Available online at www.sciencedirect.com

SCIENCE DIRECT®

Journal of Food Engineering 76 (2006) 396–401

JOURNAL OF FOOD ENGINEERING

www.elsevier.com/locate/jfoodeng

Some engineering properties of yam setts from two species of yams

O.B. Aluko [a,*], O.A. Koya [b]

[a] Department of Agricultural Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria
[b] Department of Mechanical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria

Received 26 October 2004; accepted 21 May 2005
Available online 24 August 2005

Abstract

Yam production is still mainly carried out manually by peasant farmers using yam setts as planting material. Adequate knowledge of their engineering properties is an essential prerequisite for the scientific design and development of equipment for planting and handling yam setts mechanically. Some engineering properties of yam setts from two species of yams, namely white yam (*D. rotundata*) and yellow yam (*D. cayenensis*), were investigated at different moisture contents. The properties investigated include sett density, static coefficient of friction on plywood, galvanized steel and formica surfaces, force–deformation behaviour during quasi-static radial compression, stiffness moduli and sett toughness. The coefficient of friction of yam setts of both species on formica was considerably lower than the corresponding coefficients on wood and galvanized steel, respectively. The results further showed that a considerable reduction in the coefficient of friction was achieved (0.41–0.29 and 0.45–0.25 on formica, for *D. rotundata* and *D. cayenensis*, respectively) by air-drying freshly prepared setts at ambient room temperature for at least 4 days. Sett density over the drying period ranged between 1020 and 1180 $\mathrm{kg\,m^{-3}}$ for *D. rotundata* and between 1030 and 1140 $\mathrm{kg\,m^{-3}}$ for *D. cayenensis*. The stiffness moduli were 3.53 and 5.36 $\mathrm{kN\,m^{-1}}$ for freshly prepared yam setts of *D. rotundata* and *D. cayenensis*, respectively. However, sett stiffness generally decreased as sett moisture content decreased. The toughness of freshly prepared yam setts initially increased, attaining a maximum value within the first 4 days of air-drying, and subsequently decreased with further sett drying.

Keywords: Yam setts; Structural material surfaces; Friction coefficient; Stiffness; Mechanisation

1. Introduction

Tropical root crops such as cassava, yam, sweet potato and cocoyam are important staple foods throughout Africa. These root crops are more efficient producers of calories than any other food crop in the tropics (Otoo, Okoli, & Ilona, 2001). Indeed yams (*Dioscorea*), grown principally for the carbohydrate they provide, account for about 20 per cent of the daily caloric intake of Nigerians (Iwueke, Mbata, & Okereke, 1983). In addition to being a major staple food, yam is also known to have a longstanding socio-cultural significance in the lives of some communities (Degras, 1993; Hahn, Osiru, Akoroda, & Otoo, 1987).

The fact that the traditional methods of cultivating yams are arduous, labour intensive and time consuming is well attested to in the literature (Hahn et al., 1987; Nwuba & Kaul, 1987; Odigboh & Akubuo, 1991). In an attempt to alleviate the drudgery that characterises the traditional methods of yam cultivation, some efforts to mechanise some aspects of yam production have been reported. In particular, Odigboh and Akubuo (1989, 1991) have reported the development of mechanical planters for planting seed yams and minisetts, respectively. However, as pointed out by Aluko and Makanjuola (2002), compared to seed yams and minisetts, yam setts (normally obtained by cutting large whole tubers into head, middle and tail pieces) are

---

[*] Corresponding author. Tel.: +234 36230290; fax: +234 36232041.
E-mail address: elbeeluxe@yahoo.com (O.B. Aluko).

0260-8774/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfoodeng.2005.05.051

cheaper, more readily available, do not require any specialised pre-planting treatment and are more culturally accepted. Indeed, yam production in Nigeria is mainly carried out by peasant farmers who rely on a portion of their previous season's harvest, usually between 25% and 33% (Hahn et al., 1987), as the source of yam sett planting material for the following season. The development of a method and equipment, for mechanizing the planting of traditional yam setts would therefore be a major breakthrough in the mechanization of yam production.

The engineering properties of grains, seeds and other food and animal materials, such as density and friction coefficients on different structural surfaces, are needed by design engineers for the rational design of planting, handling and storage equipment for these materials (Mohsenin, 1986). Although several researchers have studied the engineering properties of different grains and seeds, including inter alia melon seeds (Makanjuola, 1972), soya bean (Deshpande, Bal, & Ojha, 1993), lentil seeds (Carman, 1996), sunflower seeds (Gupta & Das, 1997), millet (Jain & Bal, 1997) and locust bean seed (Ogunjimi, Aviara, & Aregbesola, 2002), very limited published data are available in the literature on the engineering properties of yam setts.

The objective of this study was therefore to investigate some engineering properties of yam setts of particular relevance to the design and development of equipment for planting and handling them.

2. Experimental methods

The two species selected for this study, namely white yam (*D. rotundata*) and yellow yam (*D. cayenensis*), are arguably the most popular amongst the food yams consumed in Nigeria. Head, middle and tail setts were derived from freshly harvested tubers of these two species, which were purchased from local farmers in the Oriade and Atakunmosa East Local Government Areas, respectively, of Osun State, Nigeria. Prior to sett preparation, the tubers were carefully cleaned manually to remove soil and foreign particles adhering to the outer corky periderm of each tuber.

Immediately after preparation, an identification mark was placed on each sett and its initial weight measured to 0.001 g using an electronic balance. The initial dimensions of each sett were also measured in three mutually perpendicular axes using a pair of vernier callipers. For each sett, the measured dimensions consisted of the length and two diameters of the transverse section. The mean of the two mutually perpendicular diametric measurements was recorded for each sett. To study the drying characteristics of yam setts, selected head, middle and tail setts were then subjected to progressive air-drying at ambient room temperature over a period of three weeks. In addition to their initial weights, the weight of each sett was recorded at drying intervals of 2 days spanning the entire period of three weeks.

Representative setts were selected and used to determine the density of yam setts at different moisture contents. To achieve this, each sett was weighed on an electronic balance and its volume subsequently determined using a water displacement method similar to that reported by Shepherd and Bhardwaj (1986) and Dutta et al. (1988). The setts used in the volume determinations were coated with a very thin layer of epoxy resin to prevent the absorption of water during the experiments. The increase in sett weight due to the adhesive was negligible (less than 2%). The static coefficient of friction of yam setts was determined on three structural surface materials, namely plywood, galvanized steel and formica, which are commonly used as materials of construction for crop planting and handling equipment. This was accomplished using the inclined plane method, earlier described by Zoerb (1967) and widely adopted in the literature (Ajav, 1998; Ogunjimi et al., 2002; Oje & Ugbor, 1991; Olajide & Ade-Omowaye, 1999).

The investigation into the resistance of yam setts to crushing was carried out using selected 5 cm-long cylindrical middle setts. Each sett was subjected to a quasi-static radial compression test during which the applied compressive load and the strain were monitored and recorded until rupture or bio-yield occurred. Several of these tests were carried out on setts at different moisture contents using a compression-testing machine at a constant loading rate of 4 $\text{mm}\,\text{min}^{-1}$. The force–deformation curves obtained were subsequently analysed to determine stiffness moduli and material toughness of yam setts at different moisture contents. For each sample, sett stiffness was determined as the slope of the apparent linear elastic portion of the force–deformation curve and sett toughness, the area under the curve.

In general, tests and measurements at different moisture contents were replicated thrice. All sett moisture contents in this investigation were determined gravimetrically. To achieve this, after concluding all other experimental measurements, the setts were oven dried at 105 °C for 48 h. The setts were subsequently allowed to cool in a dessicator after which the final weight of each sett was recorded.

3. Results and discussion

The drying characteristics of the yam setts are illustrated in Fig. 1(a) and (b). A general comparison of Fig. 1(a) and (b) shows that the freshly harvested tubers of *D. cayenensis* contained a higher proportion by weight of water than did the corresponding tubers of *D. rotundata*. In general, for both *D. rotundata* (Fig. 1(a)) and *D. cayenensis* (Fig. 1(b)) sett moisture

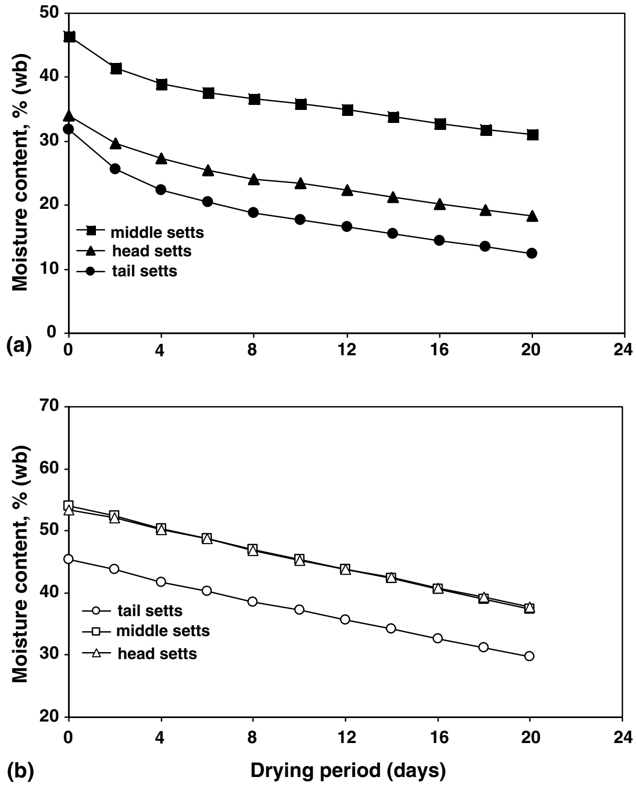

Fig. 1. Moisture content of yam setts plotted against the drying period. (a) *D. rotundata* setts; (b) *D. cayenensis* setts.

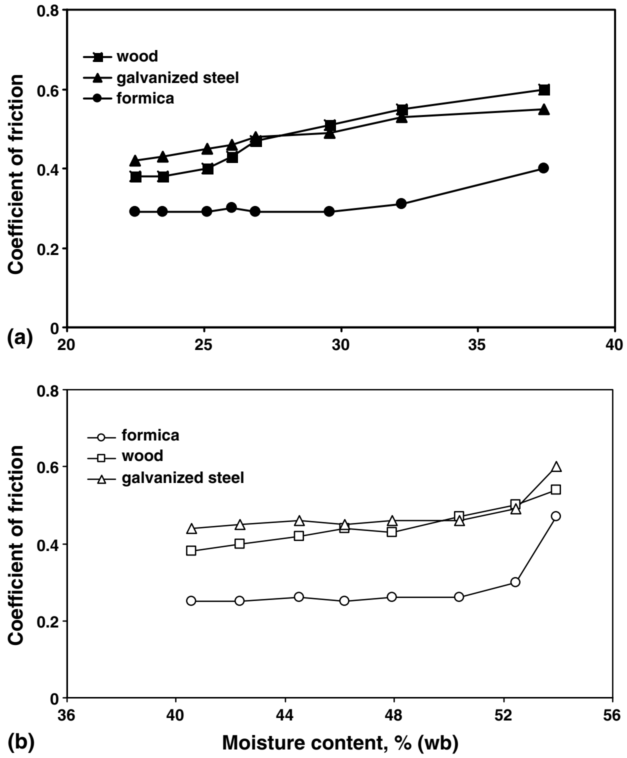

Fig. 2. Static coefficient of friction of yam setts on different structural surfaces plotted as a function of moisture content. (a) *D. rotundata* setts; (b) *D. cayenensis* setts.

content decreased as the period of drying increased. For *D. rotundata* setts, the first 4 days after sett preparation were characterised by a relatively rapid drying rate. As the period of drying extended beyond the first 4 days, the drying rate decreased and became more uniform over the latter 14 days. For *D. cayenensis* setts, however, the drying rate after sett preparation was uniform throughout the entire drying period (Fig. 1(b)). Fig. 1(a) and (b) show that the tail setts of both species had lower moisture contents than the corresponding head and middle setts. Although the middle setts of *D. rotundata* had higher moisture contents than the head setts, there was no difference in the moisture contents of the two for *D. cayenensis* setts.

The measured dimensions of yam setts used in this study were similar for both species. The length of the setts ranged from 50 to 125 mm while the mean diameter ranged from 48 to 106 mm. The static coefficient of friction of the yam setts on different structural surface materials is plotted as a function of sett moisture content in Fig. 2(a) and (b). In general, as drying proceeds initially, the coefficient of friction decreases. Subsequently, in the drier moisture range (26.0–22.5% wb for *D. rotundata* and 48.0–40.5% wb for *D. cayenensis*) the coefficient of friction assumes a more stable (residual) value. The coefficient of friction of yam setts of both species on formica was considerably lower than the corresponding coefficients on wood and galvanized steel, respectively. For *D. rotundata* setts (Fig. 2(a)), the residual value of the coefficient of friction was 0.42 on galvanized steel, 0.38 on wood and 0.29 on formica. Similarly, for *D. cayenensis* setts (Fig. 2(b)), the residual value of the coefficient of friction was 0.44 on galvanized steel, 0.38 on wood and 0.25 on formica. Although Ajav (1998) reported an average coefficient of friction of 0.60, it is difficult to make any meaningful comparison with the present results because the structural surface used was not specified. The present results, however, clearly indicate that the use of formica to line hopper side panels and other channels would constitute a significant advantage in the development of handling, metering and planting equipment for yam setts. Furthermore, in addition to reducing the moisture-dependent adhesion at the yam sett–structural material interface, the present results show that a considerable reduction in the coefficient of friction is achieved by air-drying freshly prepared yam setts for at least 4 days.

The cost implication of materials selected is an important design consideration in the development of handling, metering and planting equipment. Bruising of yam setts can lead to deterioration and poor yields (Onwueme, 1982). Therefore, in addition to enhancing sliding for metering and conveying purposes, reductions in the coefficient of friction during handling of yam setts is important to minimise the risk of bruising the setts.

Consideration of the cost implication of using formica, rather than using relatively cheaper structural surface materials, must therefore be based not only on the monetary value of the materials, but also on the relative cost of risking damage to the setts and incurring poor yields.

The variation of sett density with moisture content is illustrated in Fig. 3(a) and (b). In general, for both *D. rotundata* (Fig. 3(a)) and *D. cayenensis* (Fig. 3(b)), density increased as sett moisture content decreased. For a moisture content range of 37.4–25.1% (wb), the density of *D. rotundata* setts ranged between 1020 and 1180 kg m^{-3}. Similarly, over the moisture content range 54.0–39.0% (wb), the density of *D. cayenensis* setts ranged between 1030 and 1140 kg m^{-3}. These results are in agreement with the average density of 1096 kg m^{-3} reported by Ajav (1998) and constitute an important consideration for material selection, machine frame development and hopper capacity design for a mechanical yam sett planter.

The force–deformation curves for yam setts subjected to quasi-static radial compression at different moisture contents are shown in Fig. 4(a) and (b). The general nature of these curves is similar to that reported by Anazodo (1983) for a radially compressed corn cob. Each curve consists of an initial non-linear, non-elastic portion followed by an apparent linear elastic portion. The initial non-linear, non-elastic portion is a transient stage during which the spongy cortex of the tuber is compressed. This portion is less pronounced for *D. cayenensis* setts (Fig. 4(b)) indicating that *D. cayenensis* tubers generally have a thinner cortex than *D. rotundata* tubers. The apparent linear elastic portion of the force–deformation curves represents the primary resistance to deformation of the inner tuber tissue, following the flattening of the external spongy cortex. The upper limit of the linear elastic portion marks the onset of bio-yield or rupture (failure). The subsequent rise in the force–deformation curve observed in some cases after the onset of bio-yield can be attributed to a change from mechanical failure to sheer crushing of the test specimen.

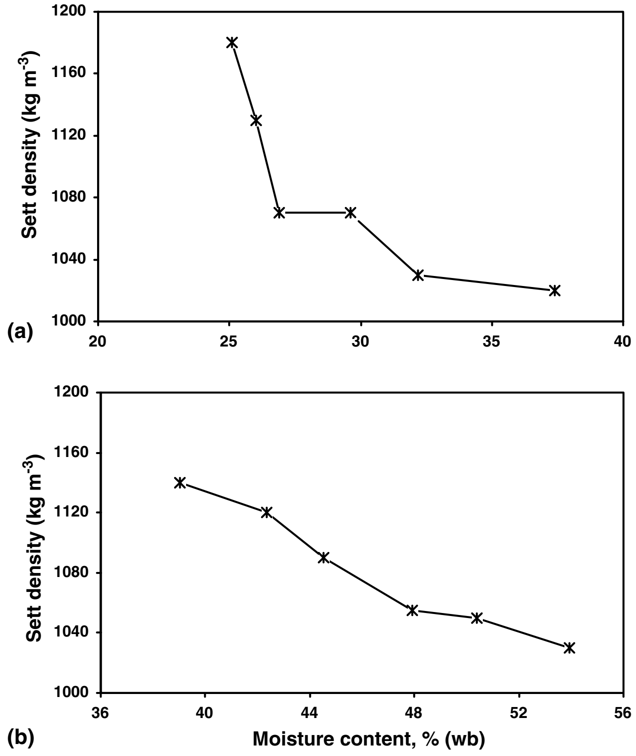

Fig. 3. Yam sett density plotted against sett moisture content. (a) *D. rotundata*; (b) *D. cayenensis*.

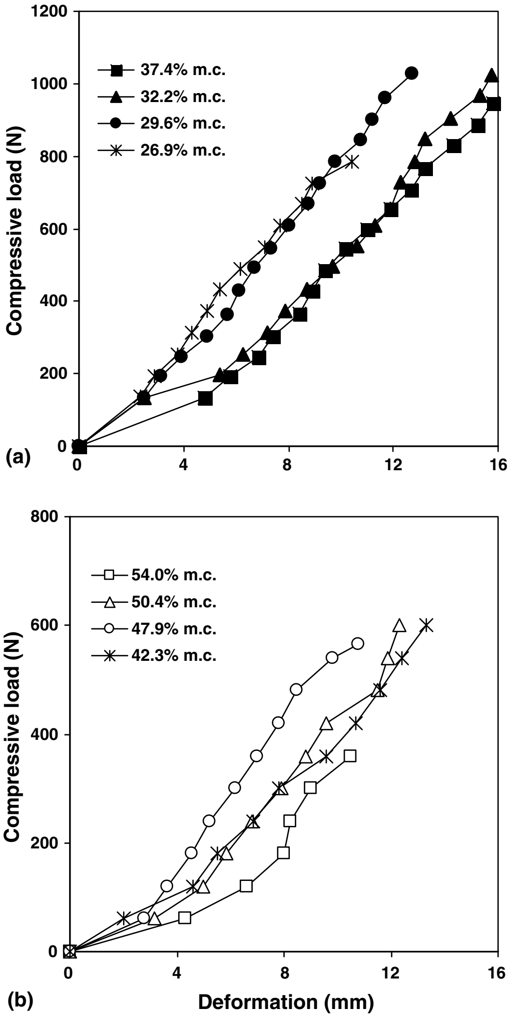

Fig. 4. Force–deformation curves for yam setts at different moisture contents. (a) *D. rotundata* setts; (b) *D. cayenensis* setts.

As pointed out earlier, further analyses of the force–deformation curves of Fig. 4(a) and (b) were carried out to determine the stiffness and material toughness of yam setts at different moisture contents. Values of stiffness and material toughness thus determined for the two species of yam setts are given in Table 1. In general, for both species, stiffness decreased as sett moisture content

Table 1
Some engineering properties of yam setts subjected to quasi-static radial compression

Properties	*D. rotundata*				*D. cayenensis*			
	% Moisture content (wb)				% Moisture content (wb)			
	37.4	32.2	29.6	26.9	54.0	50.4	47.9	42.3
Stiffness ($\mathrm{kN\,m^{-1}}$)	3.53	3.02	1.66	0.73	5.36	3.07	2.03	1.99
Toughness (J)	6.3	6.8	6.0	4.3	1.4	2.5	2.4	2.1

decreased. For a moisture content range of 37.4–26.9% (wb), the stiffness of *D. rotundata* setts ranged between 3.53 and 0.73 $\mathrm{kN\,m^{-1}}$. Similarly, over the moisture content range 54.0–42.3% (wb), the stiffness of *D. cayenensis* setts ranged between 5.36 and 1.99 $\mathrm{kN\,m^{-1}}$. For both species, the initial stages of drying of freshly prepared yam setts were characterised by an increase in sett toughness. After attaining a maximum value (6.8 J for *D. rotundata* and 2.5 J for *D. cayenensis*), toughness decreased with further sett drying.

Compared with the results of previous work on another agricultural product, the present results show that the stiffness moduli of *D. rotundata* and *D. cayenensis* yam setts are much lower than the range 92.8–94.0 $\mathrm{kN\,m^{-1}}$ reported for cocoa pods (Faborode, Dinrifo, & Ajayi, 2001). The stiffness moduli and sett toughness obtained in the present work provide important base-line data for future designs of hoppers and other yam sett planting and handling equipment.

4. Conclusions

The engineering properties of yam setts at different moisture contents were investigated using setts derived from two prominent species, *D. rotundata* and *D. cayenensis*. Freshly harvested tubers of *D. cayenensis* were found to contain a higher proportion by weight of water than corresponding tubers of *D. rotundata*. The static coefficient of friction of yam setts on plywood, galvanized steel and formica, commonly used as materials of construction for crop planting and handling equipment, was determined. The lowest values of the coefficient of friction for both *D. rotundata* and *D. cayenensis* were obtained on formica. For *D. rotundata* setts on formica, the coefficient of friction had a value of 0.4 for freshly prepared setts and a residual value of 0.29 after 4 days of air-drying at ambient room temperature. For *D. cayenensis* setts on formica, the coefficient of friction had a value of 0.47 for freshly prepared setts and a value of 0.26 after 4 days of air-drying at ambient room temperature.

The quasi-static radial compression of yam setts is characterised by two regimes of force–deformation behaviour prior to rupture or bio-yield: a non-linear, non-elastic transient stage during which the spongy cortex of the tuber is compressed and an apparent linear elastic portion representing the primary resistance to deformation of the inner tuber tissue. The stiffness moduli of yam setts were found to be considerably lower than the values earlier reported for cocoa pods. The toughness of freshly prepared yam setts initially increases, attaining a maximum value within the first 4 days of air-drying at ambient room temperature, and subsequently decreases with further sett drying. The properties determined in this study constitute important base-line data for the scientific design and development of hoppers, metering devices, delivery chutes and other components of yam sett planting and handling equipment.

References

Ajav, E. A. (1998). Engineering properties of yam setts as related to mechanization of yam planting. *Journal of Root Crops, 24*(2), 171–176.

Aluko, O. B., & Makanjuola, G. A. (2002). Preliminary studies of some agronomic and design factors relevant to the mechanization of yam sett planting on ridges. *Journal of Agricultural Engineering and Technology, 10*, 17–27.

Anazodo, U. G. N. (1983). Mechanical properties of the corn cob under quasi-static radial compression. *Transactions of the ASAE, 26*, 1222–1228.

Carman, K. (1996). Physical properties of lentil seeds. *Journal of Agricultural Engineering Research, 63*, 87–92.

Degras, L. (1993). *The yam. A tropical root crop*. London, Basingstoke: The Macmillan Press Ltd., 408pp.

Deshpande, S. D., Bal, S., & Ojha, T. P. (1993). Physical properties of soya bean. *Journal of Agricultural Engineering Research, 56*, 89–98.

Dutta, S. K., Nema, V. K., & Bhardwaj, R. K. (1988). Physical properties of gram. *Journal of Agricultural Engineering Research, 39*, 269–275.

Faborode, M. O., Dinrifo, R. R., & Ajayi, O. A. (2001). A proposed rheological model of the breaking of cocoa pods. *Ife Journal of Technology, 10*(2), 31–39.

Gupta, R. K., & Das, S. K. (1997). Physical properties of sunflower seeds. *Journal of Agricultural Engineering Research, 66*, 1–8.

Hahn, S. K., Osiru, D. S. O., Akoroda, M. O., & Otoo, J. A. (1987). Yam production and its future prospects. *Outlook on Agriculture, 16*(3), 105–110, Pergamon Journals Ltd., Great Britain.

Iwueke, C. C., Mbata, E. N., & Okereke, H. E. (1983). Rapid multiplication of seed yam by minisett technique. National Root Crops Research Institute, Umudike, Nigeria. Umudike Advisory Bulletin No. 9.

Jain, R. K., & Bal, S. (1997). Properties of pearl millet. *Journal of Agricultural Engineering Research, 66*, 85–91.

Makanjuola, G. A. (1972). A study of some of the physical properties of melon seeds. *Journal of Agricultural Engineering Research, 17*, 128–137.

Mohsenin, N. N. (1986). *Physical properties of plant and animal materials* (2nd ed. (revised)). New York: Gordon and Breach Science Publications.

Nwuba, E. I. U., & Kaul, R. N. (1987). Human energy requirement of typical Nigerian traditional tillage tools. *African Journal of Science and Technology (AJST), Series A, 6*(1), 20–28.

Odigboh, E. U., & Akubuo, C. O. (1989). A two-row automatic seed yam planter prototype. *Proceedings of the eleventh international congress on agricultural engineering*. Dublin, Ireland.

Odigboh, E. U., & Akubuo, C. O. (1991). A two-row automatic minisett yam planter. *Journal of Agricultural Engineering Research, 50*, 189–196.

Ogunjimi, L. A. O., Aviara, N. A., & Aregbesola, O. A. (2002). Some engineering properties of locust bean seed. *Journal of Food Engineering, 55*, 95–99.

Oje, K., & Ugbor, E. C. (1991). Some physical properties of oil bean seed. *Journal of Agricultural Engineering Research, 50*, 305–313.

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

Onwueme, I. C. (1982). *The Tropical Tuber Crops: Yams, Cassava, Sweet Potato and Cocoyams*. Chichester, New York, Brisbane, Toronto: John Wiley and Sons.

Otoo, J. A., Okoli, O. O., & Ilona, P. (2001). *Improved production of seed yam*. *IITA Research Guide* (63). Nigeria: IITA Ibadan, pp. 1–21.

Shepherd, H., & Bhardwaj, R. K. (1986). Moisture dependent physical properties of pigeon pea. *Journal of Agricultural Engineering Research, 35*, 227–234.

Zoerb, G. C. (1967). Instrumentation and measurement techniques for determining physical properties of farm products. *Transactions of the ASAE, 10*, 100–109.