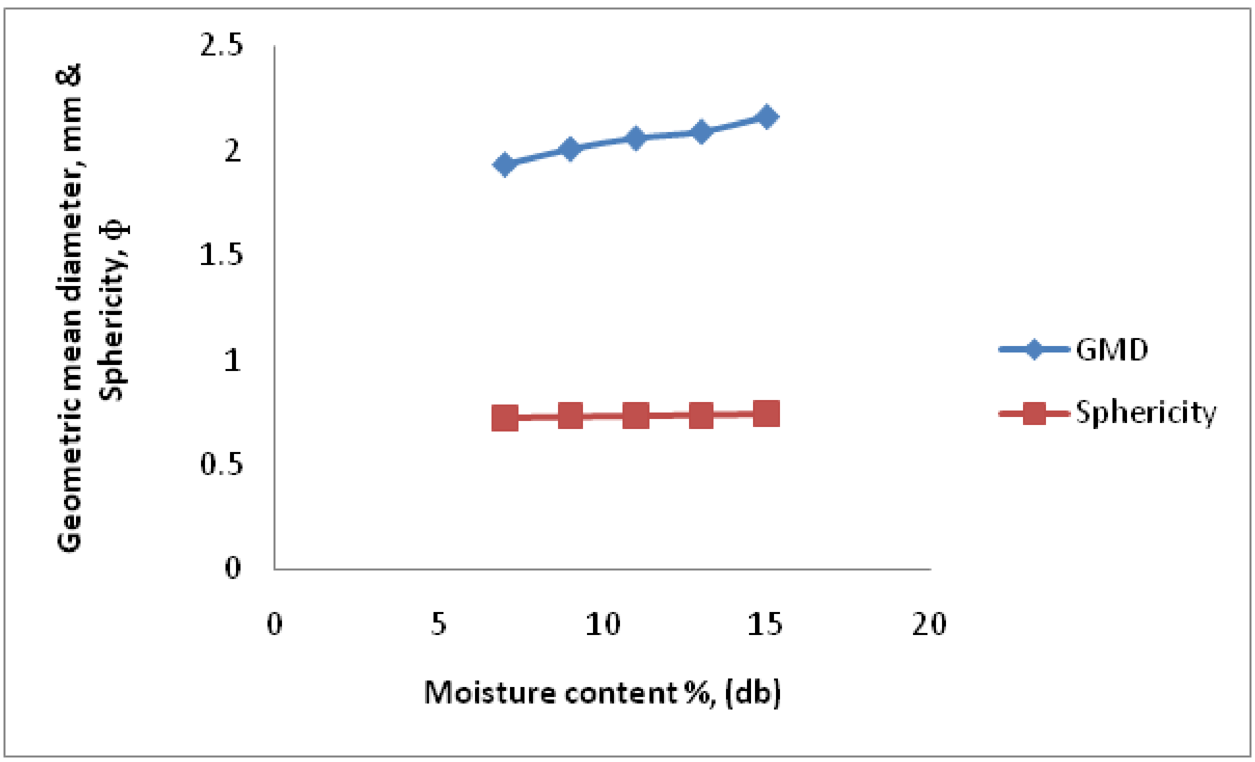

Figure 2. Effect of moisture content on geometric mean diameter and sphericity of onion seeds

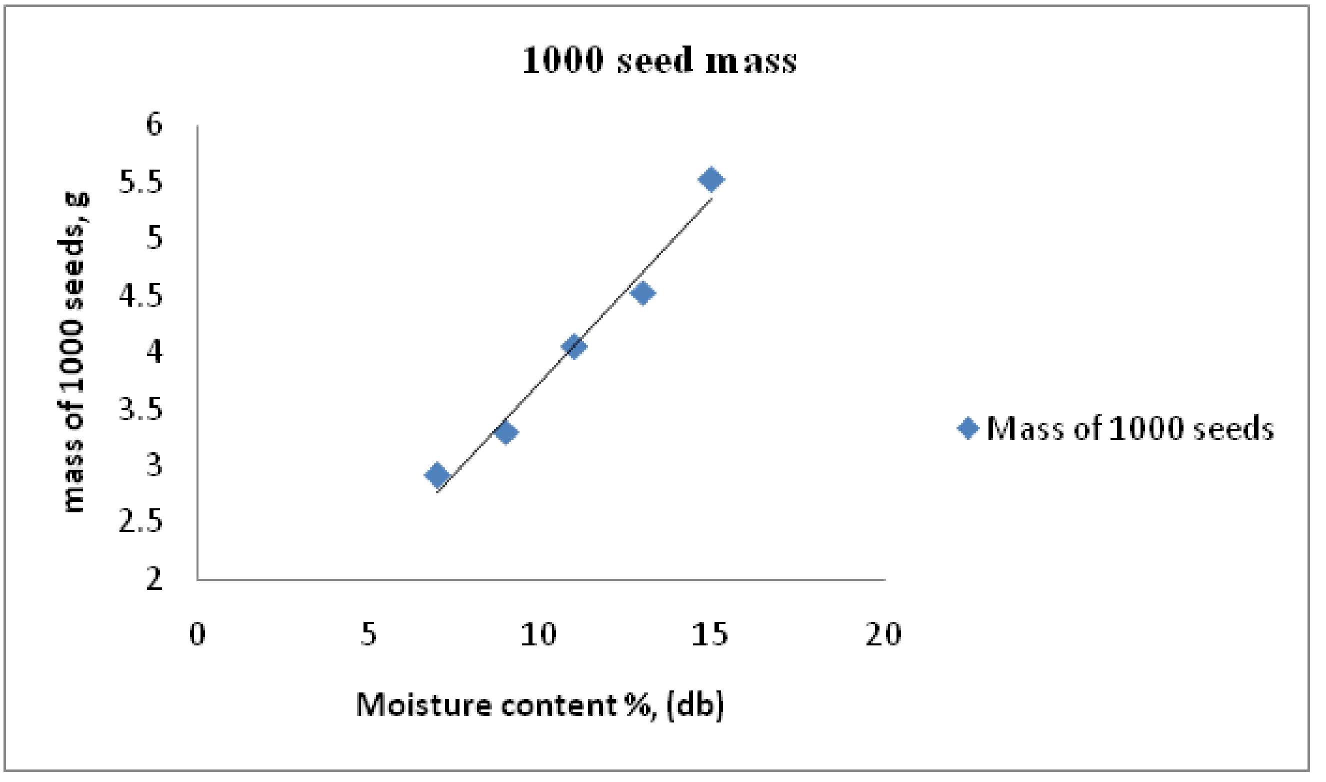

Figure 3. Effect of moisture content on mass of thousand onion seeds

Table 2. Compression loading of onion umbels

Moisture content, % (d.b)	Initial rupture force, (N)			Peak force, (N)			Energy absorbed, kJ			Deformation, mm		
	Length	Breadth	Thick-ness	Length	Breadth	Thick-ness	Length	Breadth	Thick-ness	Length	Breadth	Thick-ness
7	5.28	9.65	8.04	35.61	77.18	74.23	24.1	22.34	24.58	1.65	0.95	0.94
9	3.45	5.44	5.20	27.77	68.48	64.29	16.61	21.76	19.86	1.78	1.01	1.05
11	2.01	4.47	3.67	27.61	66.83	62.92	15.53	20.52	19.12	1.82	1.02	1.09
13	1.43	4.02	3.25	23.78	66.37	46.72	14.95	19.58	17.83	1.87	1.03	1.12
15	0.93	3.82	1.38	22.85	48.01	42.79	14.79	13.98	14.64	1.94	1.05	1.25

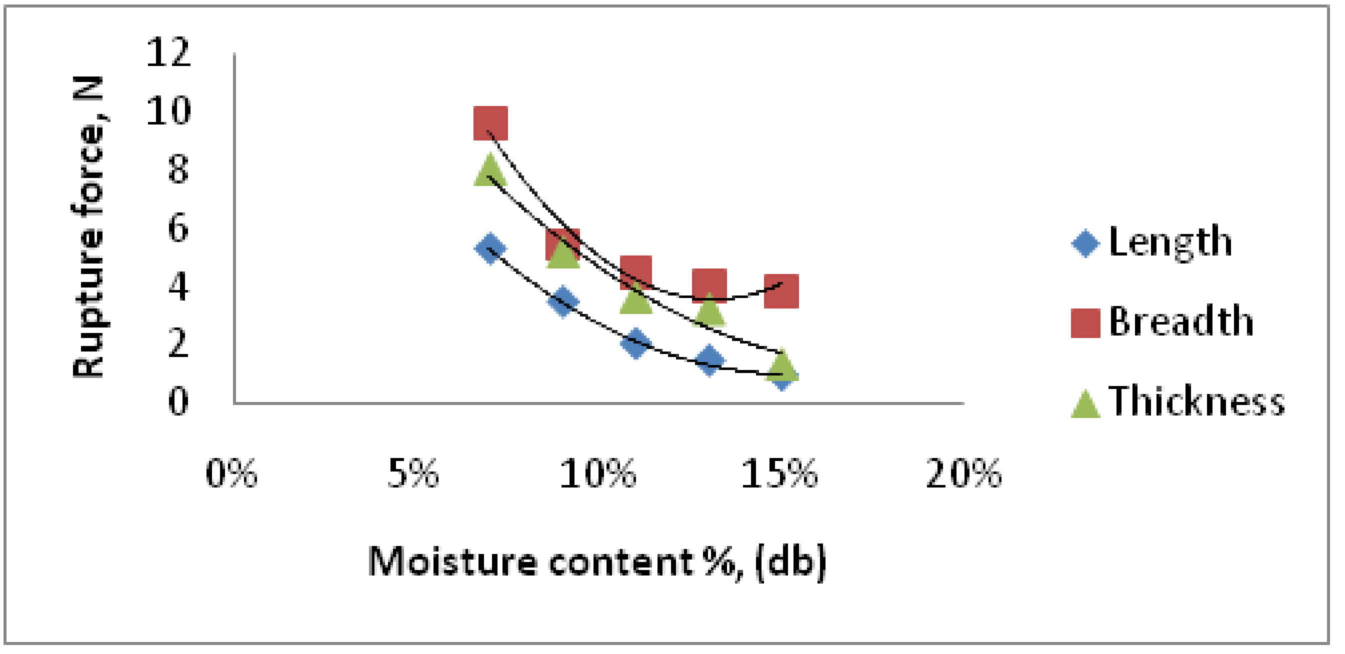

Figure 4. Effect of moisture content on initial rupture force of onion seeds during compression loading along length, onion seeds during compression loading along length, breadth and thickness breadth and thickness

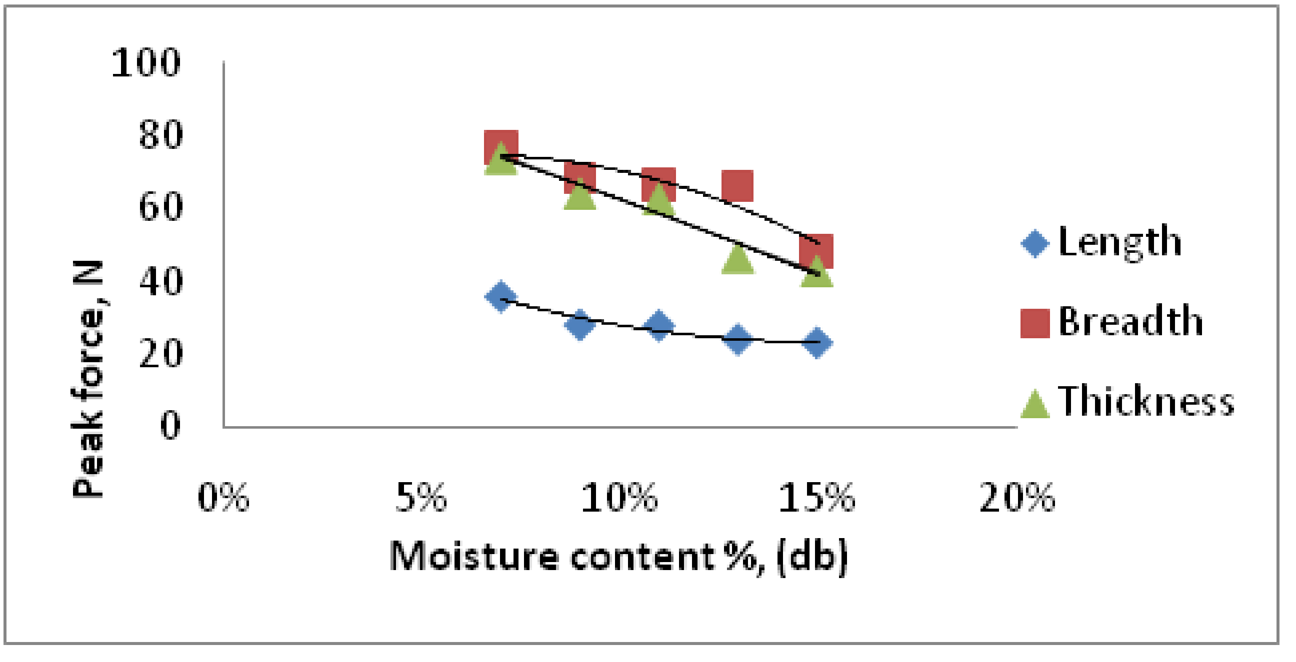

Figure 5. Effect of moisture content on peak rupture force of compression loading of onion seeds along length, breadth of onion seeds at rupture along length, breadth and thickness and thickness

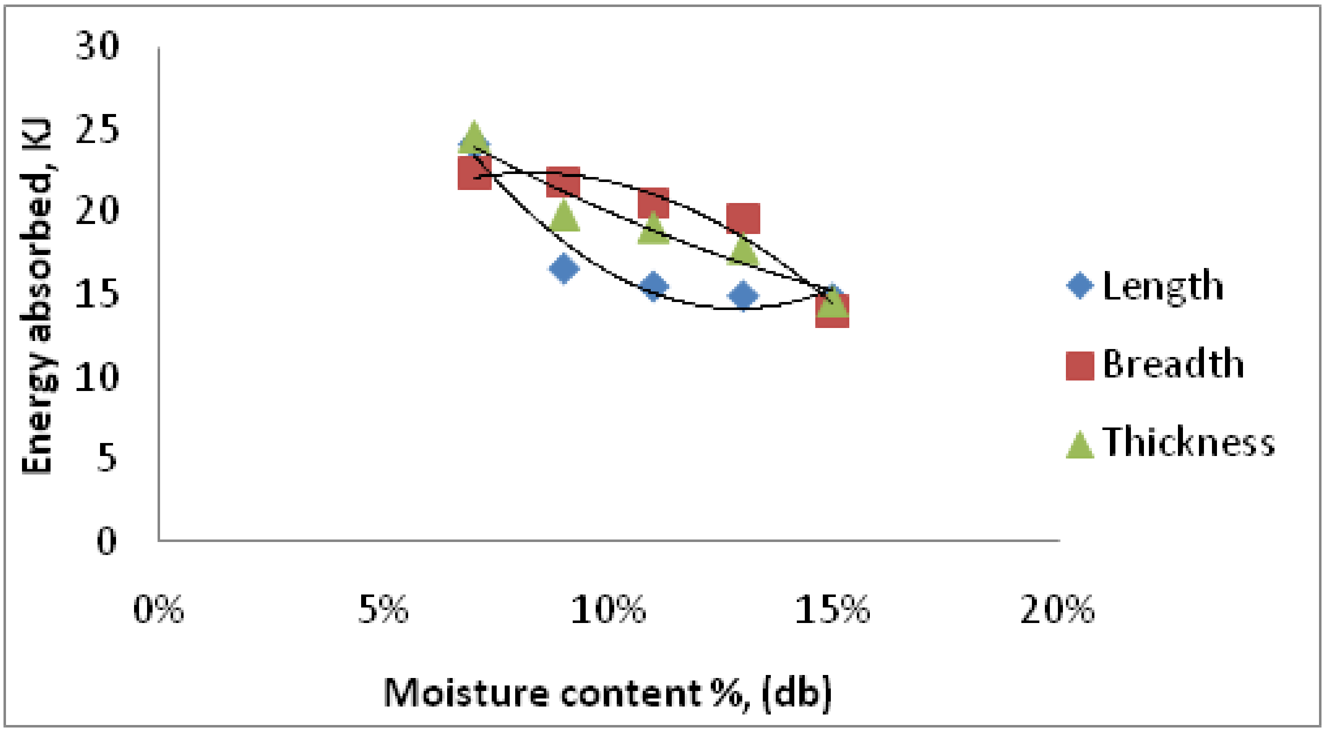

Figure 6. Effect of moisture content on energy absorbed during

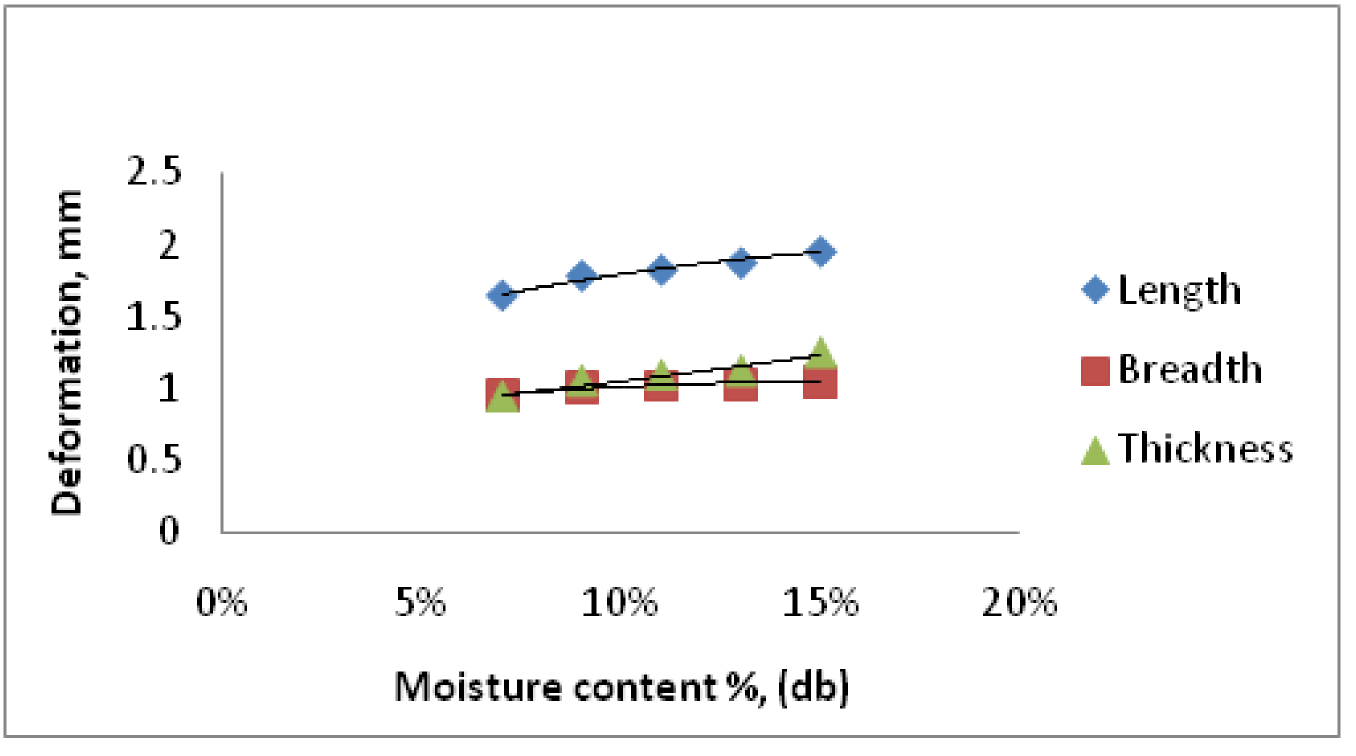

Figure 7. Effect of moisture content on deformation

$B = -3237.5x^2 + 280.5x + 68.943$ $R^2 = 0.8573$

$T = -498.75x^2 - 312.53x + 90.757$ $R^2 = 0.9449$

$L = 1812.5x^2 - 473.8x + 54.035$ $R^2 = 0.9322$

Where,

L - peak force at rupture along length, N

B - peak force at rupture along breadth, N

T - peak force at rupture along thickness, N and

x - moisture content,% (db)

The above equations are polynomial in nature with high coefficient of determination (R^2) values indicates the best fit of regression equation to the experimental results.

Energy absorbed during rupture

Figure 3. shows the effect of moisture content and orientation of loading on energy absorbed by the onion seed. Under three different axes of loading energy absorbed increased with decrease in moisture content. It is noted that seed required more energy when compressed along length and thickness. Maximum energy was observed when compressed along (24.58kJ) thickness (24.1kJ) and length, respectively. Energy at rupture increased to a maximum as the moisture content of onion seed decreased to about 7 per cent (db).The relationship between moisture content and energy absorbed during rupture is given in a polynomial equation of the following forms

$T = 449.64x^2 - 190.45x + 32.344$ $R^2 = 0.931$

$B = -1739.3x^2 + 218.57x + 15.444$ $R^2 = 0.953$

$L = 2707.1x^2 - 588.69x + 46.084$ $R^2 = 0.934$

Regression models that best fitted the relationships of the energy at rupture and moisture content were polynomial functions of the second degree order. These models have high R^2 values and therefore will be good for predictive purposes.

Deformation at rupture

The effect of moisture content on deformation of onion seeds at bio yield point and different orientation of onion seeds is shown in Figure 4. It is evident from the figure that deformation along compression axes is highly dependent on moisture content and the seeds were more deformable at higher than at lower moisture content. The deformation of seed at rupture varied in the moisture range 7 – 15 per cent (db) from 1.65 to 1.94, 0.95 – 1.05 and 0.94 – 1.25 along length, breadth and thickness, respectively. Similar to rupture force, the deformation of seed under compressive loading along three axes were found to follow a polynomial relationship with the moisture content of the seed.

$L= -19.643x^2 +7.8714x + 1.1995$, $R^2 = 0.966$

$B = -14.286x^2 + 4.2429x + 0.7296$ $R^2 = 0.9326$

$T = 5.3571x^2 + 2.2714x + 0.771$ $R^2 = 0.9422$

Results indicates that deformation along breadth is lower than length and thickness. Higher value of deformation indicates resistance of the seeds to cracking. Similar results for deformation with compressive loading were observed for other seeds such as soya bean (Paulsen 1978), melon seed (Makanjuola 1972) and pumpkin seed (Joshi 1993). The peak deformations of 1.94 and 1.25 mm occurred in the seed when loaded, along length and thickness, respectively, at a moisture content of 15% (db).

Conclusion

The following are the Conclusion drawn from the present work. The dimension of the onion seed and mass of 1000 seeds increased with increasing moisture content. Force required to initiate the rupture is highly dependent on moisture content as it increases from 7 -15%, (db). The initial rupture force value ranged from 5.28 to 0.93, 9.65 to 3.82 and 8.04 to 1.38 N along length, breadth and thickness, respectively. Peak force decreased from 35.61 to 22.85, 77.18 to 48.01 and 74.23 to 42.79 N as the moisture content increases. Energy absorbed increased with decrease in moisture content. Deformation at rupture increased with increase in moisture content.

Regression models that best fitted the relationships of the parameters (rupture force, deformation, and energy at rupture) and moisture content were polynomial functions of the second degree order. These models have high R^2 values and therefore will be good for predictive purposes. The highest and lowest forces for onion seeds to rupture were through length and thickness, respectively.

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