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Effect of Variety and Initial Moisture Content on Physical Properties of Improved Millet Grains

*Adebowale, A.A., Fetuga, G.O., Apata, C.B. and Sanni, L.O.[1]

ABSTRACT
Physical properties of agricultural materials are important for the design of appropriate equipment and systems for harvesting and post-harvest operations such as cleaning, conveying and storage. The study was conducted to determine the effect of variety and initial moisture content on some physical properties of improved Nigerian millet grains. Improved varieties of millet obtained were conditioned to different moisture contents (10, 20 and 30%) and their physical properties were determined. The grain length, width, thickness and effective geometric mean diameter increased with increasing moisture content irrespective of millet varieties, while aspect ratio (which relates kernel width and length and determines whether grains will slide or roll on their flat surfaces during handling and processing) decreased with increase in moisture content. Static coefficient of friction ranged from 0.44 – 0.99, 0.45 – 0.82, 0.40 – 0.70 and 0.37 – 0.67 for wood, mild steel, galvanized steel and glass respectively. The static coefficients of friction (an important parameter in predicting the lateral pressure on a retaining wall in storage bins or design of bins and hoppers for gravity flow) were found to increase as the moisture content increased. The study showed that variety and initial moisture content had significant effect (P<0.05) on the physical properties determined. Hence, variety and initial moisture content are critical in the design of equipment for processing, handling and storage of millet grains.

Keywords: Millet, moisture content, physical properties, improved varieties.

Introduction
Millet (*Pennisetum gambiense*) is a staple food consumed in the arid part of tropical Africa, particularly in the semi-arid region of West Africa (Purseglove, 1988). Millet comprises five genera, namely *Pennisetum*, *Paspalum*, *Panicum*, *Setaria* and *Echinochloa*. The most commonly found genus in Nigeria is the *Pennisetum* and it has two main species – *P. typhoids* and *P. Purpureum* (Labe, 1983).

Africa and Asia produce about 98% of the world's millets (FAO, 1993). In 2008, Nigeria produced over 9 million metric tonnes of paddy rice (FAOSTAT, 2010). The grains are variable in shape, size and colour. The millet shape may be elliptical, oblanceolate, hexagonal or globular in shape and greyish white, yellow, brown, cream, ivory, light blue, purple or grey in colour (IBPGR, 1993). Jain and Bal (1997) also reported a conospherial shape. It contains 8.8 – 18.2% protein, 3 – 5% fat, 59.3 – 69.5% carbohydrate, 1.2 – 2.8% fibre, 1.5 – 2.7% ash and 2.0 – 2.7% sugar (Puseglove, 1988). It also contains traces of the following minerals: calcium, phosphorus, iron and potassium (Rachie and Majmudar, 1980).

Millet may be cooked like rice, or ground into flour and made into either a light porridge or gruel eaten with sugar and milk or a thick porridge eaten with source or to produce a type of beer called "pito". Finger millet is consumed whole, thereby retaining the fibre, minerals and vitamins present in the outer layer of the grain, which is nutritionally advantageous (Usha *et al.*, 1996). It may be consumed in the form of porridge made from dry parched grain or may

[1] Department of Food Science and Technology, University of Agriculture, Abeokuta, Nigeria.
* corresponding author: deboraz2002@yahoo.com

be cooked with sugar, groundnut or other pulses to make desert.

It is a robust and quick growing cereal which is more efficient in its utilization of structure and has a high level of heat tolerance compared to sorghum or maize. Its great merit is that it can be grown on poor sandy soil in low rainfall areas and still give economic yield, although light loam, sandy well-drained soils are preferred (Rachie and Majmudar, 1980; Purseglove, 1988; Jain and Bal, 1997).

Physical properties of agricultural materials are important for designing appropriate equipment and system for planting, harvesting and post-harvest operations such as cleaning, conveying and storage (Asoegwu *et al.*, 2006). Thermal properties are useful in modelling thermal behaviour of seeds during thermal processing operations such as drying, baking and frying (Alagunsundaran *et al.*, 1991; Yang *et al.*, 2002). Therefore, increasing production, reducing crop losses and minimizing grain damage require the design of efficient handling and processing equipment which require the determination of engineering and thermal properties. Studies carried out on gram seeds, sunflower seed, pumpkin seed and lentil/seed have reported that seed moisture content affects the physical properties of grains (Dutta *et al.*, 1988; Joshi *et al.,* 1993; Amin *et al.,* 2004). This study was therefore conducted to determine the effect of initial moisture content and variety on the physical properties of improved Nigerian millet grains.

Material and Methods

Five improved varieties (04/028, 04/018, 04/023, 04/011 and 04/029) of millet were obtained from National Centre for Genetic Resources and Biotechnology, Moor Plantation Ibadan, Oyo State, Nigeria.

Preparation of grains

Millet grains were cleaned and sorted to remove all unwanted materials such as dust, chaff, stones, insect-damaged or unhealthy grains. The initial moisture content of the grains was determined according to the procedure of AOAC (1990).

Conditioning of the sample

This study was carried out within the moisture range of 10% – 30% d.b. The amount of water that was added (Q) to condition the grains to the desired moisture content was determined by making use of the following expression (Tunde-Akintunde and Akintunde, 2007):

$$Q = \frac{A\,(b - a)}{100 - b}$$

Where Q = Mass of water to be added in Kg

A = Initial mass of sample in Kg

a = Initial moisture content of sample in % d.b.

b = Final (desired) moisture content of sample in d.b.

Determination of physical properties

Principal dimensions

Fifty grains were selected randomly from bulk, according to the procedure described by Dutta *et al.* (1988). For each grain, the three principal dimension: length, width and thickness were measured using a digital micrometer screw gauge to an accuracy of 0.01 mm.

Arithmetic mean diameter (D_a):

$$Da = \frac{L+W+T}{3}$$

Effective mean diameter (D_e):

$De = (LWT)^{1/3}$ (Mohsenin, 1986)

Surface areas (S):

$S = \pi D_e^{\,2}$ (McCabe *et al.*, 1986).

Sphericity (∅:)

∅ =

Volume (V):

$$\frac{\pi BL^2}{6(2L - B)}$$ (Jain and Bal, 1997).

Where: L = length (mm), W = width (mm), T = thickness (mm) and $B = (WT)^{0.5}$.

Mass: The mass of one hundred grains was determined using an electronic balance to an accuracy of 0.0l g.

Bulk density, true density and porosity: The true density of the millet varieties was obtained by using the method described by Tunde-Akintunde and Akintunde (2007). The bulk density was then calculated as the ratio of millet weight to the volume occupied (Omobuwajo *et al.*, 1999). Porosity (P) was calculated from the relationship between bulk (Pb) and true (Pt) densities according to Mohsenin (1986) as follows:

$$P = \frac{1 - Pb \times 100}{Pt}$$

Angle of repose: Angle of repose was measured using a specially constructed box measuring 300 x 300 x 300 mm with a detachable front panel (Ogunjimi and Aviara, 2002). The box was separately filled with the millet varieties at the different initial moisture contents and the front panel was removed quickly. The millet grain was allowed to flow according to their natural flow pattern. The angle of repose was calculated by measuring the distance between the end of the flow and the box.

$$\text{Angle of repose} = \frac{\tan^{-1}(\text{horizontal distance})}{\text{Height of box}}$$

Static coefficient of friction: The static coefficient of friction for the millet grains at different moisture contents on different structural surfaces (mild steel, galvanized steel, glass and ply wood) was obtained by applying the inclined plane method which involved using a hollow metal cylinder (50 mm diameter and 50 mm height) open at both ends and filled with millet. The cylinder was then placed vertically on an adjustable tilting plate without allowing the metal cylinder to touch the inclined surface. The tilting surface was raised slowly and gradually until the cylinder just started to slide down and the angle of inclination was read from the graduated scale (Dutta *et al*, 1988; Suthar and Das, 1996)

Specific heat capacity (KJ/kg/K): The specific heat of the millet at different moisture content was measured using a modified method of Ogunjimi and Aviara (2002). In this method, millet sample of known weight and temperature was poured into a copper calorimeter placed inside a flask. The calorimeter contained a specific amount of water at a specific temperature. The mixture was stirred with a stirrer until equilibrium. The final temperature was recorded and the specific heat (Cs) was calculated as follows:

$$C_s = \frac{(M_c C_c + M_w C_w)(T_c - T_{wi})}{M_s (T_{si} - T_c)}$$

Where M_c = mass of the calorimeter, kg

M_s = mass of the sample, kg

M_w = mass of water, kg

C_c = specific heat of the Calorimeter ($Jkg^{-1}k$)

C_w = specific heat of water ($Jkg^{-1}k$)

T_{si} = Initial temperature of the sample (k)

T_{wi} = Initial temperature of water (k)

T_{cv} = final temperature of the mixture (k)

Statistical analysis

All data were subjected to statistical analysis of variance (ANOVA) using SPSS version 15.0.

Results and Discussion

The effect of variety and moisture content on the physical dimension of five improved Nigerian millet grains is shown in Table 1. All the linear dimensions of the millet grains increased linearly with grain moisture content. This was due to the swelling of the grains in the presence of moisture. This indicates that on moisture absorption, the grain expands in length, width, thickness and effective geometric diameter within the moisture range 10% – 30%. Deshpande *et al.* (1993) have found similar results with soybeans. The total average expansion from 10% – 30% grain moisture was largest along the grain length and least along its width. Average length, width and thickness were 3.87 mm, 2.00 mm and 2.05 mm respectively (Table 1). The effective geometric mean diameter was found to be higher than the thickness of the grains. These dimensions were in the same range for rapeseeds and sesame seeds as reported by Baryeh (2002), Tunde-Akintunde and Akintunde (2004), Calisir *et al*. (2005a, b), but smaller than cotton seeds (Ozarslan, 2002), Sunflower seeds (Gupta and Das, 1997) and gram seeds (Dutta *et al*., 1988). The result showed that millet grains belong to small seeds category, similar to sesame seeds, rapeseeds and black cumin. The seed dimensions are useful in the design of grain harvesting, post-harvesting, handling and processing machinery. The axial dimensions are important in determining aperture size in the design of grain handling machinery. Similar findings were reported for other grains: hazelnut (Aydin, 2002), rapeseeds (Calisir *et al.,* 2005a) and soybeans (Deshpande *et al*., 1993). The initial moisture content and variety significantly affected all linear dimensions (length, width and thickness), effective mean diameter, arithmetic mean diameter, sphericity, surface area, volume and aspect ratio of the improved millet grains. This implies that the swelling as a result of increase in moisture was pronounced in all the dimensions. The highest sphericity was recorded by variety 04/018 while the lowest sphericity was recorded by varieties 04/028 and 04/029 at 30% and 10% moisture content respectively (Table 1). Oje (1993) reported that high sphericity would make material slide rather than roll, hence millet grains will slide during handling. This property is important for designing hopper and dehulling equipment for seed grains (Oje and Ugbor, 1991).

Table 1: The effect of variety and moisture content on the physical dimensions of five improved Nigerian millet grains

Variety	Moisture content	Length (mm)	Width (mm)	Thickness (mm)	Arithmetic mean diameter (mm)	Effective geometric mean diameter	Sphericity (%)	Surface area (mm^2)	Volume (mm^3)	Aspect ratio (%)
04/028	10%	3.45	2.05	2.06	4.94	2.44	0.71	18.82	5.56	59.62
	20%	4.10	2.01	2.07	5.76	2.57	0.63	20.85	6.10	50.01
	30%	4.21	1.89	1.94	5.14	2.48	0.60	19.37	5.30	45.98
04/018	10%	3.31	1.98	2.02	4.48	2.35	0.72	17.57	5.14	60.62
	20%	3.42	1.99	2.06	4.63	2.40	0.71	18.11	5.23	58.80
	30%	3.62	1.82	1.90	4.21	2.31	0.65	16.92	4.51	50.99
04/023	10%	3.79	2.17	2.18	6.07	2.61	0.69	21.59	6.76	57.58
	20%	4.09	2.27	2.33	7.26	2.78	0.68	24.38	8.02	55.80
	30%	4.03	1.92	2.02	5.33	2.50	0.63	19.75	5.59	48.44
04/011	10%	3.89	2.18	2.10	6.00	2.61	0.67	21.48	6.58	56.26
	20%	4.13	2.01	2.01	5.60	2.54	0.62	20.44	5.92	49.40
	30%	4.14	1.82	1.97	5.00	2.45	0.60	18.95	5.15	44.55
04/029	10%	3.92	1.91	1.96	4.90	2.44	0.63	18.78	5.15	49.32
	20%	4.01	2.02	2.04	5.50	2.54	0.64	20.28	5.85	51.19
	30%	3.95	2.02	2.14	5.68	2.55	0.67	20.63	6.32	53.61
Range		3.31-4.21	1.82-2.27	1.90-2.33	4.21-7.26	2.31-2.78	0.60-0.72	16.92-24.38	4.51-8.02	44.55-60.62
Mean std dev		3.87	2.00	2.05	5.37	2.50	0.66	19.86	5.81	52.81
SE		0.29	0.13	0.11	0.76	0.12	0.04	1.86	0.86	5.06
CV		0.07	0.03	0.03	0.20	0.03	0.01	0.48	0.22	1.31
P of Variety		7.50	6.40	5.24	14.14	4.65	6.10	9.36	14.86	9.59
P of initial moisture content		**	**	**	**	**	**	**	**	**
		**	**	**	**	**	**	**	**	**
P of Variety x initial moisture content		**	**	**	**	**	**	**	**	**

Values are means of twenty replicates. ** significantly different.

Table 2 shows the effect of variety and moisture content on static coefficient of friction and specific heat capacity. The static coefficient of friction of millet grains on four surfaces (wood, mild steel, galvanized steel and glass) increased as the moisture content of the grain increased. The increase may be due to the increased adhesion between the grain and the material surfaces at higher moisture values as a result of increased cohesion of the wet grains on the structural surfaces, since the surfaces become stickier as the content increases. At all moisture contents studied, the least static coefficient was observed on glass surface. These trends may be due to the smoother and more polished surfaces of the glass relative to the other materials used. On the other hand, Amin *et al*. (2004) have reported that no variation existed between plywood and glass surface.

Jain and Bal (1997) have reported lower values for a variety of pearl millet at 7.4% moisture content. This property is needed in the design of agricultural machine hopper and other conveying equipment.

Table 2: Effect of variety and moisture content on static coefficient of friction and specific heat capacity of five improved Nigerian millet grains

		Coefficient of static variation				
Variety	**Moisture content**	**Plywood**	**Galvanized steel**	**Mild steel**	**Glass**	**Specifc heat capacity (KJ/kg/K)**
04/0011	10%	0.53	0.40	0.45	0.40	103.77
	20%	0.75	0.60	0.67	0.51	98.24
	30%	0.90	0.67	0.78	0.67	102.68
04/028	10%	0.57	0.43	0.47	0.37	88.34
	20%	0.69	0.61	0.64	0.59	97.27
	30%	0.85	0.66	0.82	0.66	104.59
04/023	10%	0.44	0.43	0.44	0.39	91.61
	20%	0.63	0.59	0.63	0.57	93.01
	30%	0.81	0.70	0.81	0.66	104.82
04/018	10%	0.46	0.41	0.46	0.41	89.08
	20%	0.66	0.57	0.66	0.54	105.61
	30%	0.82	0.69	0.82	0.63	108.25
04/029	10%	0.52	0.46	0.48	0.39	107.33
	20%	0.74	0.59	0.64	0.57	105.74
	30%	0.83	0.69	0.80	0.64	103.63
		0.44-0.90	0.40-0.70	0.44-0.82	0.37-0.82	88.20-108.25
Range		0.68	0.57	0.64	0.53	100.26
Mean						
std dev		0.15	0.11	0.15	0.11	6.81
SE		0.04	0.03	0.04	0.03	1.76
CV		22.13	19.48	23.27	21.18	6.79
P of Variety		**	ns	ns	ns	ns
P of initial moisture content		**	ns	ns	ns	**
P of Variety x initial moisture content		**	ns	ns	ns	**

Values are means of three replicates. ns not significantly different (P>0.05).
** significantly different (P<0.05).

Conclusion

The study showed that the effect of variety and moisture content on some physical properties of five improved Nigerian millet variety were significant (P<0.05). The data presented in this study would therefore be useful in the design of more efficient harvesting, handling, cleaning and processing machinery for the improved millet grain cultivars to improve their quality and added value.

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