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Research Article

Some Mechanical Properties of Soursop Seeds and Kernels at Different Moisture Contents under Compressive Loading

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Abstract: Soursop seed is an economically important oil seeds which contains about 40% oil useful in the chemical industries. The present prevalent drudgery associated with low output in its manual dehulling and oil extraction processes, has necessitated the need to study its mechanical properties to enhance the effective mechanization of its handling and processing unit operations. This study therefore, aimed at evaluating some mechanical properties of soursop seeds and kernels. The properties (rupture force and energy, bio-yield force and energy, deformation and hardness at seed vertical and horizontal direction and kernel resting position) were determined using Instron Testing Machine. Within moisture content of 8.0 to 32.5% (db), rupture force, rupture energy, bio-yield force, bio-yield energy, deformation and hardness ranged from 43.98-20.0 N, 40.0-188.0 N.mm, 41.5-22.3 N, 6.73-1.89 N.mm, 1.89-3.58 mm and 23.27-5.59 N/mm, respectively, at the seed horizontal direction, from 576.8-787.7 N, 512.0-1488.6 N.mm, 144.9-1751.7 N, 41.0-246.0 N.mm, 2.19-4.42 mm and 29.1-35.8 N/mm, respectively, at the seed vertical direction and from 576.8 to 787.7 N, 512.3 to 1488.6 N.mm, 44.9 to 1751.7 N, 6.73 to 1.8 N.mm, 2.19 to 4.42 mm and 29.31 to 31.66 N/mm at the kernel resting position. The study established that the mechanical properties of soursop seeds and kernels depend on moisture content ($p \leq 0.05$), which is useful for engineers in the development of soursop seed dehuller and oil-expeller.

Keywords: Dehuller and expeller, mechanical properties, moisture content, soursop seed and kernel

INTRODUCTION

Soursop (*Annona muricata* L.) is an oilseed herbaceous crop of the *Annonaceae* family. It is commonly found in tropical region of the world and originated from the North and South America (Syahida *et al*., 2012). In Nigeria, soursop trees yields up to 10 t/ha and the fruits weigh between 0.5 to 2.0 kg, contain dark brown seeds and mostly abounds in the western part of the country; mainly grown in home gardens for its fruits and ornamental value and generally known as "*chap chap*" (Oloyede *et al*., 2015; Fasakin *et al*., 2008; Oyenuga, 1978). The seeds dimensions are about 14.91 mm in length, 8.71 mm in width and 5.39 mm in thickness at safe storage moisture content of 8.0% (db) (Oloyede *et al*., 2015). The dehulled seedcaruncles (kernels) are white and contain up to 40% pale yellow viscous oil (Kimbonguila *et al*., 2010).

Chemical analysis of the seed averaged 40% oil, 21.43% crude protein and 29.05% carbohydrate (Onimawo, 2002; Kimbonguila *et al*., 2010). The seed oil is unsaturated type and can be classified in the oleic-linoleic acid group which is one of the most important polyunsaturated fatty acid in human food because of its prevention of distinct heart vascular diseases (Boelhouwer, 1983). The oil extraction can be used for cosmetic and varnish production due to high unsaponifiable matter content (Kimbonguila *et al*., 2010). The extract from the crushed seed of unripesoursop have been used as larvicide agent against mosquito larvae and pest such as army worms and pea aphids (Alfrtis *et al*., 2012).

In the oil industries, dehulling of the seeds before other production steps must be done (Turkan *et al*., 2006). In these stages, mechanical properties of soursop seeds and kernels under compression at a range of moisture levels are important in addition to physical properties for optimizing equipment design, oil extraction and handling. Also provide information on resistance of the seed to cracking and force needed for kernel size reduction. Physical properties of soursop seeds at a range of moisture levels were already reported by Oloyede *et al.* (2015).

A lot of researches on mechanical properties have been reported for different seed types such as pea seed (Paksoy and Aydin, 2006), melon seed (Abu *et al*., 2007), soybean (Kibar and Öztürk, 2008), barbery fruit (Fathohzadeh and Rajabipour, 2008), flax seed (Ayman, 2009), jatropha seed and kernel (Karaj and Muller, 2010), palm-kernel seed (Ozumba and Obiakor,

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2011), white sesame seed (Hosain, 2012), castor seed (Ardebili *et al*., 2012) and canavalia seed and kernel (Niveditha *et al*., 2013). Moreover, due to present prevalent drudgery associated with low output in soursop seeds manual dehulling and oil extraction processes, has necessitated the need to study some moisture-dependent mechanical properties of soursop seeds and kernels since it does not appear to be available in literature.

The specific objectives of this study were to determine some mechanical properties of soursop seeds and kernels namely rupture force; rupture energy, bioyield force, bioyield energy, deformation at rupture point and hardness over a range of moisture levels and to evaluate their dependence on moisture content. The rupture force, F_r (N) is the minimum force required to break the sample. Deformation at rupture point, R_{DP} (mm) is the deformation at loading direction. Rupture energy R_e (N.mm) is the energy needed to rupture the sample which was determined by the machine using area under the curve between the initial point and the rupture point. Hardness is the ratio of rupture force and the deformation at rupture point (Karaj and Muller, 2010). Figure 1 and 2 shows soursop kernels and seeds.

MATERIALS AND METHODS

Sample preparation: Soursop seeds used for this study were obtained from sour-sop plants grown in Ogbomoso, Nigeria. The seeds were manually cleaned and stored at room temperature (28°-32°C). The initial moisture contents (db) of the seed and kernel were determined by oven dry method (Laboratory oven, model DHG-9101.ISA) at 103±2°C (ASAE, 2001) until a constant weight was obtained. The samples of desired moisture levels (8, 11.9, 15.4, 22.6 and 32.5% db) were prepared by adding calculated amount of water, thoroughly mixing and then sealed in separate polythene bags. The samples were kept in a refrigerator (Thermocool, HR-170T) for at least seven days at temperature of 5 ± 2°C to enable the uniform distribution of moisture throughout the samples. The required quantities of the sample were allowed to warm to room temperature prior to each test. The quantity of water added was estimated from Eq. (1) as used by (Milani *et al*., 2007; Koocheki *et al*., 2007; Hojat *et al*., 2009):

$$Q = \frac{W(M_f - M_i)}{100 - M_f} \quad (1)$$

where,

Q = The quantity of water added (g)
W = The initial weight of the sample (g)
M_i = The initial moisture content of the sample (db, %)
M_f, = Desired moisture content of the sample (db, %)

Fig. 1: Soursop kernels

Fig. 2: Soursop seeds

Mechanical properties: All laboratory compression tests were carried out using Instron Testing Machine (STM-5, SANTAM), that is equipped with a 50 kg compression load cell and integrator. The measurement accuracy was 0.001 N in force and 0.001 mm in deformation (Moshenin, 1986; Ahmadi *et al*., 2012). Rupture force, rupture energy, bio-yield force, bio-yield energy, deformation at rupture point and hardness were determined from the forces acting on the two sections length (vertical) and width (horizontal) for the seed and at kernel resting position; at a loading speed of 5 mm/min which is suitable for highly oil bearing materials (ASABE, 2004). An individual sample was placed on the lower plate (Fig. 3) and the cylindrical probe attached to the chuck moved downward with a constant speed until fracture occurred as is denoted by bio-yield point (rupture point) in the force-deformation curve (Fig. 4). Once the fracture was detected the loading was stopped. Five replicates were made for each loading. Samples hardness were calculated using Eq. (2) described by (Karaj and Muller, 2010):

$$H = \frac{Fr}{Rdp} \quad (2)$$

where,

H = Hardness (N/mm)
F_r = The rupture force (N)
R_{dp} = The Deformation at rupture point (mm)

Data analysis: Data were analyzed using Analysis of Variance in SPSS (SPSS Inc. 20). Regression analyses were carried out using Microsoft Excel 2010 software to determine the effect of moisture content on the mechanical properties of seed and kernel.

Fig. 3: Compressive tests for soursop seeds and kernels

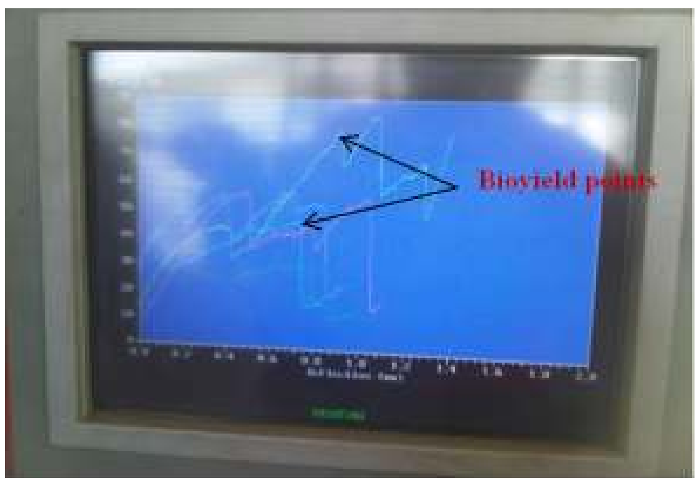

Fig. 4: Force-deformation curve

RESULTS AND DISCUSSION

Samples moisture content: The mean initial moisture contents for the samples were found to be 11.9% (db) for the seeds and 7.9% (db) for the kernels. The five moisture levels obtained after conditioning the samples were 8, 11.9, 15.4, 22.6 and 32.5% (db), respectively. The studies were carried out at the above moisture levels.

Rupture force: The rupture force of the seeds and kernels at the three major directions are presented in Fig. 5. The rupture force of the seed increased logarithmically from 30.78 to 69.33 N for vertical and quadratically from 43.98 to 20.0 N for horizontal as moisture content increased from 8.0 to 32.5% (db). The force required to fracture the seed at vertical direction was significantly higher than horizontal position ($p \leq 0.05$) at all experimental moisture levels except at 8.0% moisture level. This may be attributed to the force applied on the hilum portion of seed in vertical direction leading to easy fracture of the seed. Thus soursop seeds required higher force to fracture at vertical direction than horizontal. Similar results were reported by Ahmadi *et al*. (2012) for fennel seed and Niveditha *et al*. (2013) for seeds and kernels of *canavalia*. Moreover, at the kernel resting position, rupture force increased linearly from 576.8 to 787.7 N. The higher value of rupture force for kernel than seed may be due to its hard texture and loading direction.

Similar results were found by Hosain (2012) for sesame seeds as it was not reported for different directions of load.

The relationship between the sample rupture forces with moisture contents at vertical, horizontal and kernel resting position was significantly correlated ($p \leq 0.05$) and can be expressed using the following equations:

$$R_f = 2.894\ln(mc) - 13.816 \quad R^2 = 0.839 \qquad (3)$$

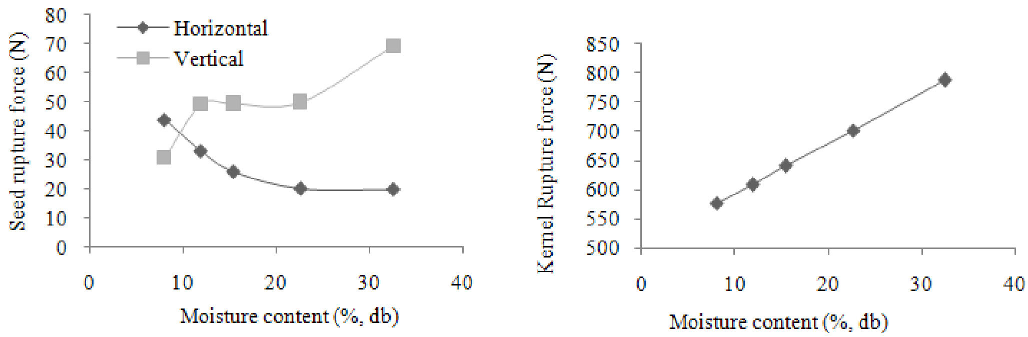

Fig. 5: Effect of moisture content on rupture force of soursop seed and kernel

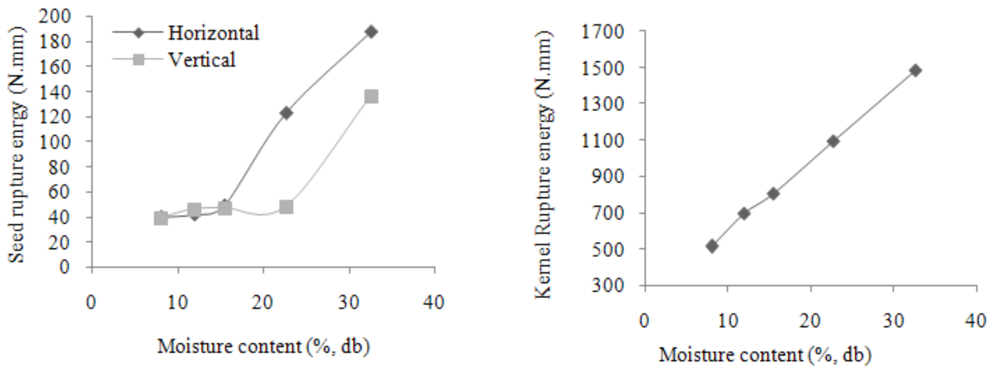

Fig. 6: Effect of moisture content on rupture energy and seed of soursop seed and kernel

$$R_f = 0.078mc^2 - 3.884mc + 69.698 \; R^2 = 0.992 \quad (4)$$

$$R_f = 1.274mc + 26.741 \; R^2 = 0.998 \quad (5)$$

where, R_f is the rupture force (N) and *mc* is the moisture content (%, db).

Dehulling and oil-extraction efficiency is a subject of rupture force and moisture content (Karaj and Muller, 2010). Therefore, for the design of dehuller and oil expeller, the values of the rupture force for seeds and kernels will be needed for the design of dehuller and oil-expeller chamber and in determination of pulley size so as to determine the required speed that will supply the force needed to dehulled the seed and to extract oil from the kernel, at a particular moisture content. Table 1 shows the mean values of mechanical properties of seed and kernel analysed by Duncan multiple range tests ($p \leq 0.05$).

Rupture energy: Energy for rupture of seeds and kernels is shown in Fig. 6. Energy for rupture was generally higher for kernels than for seeds and increased linearly for kernels from 512.3 to 1488.6 N.mm and quadratically for seed both at vertical and horizontal directions from 38.97 to 135.97 N.mm and from 39.97 to 187.97 N.mm, respectively as moisture content increased. Similar results were reported by Karaj and Muller (2010) for *jatropha*. Higher energy for rupture was needed for soursop seeds for horizontal direction than vertical direction. In seed vertical, horizontal and kernel resting position, energy for rupture showed a strong significant ($p \leq 0.05$) correlation to moisture content. This indicates that dehulling efficiency depends on the orientation of the sample on the crushing bars and on the moisture content.

The relationship between rupture energy and moisture contents at seed vertical, horizontal and kernel resting position was significantly correlated ($p \leq 0.05$) and can be expressed using the following equations:

$$R_e = 0.267mc^2 - 7.298 + 87.63 \; R^2 = 0.953 \quad (6)$$

$$R_e = 0.135mc^2 - 1.046mc + 15.14 \; R^2 = 0.969 \quad (7)$$

$$R_e = 1.274mc + 26.741 \; R^2 = 0.998 \quad (8)$$

where,
R_e = The rupture energy (N.mm)
mc = The moisture content (%, db)

Bioyield force and energy: The seed bio-yield force for both vertical and horizontal directions decreased linearly from 27.13 to 20.26 N and 41.5 to 22.3 N, respectively while the kernel bio-yield force increased with increase in moisture content from 144.9 to 1751.7 N as moisture content increased from 8.0 to 32.5% (db)

Table 1: Mechanical properties of soursop seed and kernel analysed by Duncan multiple range tests ($p \leq 0.05$)

Moisture content (%. db) Loading direction	8	11.9	15.4	22.6	32.5
Horizontal direction for the seed					
Rupture force (N)	43.98 ± 0.01^{e}	33.23 ± 0.01^{d}	26.07 ± 0.1^{c}	20.27 ± 0.1^{b}	19.97 ± 0.1^{a}
Rupture energy (N.mm)	39.97 ± 0.1^{a}	41.97 ± 0.1^{a}	48.97 ± 0.1^{c}	122.93 ± 0.1^{d}	187.97 ± 0.1^{e}
Bio-yield force (N)	41.47 ± 0.1^{e}	36.67 ± 0.1^{d}	32.37 ± 0.1^{c}	25.4 ± 0.00^{b}	22.23 ± 0.00^{a}
Bio-yield energy (N.mm)	6.73 ± 0.01^{e}	5.57 ± 0.1^{d}	4.57 ± 0.1^{c}	3.77 ± 0.1^{b}	1.77 ± 0.1^{a}
Deformation (mm)	1.89 ± 0.01^{a}	2.74 ± 0.01^{ab}	2.75 ± 0.01^{bc}	2.76 ± 0.01^{c}	3.58 ± 0.01^{d}
Hardness (N/mm)	23.27 ± 1.6^{e}	12.13 ± 0.73^{d}	9.49 ± 0.56^{c}	7.36 ± 1.51^{b}	5.59 ± 1.43^{a}
Vertical direction for the seed					
Rupture force (N)	30.78 ± 0.01^{a}	49.26 ± 0.01^{b}	49.53 ± 0.01^{c}	49.93 ± 0.1^{d}	69.33 ± 0.01^{e}
Rupture energy (N.mm)	38.97 ± 0.1^{a}	45.97 ± 0.1^{b}	46.87 ± 0.1^{c}	$47.93\pm0.^{d}$	135.97 ± 0.1^{e}
Bio-yield force (N)	27.13 ± 0.01^{e}	26.23 ± 0.01^{d}	25.42 ± 0.01^{c}	23.75 ± 0.01^{b}	20.26 ± 0.01^{a}
Bio-yield energy (N.mm)	3.79 ± 0.1^{a}	5.17 ± 0.1^{b}	6.27 ± 0.1^{c}	8.67 ± 0.1^{d}	12 ± 0.00^{e}
Deformation (mm)	1.05 ± 0.01^{a}	1.38 ± 0.01^{b}	1.39 ± 0.01^{bc}	1.40 ± 0.01^{c}	2.19 ± 0.01^{d}
Hardness (N/mm)	29.31 ± 1.33^{a}	35.44 ± 1.7^{b}	35.89 ± 1.73^{c}	35.71 ± 1.5^{d}	31.66 ± 1.31^{e}
Resting position for kernel					
Rupture force (N)	576.77 ± 0.1^{a}	608.17 ± 0.1^{b}	640.5 ± 0.1^{c}	702.5 ± 0.1^{d}	787.67 ± 0.1^{e}
Rupture energy (N.mm)	512.3 ± 0.6^{a}	698.7 ± 0.6^{b}	807 ± 0.0^{c}	1093.7 ± 0.6^{d}	1488.6 ± 0.6^{e}
Bio-yield force (N)	144.9 ± 0.1^{a}	549.7 ± 0.1^{b}	630.2 ± 0.1^{c}	1102.4 ± 0.1^{d}	1751.7 ± 0.1^{e}
Bio-yield energy (N.mm)	41.33 ± 0.6^{a}	82.67 ± 0.6^{b}	121.67 ± 0.6^{c}	201.4 ± 0.6^{d}	245.67 ± 0.6^{e}
Deformation (mm)	2.16 ± 0.01^{a}	2.39 ± 0.01^{b}	2.84 ± 0.01^{c}	3.47 ± 0.01^{d}	4.42 ± 0.01^{d}
Hardness (N/mm	267.04 ± 1.73^{e}	254.48 ± 0.93^{d}	225.53 ± 1.2^{c}	200.71 ± 1.4^{b}	178.2 ± 1.6^{a}

a, b, c, d, e: Means superscript with different letters in the same row differ significantly

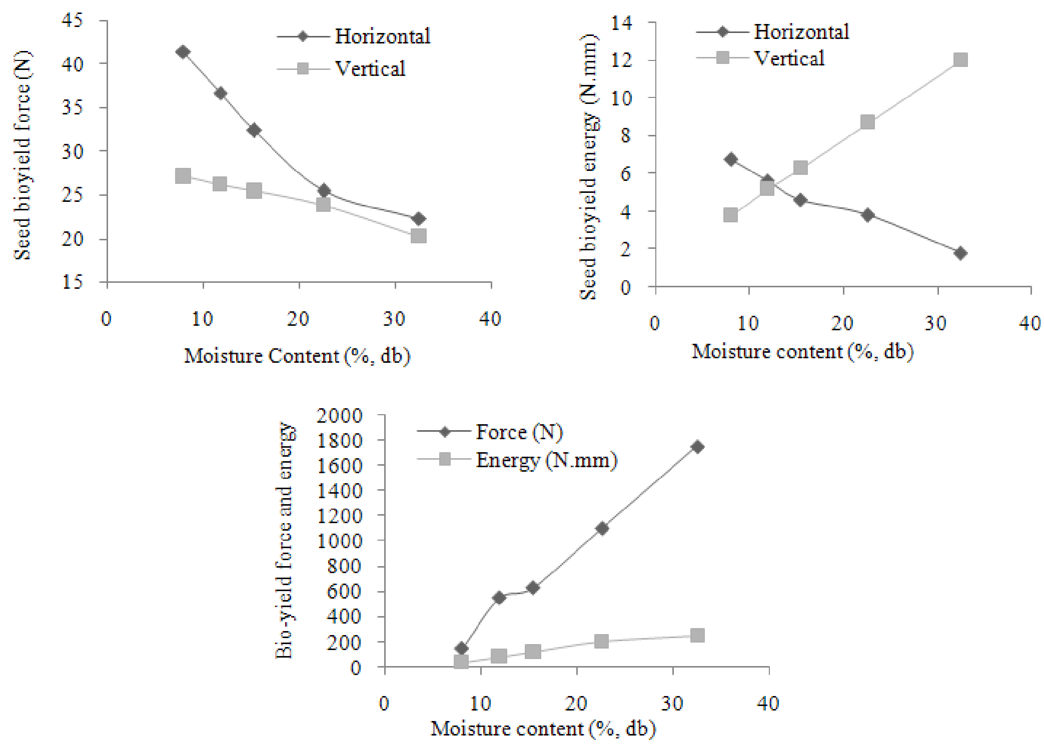

Fig. 7: Effect of moisture content on bioyield force and energy of soursop seed and kernel

(Fig. 7). Similar findings were reported by Adigun and Alonge (2000) for bioyield force of pods of proposis Africana but were not reported for different directions of load which is essential for machine design. Kernels have higher bioyield force in corresponding to its rupture force than seed at its two major loading directions. This implies that the design bioyield force required for efficient oil-expelling at the kernel oil point (bioyield point) along with its rupture force should be greater than experimental data when designing soursop seed oil-expeller.

Moreover, at seed vertical, horizontal and kernel resting position, seed bioyield energy decreased linearly for horizontal from 6.73 to 1.8 N.mm and increased linearly for vertical and kernel resting position from 3.8 to 12.0 N.mm and from 41.0 to 246.0 N.mm, respectively. The relationship between bioyield force and energy and moisture contents at seed vertical,

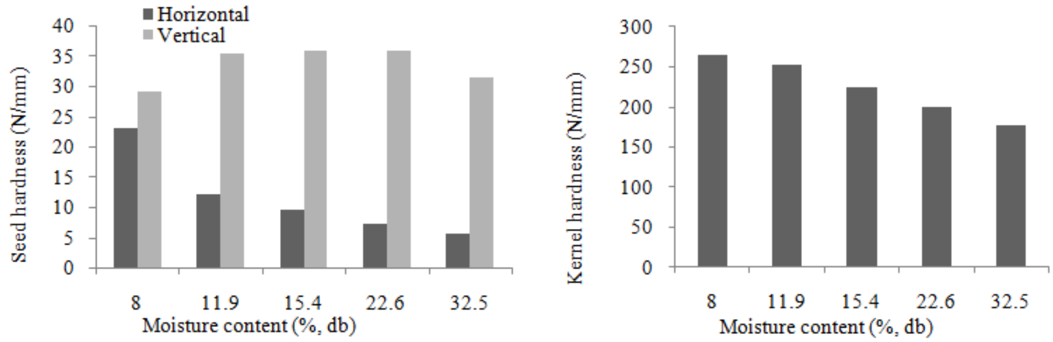

Fig. 8: Effect of moisture content on hardness of soursop seed and kernel

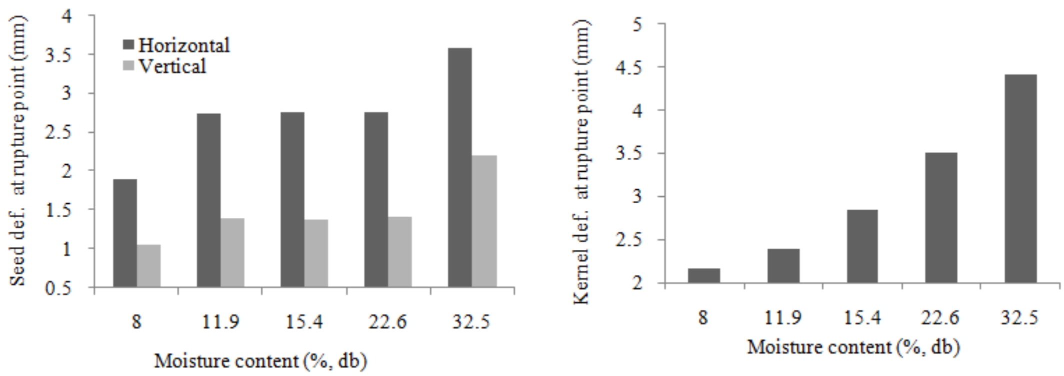

Fig. 9: Effect of moisture content on deformation at rupture point of soursop seed and kernel

horizontal and kernel resting position was significantly correlated (p≤0.05) and can be expressed using the following equations:

$$B_f = 0.278mc + 27.577 \qquad R^2 = 0.988 \tag{9}$$

$$B_e = 0.388mc + 1.177\ R^2 = 0.999 \tag{10}$$

$$B_f = -0.788mc + 45.898\ R^2 = 0.933 \tag{11}$$

$$B_e = -0.191mc + 7.956\ R^2 = 0.978 \tag{12}$$

$$B_f = 63.13mc - 305.61\ R^2 = 0.998 \tag{13}$$

$$B_e = 8.545mc + 15.685\ R^2 = 0.963 \tag{14}$$

where,

B_f and B_e = The bio-yield force (N) and energy (N.mm)
mc = The moisture content (%, db)

Effect of moisture content on hardness: The effect of moisture content on hardness of the kerneland seed in horizontal and vertical directions is depicted in Fig. 8. The hardness of seed in horizontal and at kernel resting position decreased linearly with moisture content from 23.27 to 5.59 N/mm and 267.04 to 178.21 N/mm, respectively. However, hardness of seed in vertical direction increased quadratically from 29.31 to 31.66 N/mm with increasing moisture content. Moreover, the hardness of the seed in vertical direction was higher than horizontal direction at all experimental moisture levels while the hardness of kernel was generally higher than that of the seed. This can be as a result of the hard texture of the kernel and loading position in contrast to seed directions of loads. Similar results were found by Sirisomboon *et al.* (2007) for jatropha fruits nuts and kernels, but they were not reported for different directions of load which is essential information for machine design. Also, Karaj and Muller (2010) reported similar results for jatrophacurcas seed and kernel sample with unit mass.

Thus, data on the seed and kernel hardness is useful in the selection of dehulling and expelling mechanisms when designing soursop seed dehuller and oil-expeller. The relationship between sample Hardness (*H*) and moisture content (*mc*) at the seed horizontal, vertical and kernel resting position was significantly correlated (p≤0.05) and can be expressed using the following equations:

$$H = -4.013mc + 23.607\ R^2 = 0.826 \tag{15}$$

$$H = -1.499mc^2 + 9.943mc + 21.61\ R^2 = 0.963 \tag{16}$$

$$H = -23.143mc + 294.6\ R^2 = 0.989 \tag{17}$$

Deformation at rupture point: The deformation at rupture point for both seeds and kernelsare presented in Fig. 9. The seed deformation in horizontal direction increased slowly from 1.89 to 3.58 mm, from 1.05 to 2.19 mm in the vertical position of the seed and from 2.19 to 4.42 at the kernel resting position. Deformation at rupture point of kernel showed generally higher value than seed. Thus, seed at the two directions of load needs lower compression to rupture than kernel. Moreover, the deformation at rupture point in horizontal direction of the seed was higher than deformation in the vertical direction except at lowest moisture level (8.0%); this showed that seed needs lower compression to rupture in vertical direction than horizontal. Similar results were also reported by Hojat *et al*. (2009) for fennel seed along the seed length and width sections and Fathohzadeh and Rajabipour (2008) for barbery but not reported for different loading direction. The higher values of deformation at higher moisture level may be due to the flexibility and viscoelastic property of the material under higher moisture content (Fathohzadeh and Rajabipour, 2008). The relationship between deformation at rupture point (D_{rpt}) and moisture content (*mc*) at the seed horizontal, vertical and kernel resting position was significantly correlated ($p \leq 0.05$) and can be expressed respectively using the following equations:

$$D_{rpt} = 0.0553mc + 1.745 \quad R^2 = 0.803 \tag{18}$$

$$D_{rpt} = 0.0401mc + 0.758 \quad R^2 = 0.845 \tag{19}$$

$$D_{rpt} = 0.563mc + 1.373 \quad R^2 = 0.946 \tag{20}$$

CONCLUSION

This study provided basic information on some mechanical properties of soursop seeds and kernels such as rupture force, rupture energy, bio-yield force, bio-yield energy, hardness and deformation at rupture point in relation to moisture contents and revealed the following conclusions:

- Rupture force and energy for seed in vertical and horizontal direction and at kernel resting position ranged from 30.78 to 69.33 N and 38.97 to 135.97 N.m, 43.98 to 20.0 N and 39.97 to 187.97 N.mm, 576.8 to 787.7 N and 512.3 to 1488.6 N.mm, respectively as moisture content increased from 8.0 to 32.5% (db).
- Bioyield force and energy for seed in vertical and horizontal directions and at kernel resting position ranged from 27.13 to 20.26 N and 6.73 to 1.8 N.mm, 41.5 to 22.3 N and 3.8 to 12.0 N.mm and 44.9 to 1751.7 N and 6.73 to 1.8 N.mm, respectively with increasing moisture contents.
- Hardness of seed at vertical and horizontal directions and kernel resting position ranged from 267.04 to 178.21 N/mm, 23.27 to 5.59 N/mm and 29.31 to 31.66 N/mm, respectively with increasing moisture contents.
- Deformation at rupture point in horizontal and vertical directions of seed and at kernel resting position with increasing moisture contents ranged from 1.89 to 3.58 mm, 1.05 to 2.19 mm and 2.19 to 4.42 mm, respectively.
- The study established that the engineering properties of soursop seeds and kernels depend on the moisture content ($p \leq 0.05$). Data obtained will be useful for engineers in the development of soursop seed dehuller, oil-expeller and other handling and processing machines.

Abbreviations:

mm	= Millimeters
N	= Newton
N.mm	= Newton millimeters
N/mm	= Newton per millimeters
R_f, N	= Rupture force
R_e, N.mm	= Rupture energy
B_f, N	= Bioyield force
D_f, mm	= Deformation at rupture point
H, N/mm^2	= Hardness
MC, %	= Moisture content
db	= Dry basis
W, kg	= Weight of sample
M_i, %	= Initial moisture content
M_f, %	= Final moisture content
Q, g	= Quantity of water

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