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PHYSICAL PROPERTIES OF TWO VARIETIES OF SWEET POTATO GROWN IN COASTAL SAVANNAH ZONE OF GHANA

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ABSTRACT
The physical properties of sweetpotatoes and other fruits and vegetables are necessary for the design of equipment to handle, transport, market, process, and store the crop. The physical properties of two sweetpotato varieties (TIS 2 and Ukerewe) of moisture content 68% and 60% (wb) respectively were determined. In these moisture contents, the intermediate (width), minor (thickness), and geometric mean diameter were higher in TIS 2 than Ukerewe from, 5.7±1.3, 4.9±1.1, 6.84±1.12, cm to, 3.9±0.9, 3.5±0.9, and 5.45±1.10 cm respectively. However, the major diameter (length) was higher in Ukerewe from 12.3±2.8 to 11.6±2.2 cm. The roots surface area, volume, and mass were also higher in TIS 2 than in Ukerewe from 159.9±59.4 cm^2, 161.01±74.7 cm^3, 177.6±81.5g to 103.2±42.6 cm^2, 92. 78 cm^3, and 99.5±62.8 g respectively; the sphericity was higher in Ukerewe than in TIS 2 from 0.80±0.06 to 0.62±0.02; true and bulk densities were also higher in TIS 2 than in Ukerewe from 1.1145±0.111 to 1.0935±0.118 g/cm^3 and from 0.595 to 0.578 g/cm^3; the 500-root weight was higher in TIS 2 from 111±1.58 to 73±3.91kg than in Ukerewe; the porosity was higher in Ukerewe from 47.4±3.0% to 46.2±3.5% than in TIS 2; the angle of repose was also higher in TIS 2 than Ukerewe from 38^o to 37^o. The coefficients of static friction were higher for TIS 2 than Ukerewe from 0.70 to 0.67, 0.62 to 0.51, 0.70 to 0.67, and 0.58 to 0.51 for nylon, polyethene, cardboard, and plywood structural surfaces respectively.

KEYWORDS: sweetpotato; TIS 2; Ukerewe; physical properties; sphericity; porosity; angle of repose; coefficient of static friction

INTRODUCTION

Sweet potato (Ipomoea batatas (L) Lam) is a native of tropical America, which belongs to the family Convolvulaceae. It is sometimes classified as a vegetable (McClure & Morrow, 1987) and at other times considered to be a root. It is currently seen as a very important crop and is likely to increase its importance over the next 20 years (Scott et al 2000). The crop is cultivated throughout tropical, subtropical and is ranked seventh among the most important food crops worldwide (Scott, 1992). In Africa, sweet potato has recently gained importance because of its potential of alleviating poverty, reducing night blindness, and improving the diet of the rural poor. In terms of area under cultivation, Nigeria is the leading producer in Africa followed by Uganda (FAO, 2004), although majority come from Southern and Eastern Africa (Root, 1994). Sweet potato yields recorded in Africa is between 41-21 tons per hectare in 140 days without fertilizer (IITA, 1988) while unimproved varieties average only 14 tons per hectare when harvested in 180-240 days after planting. In Ghana, sweet potato is grown by peasant and small-holder farmers scattered in Upper East and Central regions. These two regions in Ghana produce about 93603 metric tons (SRID, 2007).Yields of sweet potato recorded in Ghana at the subsistence level are quite low compared with the IITA varietal studies. Studies conducted to evaluate 19 sweet potato varieties for yield at Ohawu by Missah et. al., (1991) revealed that an average yield of between 6-16 t/ha were recorded for improved varieties and 3.2- 10.8 t/ha for local varieties. Furthermore, at University of Cape Coast, Tsegah (1987) obtained yield of 2 to 10 t/ha for an improved variety. However there has been an improvement in yields due to the release of improved varieties and good agronomic practices.

The physical properties of sweet potato, like those of other agricultural materials such as fruits and vegetables are essential for the design of equipment for handling, harvesting, and storing the tubers or determining the behavior of the tubers for its handling. Various types of cleaning, grading and separation equipment are designed on the basis of the physical properties of the agricultural materials. Physical properties affect the converting characteristics of solid materials by air or water and cooling and heating load of food products (Sahay and Singh, 1994). It is therefore necessary to determine these properties. The properties of different types of grains, seeds, fruits and vegetables have been determined by other researchers such as (Baryeh, 2001; Bart-Plange & Baryeh, 2005; Sharma, Dubey and Teckchandani, 1985; Sreenarayanan,;; Dutta, Nema & Bhardwaj, 1988; Joshi, Das, & Mukherji, 1993; Deshpande et al, 1993; Suthar & Das, 1996; Gupta & Das, 1997, 1998; Jain & Bal, 1997; Aviara,; McClure & Morrow, 1987). The physical properties of TIS 2 and Ukerewe varieties of sweet potato are however unknown. This study therefore, presents the results of the determination of some physical properties of two varieties of sweetpotato useful in the design of harvesting and handling equipment.

Theoretical Background

According to Moshenin (1970), the degree of sphericity, *ø*, can be expressed as follows:

$$\emptyset = \frac{(abc)^{0.333}}{a}, \quad (1)$$

Where a, b, and c are the root major (length), intermediate (width), and minor (thickness) diameters.
The geometric mean diameter, Dg is given by Sreenarayanan et al (1985) and Sharma et al (1985) as

$$D_g = (abc)^{0.333}, \quad (2)$$

Jain and Bal (1997) have also stated that sphericity, $\emptyset$, root volume V, and root surface area, S, for a cono-spherically shaped root may be given by

$$\emptyset = [\frac{B(2a-B)}{a^2}]^{0.333} \quad (3)$$

$$V = \frac{\pi a^2 B^2}{6(2a-B)} \quad (4)$$

$$S = \frac{\pi a^2 B}{2a \quad D} \quad (5)$$

Where, $B = (bc)^{0.5}$

The root surface area S was also found by (Phillips,1944; Moustafa, 1971; Rees et al, 2003), assuming the root shape to be a prolate spheroids to be given by

$$S = 2\pi b^2 + \frac{2\pi ab}{e} \text{Sin}^{-1}(e), \quad \text{where}$$

$$e = [1 - (\frac{b}{a})^2]^{0.5}, \quad (6)$$

The corresponding volume V is also given by

$$V = \frac{4\pi}{3} ab^2, \quad (7)$$

Diehl *et al* (1988) and Wilhelm *et. al*., (2004), have also stated that volume of particulate solids, V_s for irregular shaped fruits and vegetable can be found experimentally by

$$V_s = \frac{W_{bws} - W_{bw}}{\rho_w}, \quad (8)$$

Where, $W_{bws}$is the weight when the solid is completely submerged in water; W_{bw} is the weight of beaker and water; and ρ_w is the density of water.

According to Mohsenin (1970) and Thompson and Isaacs (1967), the porosity, ε is given by

$$\varepsilon - \left[\frac{\rho_p - \rho_b}{\rho_p}\right] 100, \quad (9)$$

Where ρ_b is the bulk density; ρ_p is particle density.

MATERIALS AND METHODS

Two varieties of Sweet potato roots (TIS 2 and Ukerewe), which were grown on the same soil and harvested 4 months after planting, were obtained from the School of Agriculture, University of Cape Coast research farm. The average moisture content at harvest was found to be 68% (wb) for TIS 2 and 60% (wb) for the Ukerewe varieties.
100 tubers were selected at random after harvest and the major (length), intermediate (width), and minor (thickness) diameters were measured in three mutually perpendicular directions using a venier caliper to a 0.01 mm accuracy. Several researchers (Edison & Boron, 1971; Mohsenin,1987; Tennes et al., 1969; McClure & Morrow,1987) have measured these dimensions for other fruits and vegetables in a similar manner to determine size and shape properties. The sphericity was calculated using equations (1) and (3), the volume using equations (4), (7) and (8), and the surface area using equations (5) and (6). Root mass was measured with a sensitive electronic balance of 0.001g sensitivity. The corresponding volume of the roots were measured using the platform scale method described by (Diehl,et al,1988; Wilhelm et. al., 2004) using equation (8) and similarity to geometric solids using equations (4) and (7). The particulate density was calculated from the ratio of the root mass to the corresponding volume.
After the determination of the dimensions and mass, all other measurements which followed were replicated five times at the moisture content considered, and the averages were calculated. The bulk density was determined by the method described by (Sharma et al, 1985; Deshpande, et al, 1993; Suthar & Das, 1996; Bart-Plange et al, 2005). The porosity was then calculated using equation (9).
To determine the dynamic angle of repose, a plywood measuring 100 cm in diameter was used and the tubers were allowed to fall from a height of 15 cm to form a natural heap. The angle of repose is taken to be the arctangent of the ratio of height of the conical heap to the diameter of the cone. This method has been used by other investigators (Joshi et. al., 1993; Kaleemullah and Gunasekar, 2002; Sailik et. al., 2003 and Karababa, 2006)
500-root weight was also determined using a spring balance of 0.01kg sensitivity. 500 roots were selected at random and weighed. This was done because in Ghana, sweet potatoes are usually handled, transported and marketed in nylon sacks of nearly 500 roots capacity or weight. Other researchers have used similar method for other grains, seeds, fruits, and vegetables (Bart-Plange et al, 2005; Baryeh, 2001).
The coefficient of static friction was determined with respect to four structural surfaces: nylon, cardboard, polyethene, and plywood. These are common materials used for the design of equipment for handling and processing of sweet potato tubers and the construction of storage structures. To measure the coefficient of static friction, a hollow cuboid made of cardboard with dimensions 33 cm by 20 cm by 13 cm and open at both ends was filled with the roots and placed on an adjustable tilting device such that the cardboard did not touch the table surface. The tilting device was raised gradually by means of a screw device until the cuboid started to slide down. The angle of the surface was read from a protractor fitted to the device and the static coefficient of friction was taken as the tangent of the angle. Other researchers have used this method for other grains, seeds, fruits and vegetables (Joshi et al, 1993; McClure & Morrow, 1987; Nimkar et al., 2005; Bart-Plange et al., 2005; Pradhan et al., 2009).

RESULT AND DISCUSSION

Linear dimensions

The mean and standard deviation of the major, intermediate, and minor diameters of TIS 2 and Ukerewe were calculated as: 11.6±2.2, 5.7±1.3, 4.9±1.1 cm and 12.3±2.8, 3.9±0.9, 3.5±0.9 cm at the 68% and 60% moisture contents respectively. The mean major diameters of the TIS 2 and Ukerewe varieties were slightly higher whereas the intermediate and minor diameters were lower than what McClure & Morrow (1987) recorded (i.e 7.0, 6.2, and 5.3 cm) in the Norchip potato variety. At these moisture contents, the intermediate (width), minor (thickness), and geometric mean diameter were higher in TIS 2 than Ukerewe. However, the major diameter (length) was higher in Ukerewe than TIS 2. Very low correlation was observed between these dimensions and root moisture content. The L/W, L/T, and L/D_g ratios are 2.1±0.52, 2.47±0.61, 1.7±0.28 and 3.26±0.85, 3.72±1.04, 2.29±0.41 for TIS 2 and Ukerewe respectively. L/T exhibits the highest ratio in TIS 2, followed by L/W and L/Dg. This means that the values of Dg are generally the highest, followed by W and T in TIS 2. Baryeh (2001) reported a similar trend in Bambara groundnut. However, L/W exhibits the highest ratio in Ukerewe, followed by L/T, and L/Dg indicating that Dg is generally the highest, followed by T and W in Ukerewe. The ratios are all higher than those reported for bambara groundnut by Baryeh (2001).

Sphericity

The sphericity, $\emptyset$, given by equation (3) gives higher values compared to the one by equation (1). TIS 2 recorded 0.62±0.02 by equation (3) and 0.60±0.099 by equation (1) whereas Ukerewe recorded 0.80±0.06 and 0.45±0.09 respectively. This is due to the shape assumption for the two equations. The cono-spherical shape assumed in equation (3) is closer to the shape of the sweetpotato varieties used in this study compared to the elliptical shape assumed in equation (1). The sphericity ranges from 0.62 at 68% moisture content for TIS 2 to 0.80 at 60% moisture content in Ukerewe using equation (3). This indicates that the assumption of the shape of the root to be a cono-spherical is on the average 62% explained in TSI2 and 80% in Ukerewe. The sphericity decreased from root moisture content of 68% in TIS 2 to 60% in Ukerewe. Deshpande et al (1993) however recorded increase in sphericity of soybean with grain moisture content. This means that a separation machine with circular holes will easily let root through its holes. During unloading, the roots will roll away far from intended unloading spot.

Surface area

The root surface area given by equation (5) displays lower values compared to the one by equation (6). TIS 2 displayed average surface area of 99.8±58.5 cm^2 and 159.9±59.4 cm^2 by equations (5) and (6) whereas Ukerewe displayed 21.6±8.8 cm^2 and 103.2±42.6 cm^2. The differences in areas by the two equations are again due to the different root shapes assumed for the equations. There is however an increase in surface area from TIS 2 with moisture content of 68% to Ukerewe with moisture content of 60%. Generally, the surface areas of the TIS 2 sweetpotato variety are higher than those of Ukerewe.

Volume

The root volume, V given by equations (4), (7) and (8) for TIS 2 and Ukerewe are 97.94, 214.38, 161.01 and 7.20, 109.69, 92.78 cm^3 respectively. The experimental volume as given by equation (8) was taken to be the standard volume of the roots. Root volumes given by equation (4) are generally lower than the experimental volume whereas volumes given by equation (7) are higher than the experimental volumes. This might be attributable to the different shapes assumed by the two equations. In the TIS 2, the assumed volume by equation (4) was lower by 39% but it was 92% lower in Ukerewe. Similarly, the assumed volume by equation (7) was 33% higher in TIS 2 but only 18% in Ukerewe. This means that the volume of a prolate spheroid is closer to the assumed volume of Ukerewe whereas the cono-spheroid is closer to the TIS 2 sweetpotato varieties. Average volumes of 161.01 and 92.78 cm^3 could be used for storage and packaging designs of TIS 2 and Ukerewe with 0.33 and 0.18 design safety factors respectively.

Mass

The average and standard deviation of the individual root mass of the TIS 2 and the Ukerewe sweet potato varieties are 177.6±81.5 and 99.5±62.8 g respectively. A frequency distribution analysis using SPSS showed that 38% of the TIS 2 are between 200 and 364g at 68% moisture content whilst only 10% of the Ukerewe are between 200 and 342g at 60% moisture content. Besides, 20% of the TIS 2 are between 44.6 and 100 g whilst 42% are between 100 and 200g. The Ukerewe had 65% of the root mass between 29.5 and 100g whilst 25% were between 100 and 200g. The individual root masses are generally higher in TIS 2 than the Ukerewe. This was not surprising since the TIS 2 had higher moisture content than those of Ukerewe. These differences might be attributable to the different cell arrangements and the fact that moisture affects weight. Bart-Plange & Baryeh (2003) reported that the higher the moisture content the higher the cocoa bean mass.

500-root weight

The 500-root weight for the TIS 2 and Ukerewe are 111±1.58 and 73±3.91kg respectively. On the average, the 500-tuber weight of the TIS 2 variety was heavier than the Ukerewe variety at 68% and 60% moisture content respectively. This was again not surprising since the TIS 2 had higher moisture content than the Ukerewe. These differences might be attributable to the different cell arrangements and the fact that moisture affects weight. Bart-Plange & Baryeh (2003) reported that the higher the moisture content the higher the cocoa bean mass.

Root and Bulk densities

The root densities for TIS 2 and Ukerewe are 1.1145±0.111 and 1.0935±0.118 g/cm^3at 68% and 60% moisture content respectively. The corresponding bulk densities are 595 and 578 kg/m^3. The particle and bulk densities recorded indicated that the TIS 2 sweetpotatoes are denser than the Ukerewe. The bulk density values recorded agree with bulk density of apple (577 kg/m^3). The densities increased as the moisture content increased from 60% in Ukerewe to 68% in TIS 2. The bulk density of bambara groundnut (Baryeh, 2001), coffee (Chandrasekar & Viswanathan, 1999, pumpkin seeds (Joshi et al., 1993), and karinga seeds(Suthar & Das, 1996) increase as moisture content increases, while that of sunflower seeds (Gupta & Das, 1997),cumin seeds (Singh & Goswami, 1996), and soybeans (Deshpande et al ,1993) decrease as moisture content increases. These discrepancies could be due to the cell structure and the volume and mass increase characteristics of different roots, grains, and seeds as moisture content increases.

Porosity

The average porosities and standard deviations of TSI 2 and Ukerewe sweet potato varieties are 46.2±3.5% and 47.4±3.0% respectively. The porosity of Ukerewe is slightly higher than that of TIS 2. This indicates that the porosity increased from a moisture content of 68% in TIS 2 to 60% in Ukerewe. The porosity values show that when the roots of the two varieties are placed in a container, the airspaces between the TIS 2 are more than the Ukerewe variety. Values recorded agrees with porosities of grains and seeds such as wheat (42-46%), sorghum (43-46%), soybeans (41-44%), and shelled corn (39 - 48%) (Thompson and Isaacs, 1967). The variation is not high as found in these grains and seeds.

Angle of repose

The angle of repose was recorded to be 38^{o} in TSI 2 and 37^{o} in Ukerewe. Low angle of repose makes the roots spread out wider on a plane surface compared to high angle of repose. Low angle of repose is often advisable during belt conveying while high angle of repose is more desirable when unloading unto a horizontal surface. This means that the Ukerewe sweetpotato spreads wider than the TIS 2 when it forms a natural heap. There was also decrease in the angle of repose from a TIS 2 (moisture content 68%) to the Ukerewe (moisture content 60%) variety. The angle of repose of many grains increases with grain moisture content from 19.8^{o} at 5% moisture content to 23.5^{o} at 20% and decreases gently thereafter to 21^{o} at 35% moisture content (Baryeh, 2001). The slight change in the root angle of repose could be due to the differences in the surface roughness of the two sweetpotato varieties.

Coefficient of friction

The static coefficient of friction at the root moisture content considered for the four different structural surfaces of nylon, polyethene, cardboard, and plywood gave 0.70, 0.62,0.70, 0.58 for TIS 2 and 0.67, 0.51, 0.67, and 0.51 for Ukerewe. Coefficient of friction values were higher in TIS 2 for all structural surfaces used than in Ukerewe. Nylon and the cardboard recorded the highest, followed by plywood and polyethene. This trend could be due to the smoother and more polished surface of polyethene and plywood than nylon and cardboard. The roots also have the ability of sticking to some surfaces as they slide on them. The coefficient of friction has also been found to be higher on plywood than on galvanized iron for millet (Baryeh, 2000) and guna seeds (Aviara et al., 1999). The friction is important in the design of conveyors because friction is necessary to hold the roots to the conveying surface without slipping or sliding backward. If plywood is to be used for conveying the roots, it will be advisable to roughen the surface to increase friction between the roots and the surface. On the other hand, discharging requires less friction to enhance the discharging process.

CONCLUSIONS

1. All the linear dimensions of the roots, root surface area, root volume, mass are higher in TIS 2 than Ukerewe except the major diameter (length)
2. The shape of the Ukerewe is more cono-spherical than the TIS 2 whereas the volume of a prolate spheroid is closer to Ukerewe than TIS 2
3. 62% of the TIS 2 roots mass are between 44.6 and 200g whiles 90% of the Ukerewe are between 29.5 and 200g
4. The 500-root weight of TIS 2 is heavier than that of Ukerewe.
5. Particle and bulk densities are higher in TIS 2 than Ukerewe
6. The porosity of Ukerewe is slightly higher but angle of repose is lower than TIS 2
7. Coefficient of friction of the two varieties is highest for nylon and cardboard, followed by polyethene and plywood with values higher in TIS 2 than Ukerewe.

REFERENCES

Ahn, P.M. (1993)"Tropical soil and fertilizer use", International Trop. Agric Series. *Longman Science and Technology Ltd*. U.K.

Aviara,N. A. Gwandzang,M. I., & Haque, M. A. (1999) Physical properties of guna seeds. *Journal of Agricultural Engineering Research*, 73, 105-111.

Bart-Plange, A., Dzisi, K. A., and Darko, J. O. (2005) Effect of moisture content on selected physical properties of two varieties of cowpea. *Agric. & Food Sci. Jour. Of Ghana*. 4, 329-340.

Baryeh, E. A. (2001). Physical properties of bambara groundnut. *Journal of Food Engineering*, 47, 321-326.

Baryeh, E. A. (2000) Physical properties of millet. *Journal of Agricultural Engineering Research*

Chandrasekar,V., & Viswanathan, R. (1999) Physical and thermal properties of coffee. *Journal of Agricultural Engineering Research*, 73, 227-234

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

Duku, I.G. (2005) *The effect of defoliation and Post-harvest handling techniques on the Shelf-life of Sweet Potato*. An unpublished M.Phil Thesis, University of Cape Coast, Cape Coast, Ghana.

Dutta, S. K., Nema, V. K., & Bhardwaj. R. J. (1988) Physical properties of gram. *Journal of Agricultural Engineering Research*, 39, 259-268.

FAO (2006). FAOSTAT Database (2005) Rome, Italy: Food and Agriculture Organization of the United States. http://apps. fao.org/deefault.jgp

FAO (2004) Roots, Tubers, Plaintains and Bananas in human Nutrition. Food and Agriculture Organization of the United States.

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

Gupta, R. K., & Das, S. K.(1998) Friction coefficients of sunflower seeds and kernel on various structural surfaces.

Journal of Agricultural Engineering Research, 72, 175-180.

International Institute of Tropical Agriculture (IITA) (1985): Root and Root crop production manual number 9. *IITA Nigeria*.

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

Joshi, D. C., Das, S. K., & Mukherji, R. K. (1993) Physical properties of pumpkin seeds. *Journal of Agricultural Engineering Research*, 54, 219-229.

Kaleemullah, S., and Gunasekar, J. J. (2002) Moisture-dependent physical properties of Arecanut Kernels. *Biosystems Engineering*. 82, 331-338.

Karababa, E. (2006) Physical properties of popcorn kernels. *Journal of Food Engineering*. 72, 100-107.

McClure, J.E and C.T. Morrow (1987) Computer vision sorting of potatoes. Paper 87-6501. American Society of Agricultural Engineers, St Joseph, Michigan 49085.

Missah, A., Kissiedu, A.F.K. Okoli, O.O. (1991) *Preliminary evaluation of 19 Sweet Potato Varieties for Yield and Resistance to major Pests (cylas sp. Amd alcidodes sp.) in the Coastal Savannah Zone of Ghana*.

Mohsenin, N.N. (1986) Physical properties of plant and Animal Materials, Second Edition. *Gordon and Breach Science Publishers*, New York. 891p

Moustafa, S.M.A. (1971)Theoretical prediction of volume, surface area, and center of gravity for agricultural products. *Transactions of ASAE* 14 (3): 549-553.

Mutandwa, E., and Gadzirayi, C. T., (2007) Comparative Assessment of Indigenous Methods of Sweet Potato Preservation among Smallholder Farmers: Case of Grass, Ash and Soil based Approaches in Zimbabwe. *Published in African Studies* Quarterly 9, no. 3:(online)URL: http://www.web.africa.ufl.edu/asq/v9/v9i3a.

Nimkar, P. M., Dipali, S.M., Renu, F. M. D., (2005) Physical properties of moth gram. *Biosystems Engineering*. 91, 183-189.

Onyekwere, P.S.N., and Okafor, E.C. (1992) Water requirements of sweet potato. Proc. 4th symposium, ISTRC-AB (*Proceeding of the fourth triennial symposium of the international society for tropical root crop-Africa Branch*); pp 335-336.

Picha, D.H. (1986) Weight loss in Sweet potato during curing and storage: Contribution of transpiration and respiration. *Journal of American Society of Horticultural Scientists*. 111:889-892.

Pradhan, R. C., Naik, S. N., Bhatnagar, N., and Vijay, V. K (2009) Moisture-dependent physical properties of jatropha fruit. *Journal of industrial crops and products*, 29, 341-347.

Rees, D., Van Oirschot, Q. E. A., Amour, R., Rwiza, E., Kapinga, R. and Carey, T. (2003) Cultivar variation in keeping quality of sweet potatoes. *Postharvest Biology and Technology* 28 (2003) 313-325.

Sahay, K. M., & Singh, K. K. (1994) *Unit operation in agricultural processing*. New Delhi:Vikas

Scott, G. J. (1992) Transforming Traditional Food Crops: Product development for roots and tubers. In Scott, G. J, Wiersema, S., Ferguson, P. I. (Eds), Product Development for Roots and Tuber Crops, Vol. 1, Asia International Potato Center (CIP), Lima, Peru, pp 3-20.

Scott, G. J., Best, R., Rosegrant, M & Bokanga, M (2000) Roots and Tuber in the Global Food Systems: a vision statement to the year 2020, International Potato Center (CIP), Lima, Peru

Sharma, S. K., Dubey R. K., & Teckchandani, C. K. (1985) Engineering properties of black gram, soybean and green gram. *Proceedings of the Indian society of Agricultural Engineers*, 3, 181-185

Shepherd, H., & Bhardwaj, R. J. (!986) Moisture dependent physical properties of pigeon pea. *Journal of Agricultural Engineering Research*, 35, 227-234.

Singh, K. K., & Goswami, T. K. (1996) Physical properties of cumin seed. *Journal of Agricultural Engineering Research*,64, 93-98.

Sreenarayanan, V. V., Subramanian, V., & Visvanathan, R. (1985) Physical and thermal properties of soybean. *Proceedings of Indian Society of agricultural Engineers*, 3, 161-169.

Stroshine, R. & Hamann, D. (1995) Physical properties of agricultural materials and food products. Department of Agricultural and Biological Engineering, Purdue University, West Lafayette.

Suthar, S.H. & Das, S.K.(1996) Some physical properties of karingda seeds. *Journal of Agricultural Engineering Research*, 65, 15-22.

Tennes, B.R. and J.H. Levin, and B.A. Stout (1969) Sweet cherry properties useful in harvesting and handling equipment design. *Transactions of ASAE* 12 (5): 710-714.

Thompson, R.A. and G.W. Isaacs (1967) Porosity Determinations of grains and seeds with an air-comparison pycnometer. *Transactions of ASAE* 10 (5): 693-696.

Walter, W.M., Jr., and M.W. Hoover (1984) Effect of pre-processing storage conditions on acceptance of sweet potato patties. *J. Food Sci*.49:1258-1261.

Woolfe, J.A. (1992) "Sweet potato: an untapped food resource", *Cambridge University press and the international potato center (CIP)*. Cambridge, UK.