PHYSICAL AND FRICTIONAL PROPERTIES OF SHEANUT

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ABSTRACT

Physical and frictional properties of sheanut (Butyrospernum paradoxum) and kernel were deter-mined to explore the possibility of developing their handling and processing equipment. At a mois-ture content of 3.84% (db), measurements yielded an average major diameter of 36.63mm, interme-diate diameter of 29.30mm and minor diameter of 27.93mm for the nut. Corresponding values for the kernel were 29.62mm, 20.30mm, and 18.20mm. The kernel and shell constituted about 60.16 and 39.84% of the nut by mass. The roundness and sphericity of nut ranged from 68 to 81%, and 78 to 88%, while corresponding values for kernel were between 59 and 69% and 68 and 75% respec-tively. The volume, particle density, bulk density, porosity and angle of repose of the nut were 18200mm³, 616.13 kg/m³, 282.52 kg/m³, 54% and 23.32⁰ respectively. The static and kinetic coeffi-cients of friction on different structural surfaces (galvanized steel sheet, glass, hessian bag mate-rial and plywood) ranged from 0.173 to 0.445 and 0.157 to 0.412 respectively. For the kernel, the particle density and porosity decreased from 1137 to 1088.53 kg/m³, and 57.56 to 45.28% respec-tively, as the moisture content increased from 3.32 to 20.70% (db). The volume, bulk density, angle of repose and static and kinetic coefficients of friction on the same structural surfaces, increased from 5833.33 to 6576.67mm³, 482.51 to 595.60kg/m³, 30.20 to 36⁰, and 0.217 to 0.857 and 0.203 to 0.729, respectively in the above moisture range. The axial dimensions of the kernel also increased with moisture content. The study reveals that a mechanical cracker with pneumatic separator for the kernel and shell could be developed for the sheanut.

Keywords: *Sheanut, Butyrospernum paradoxum, Physical properties, Frictional properties*

INTRODUCTION

Shea-nut (*Butyrospernum Paradoxum*) is an oil rich tropical tree crop, which is indigenous to the West African Savannah Zone. Its fruit con-tains one or two nuts, which are brown and shiny. The fruit pulp is eaten, but the tree is mainly important for its nut, which contains a kernel (Fig.1) with an oil content ranging from 45 to 60% (Opeke, 1992). The oil, known as shea butter, is used in the manufacture of soap, candle,
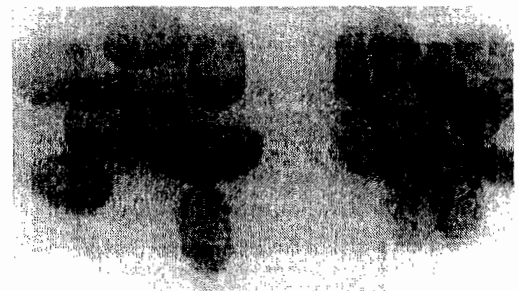
Sheanut   a. - Nut   b. - Kernel

cosmetics, pharmaceutical products and butter sub-stitutes. The kernel is obtained from nut by crack-

ing with stones, mortar and pestle. In the traditional process of extracting the oil, the kernel is subjected to a series of operations, which include sleeping, roasting, pounding or grinding, and boiling.

The present methods of carrying out these operations, which involve manual labour, are tasky and wasteful. Improved methods of processing the nut and kernel using suitable machines and equipment can be developed if the physical properties are known.

Researchers have investigated physical properties of several agricultural products for similar purpose. Dutta *et al.* (1988), Deshpande *et al.* (1993) and Oje (1993) determined the size of gram, soybean and thevetia nut, by measuring their principal axial dimensions. Makanjuola (1972), Joshi *et al.* (1993), Suthar and Das (1996) and Carman (1996), correlated the values of these dimensions for the seeds and kernels of watermelon, pumpkin, karingda and lentil, respectively. Kaleemullah (1992), Deshpande *et al.* (1993) and Aviara *et al.* (1999) investigated the variation of these dimensions with moisture content for groundnut kernel, soybean and guna seed respectively. Other properties that have been studied include roundness and sphericity, particle and bulk densities, porosity, static and kinetic coefficients of friction and angle of repose.

Roundness is a measure of the sharpness of the corners of a solid and has been defined as the ratio of the largest projected area of an object in its position of natural rest to the area of the smallest circumscribing circle. Sphericity expresses the shape character of a solid relative to that of a sphere of the same volume. It has bee defined as the ratio of the surface area of a sphere, which has the same volumes as that of the solid, to the surface area of the solid (Dutta *et al* 1988). Mohsenin (1986) reported that there are several methods of finding roundness and sphericity but that the most frequently used method is the one due to Curray (1951). The expressions used are

$$\text{Roundness} \quad = \quad \frac{A_p}{A_c} \qquad (1)$$

$$\text{and Sphericity} \quad = \quad \frac{d_i}{d_c} \qquad (2)$$

Particle density has been determined by some researchers (Joshi *et al.* 1993, Suthar and Das 1996, Nelson 1980, Brusewitz 1975 and Thompson and Isaacs 1967) using the gas displacement method, while others (Dutta *et al.* 1988, Shepherd and Bhardwaj 1986, Oje and Ugbor 1991, Oje 1994 and Aviara *et al* 1999) employed the water displacement method. Most of the investigators determined the bulk density following the AOAC (1980) recommended method. The relationship between porosity, particle density and bulk density has been frequently employed in determining the porosity of grains and seeds. This relationship is given by Mohsenin (1986) as

$$P = (1 - \frac{\rho_b}{\rho_t}) \times 100 \qquad (3)$$

Methods that have been used in studying the coefficient of friction of agricultural products vary from moving a given surface against the material (Lawton 1980) and tilting an inclined plane (Dutta *et al.* 1988, Aviara *et al.* 1999, Mohsenin 1986) to the shear box equipment (Osunade and Lasisi 1994). The structural surfaces employed are galvanized steel sheet and plywood. Investigators (Fraser *et al* 1978; Dutta *et al.* 1988 and Aviara *et al* 1999), using a specially constructed box with removable front panel have conducted studies on the angle of repose of grains and seeds. Most of the investigations show that the physical properties of agricultural products are moisture dependent. Olajide *et al.* (2001) studied some physical properties of shea nut kernel, but they did not include those of the nut. Also, the effect of moisture content on the physical properties of shea nut kernel does not seem to have been investigated. Aviara *et al.* (1999) noted that the moisture dependent characteristics of physical properties have effect on the adjustment and performance of agricultural product processing machines. They further noted that a range of moisture content usually exists within which the optimum performance of the machine is achieved. Sheanut kernel processing involves moisture conditioning, therefore, there is the need to investigate the effect of moisture on its physical properties. The objective of this work was to determine the physical properties of shea-nut and kernel, namely principal axial dimensions, roundness,

determine the physical properties of shea-nut and kernel, namely principal axial dimensions, roundness, sphericity, particle and bulk densities, porosity, angle of repose and static and kinetic coefficients of friction, and to investigate the variation of these properties with moisture content for the kernel.

MATERIALS AND METHOD

For this work, about 50kg of dried shea-nut at stable storage condition was obtained from Izge in Gwoza Local Government Area of Borno State, Nigeria. The nuts were cleaned and sampled for experiments using a multi-slot riffle box divider. To obtain intact kernels, some quantities of nuts were manually cracked and the resulting nuts and kernels were stored separately in sealed polyethylene bags.

Since the nut is oil yielding, the moisture content was determined using the method reported by Ajibola et al (1990) and Oje (1993). This involved the oven drying of nut samples at 130^0C for 6 hours, with weight loss monitored on hourly basis to give an idea of the time at which the weight began to remain constant. Weight of samples was found to remain constant after oven drying for a period of about 4 hours. The stable storage moisture content of nut was found to be $3.84 \pm 0.16\%$ (db). At this moisture content the nut was found to be easily cracked to release the kernel. The kernel obtained from the nut at the above moisture content was found to have moisture content of 3.32%(db). Tests were carried out on the nut at the moisture content of 3.84%(db). For the kernel, four moisture levels in the range from 3.32 to 20.70% (db) were used in order to investigate the effect of moisture content on the physical properties. Kernel samples of desired moisture level in the above range were prepared by conditioning the samples using the method of Ezeike (1986). This involved the soaking of samples for a period of one to four hours followed by spreading out in thin layer to dry in natural air for about eight hours. After this, the samples were sealed in polyethylene bags and stored in this condition for a further twenty-four hours. This allowed the achievement of stable and uniform moisture content of the samples.

To determine the nut and kernel sizes, 100 nuts were randomly selected following a similar method to that employed by Dutta et al (1988). For each nut and kernel, the three principal axial dimension namely major, intermediate and minor diameters were measured using a vernier calliper reading to 0.05mm. Since the size of the nut is considered to be an important parameter in processing, the bulk sample of nuts was classified into three categories namely large (>40mm), medium (35 to 40mm) and small (<35mm) based on their major diameter. The frequency distribution of the sizes of the nut in the sample was estimated. The correlation between the nut and kernel dimensions was determined and the variation of kernel dimensions with moisture content investigated. Nut and kernel masses were obtained with an electronic balance weighing to 0.001g. This was used to determine the percentages of the nut mass which the kernel and shells constitute.

Roundness and sphericity were determined by tracing the shadowgraphs of twenty nuts and kernels of virtually the same size and of the same moisture content in three mutually perpendicular positions on graph sheets. The projected area was determined by method of counting the squares and the diameters of the inscribing and circumscribing circles of the projected view were measured.

Particle density was determined by the water displacement method (Shepherd and Bhardwaj 1986; Dutta et al. 1988 and Aviara et al. 1999). Samples were coated with very thin layer of araldite to prevent the absorption of water during the experiment. Increase in nut and kernel weight due to the adhesive was negligible (less than 2.5%). Thirty nuts and their corresponding kernels were used.
Bulk density was determined using the AOAC (1980) method. This involved the filling of a 1500ml cylinder with either nut or kernel from a height of 15cm and weighing the content. Porosity was calculated using the relationship between it and the true and bulk densities.

In determining the angle of repose, a specially constructed open-ended box made of plywood and 150mm x 150mm x 150mm in size with removable front panel was used. The box was placed on a table and filled with nuts or kernels. The front panel was quickly removed to allow the material to slide and assume its natural slope in bulk. The angle of repose was calculated from the depth of the free surface of the product, measured at two known horizontal distances from one end of the box. The static coefficient of friction

was evaluated on five structural surfaces namely galvanized steel sheet, glass, hessian bag material, plywood with wood grains parallel to the direction of movement and plywood with wood grains perpendicular to the direction of movement. The inclined plane method was used (Dutta *et al.* 1988 and Mohsenin 1986). This involved the placing of an open-ended box on an adjustable tilting surface, which was formed with a structural surface. The box was filled with nuts or kernels and the structural surface with the box and its content on top was gradually raised with a screw device until the box just started to slide down. The angle of tilt was read from a graduated scale and the tangent of this angle was taken as the static coefficient of friction. For the kinetic coefficient of friction, the method that was employed by Kaleemullah (1992) was used. The open-ended box used in determining the static coefficient of friction was placed on a horizontal surface made of the structural material on which the kinetic coefficient of friction of sheanut and kernel was being determined. The box was filled with nuts or kernels. It was connected by means of a string, parallel to the surface and passed over a pulley, to a pan hanging from it. Weights were placed in the pan until the box and its content moved uniformly when given a gentle push. The kinetic coefficient of friction of the product on a given structural surface was determined using the formula

$$\mu = \frac{\text{weight of pan} + \text{weight placed in pan to move the box}}{\text{weight of box} + \text{weight of sample}}$$

$$\dots\dots (4)$$

All experiments were repeated five times and the average values are reported.

RESULTS AND DISCUSSION

Nut and kernel sizes

The results obtained from measurements of nut dimensions are presented in Table 1. Fig. 2 shows the frequency distribution curves for the major intermediate and minor diameters as well as nut mass. The trend shown by each curve tends towards a normal distribution. About 52% of the nuts were of the medium size. $(35\text{mm} < a_n < 40\text{mm})$,

32% were small size $(a_n < 35\text{mm})$ and 16% were large size $(a_n > 40\text{mm})$. It was established that the following general expression could be used to describe the relationships among the dimensions of the nut.

$$a_n = 1.254b_n = 1.318c_n = 3327.30m_n \quad (5)$$

The coefficients of correlation (Table 2) show that the a_n/b_n and a_n/c_n ratios are highly significant. This indicates that the intermediate and minor diameters are closely related to the major diameter of the nut, while the mass does not seem to show much association. The kernel showed the following relationships among the dimensions and mass at the moisture content of 3.32% (db).

$$a_k = 1.45b_k = 1.636c_k = 3404.61m_k \quad (6)$$

The coefficients of correlation presented in Table 2 show that the a_k/b_n ratio is highly significant as compared to a_k/c_k. The mass of kernel does not seem to have much relationship with the major diameter. The kernel was found to constitute about 60.16% of the nut by mass, while the shell was about 38.84%. The correlation between the nut and kernel dimensions are also presented in Table 2 and the variation of kernel dimensions with moisture content in the moisture range of 3.32 –20.70% (db) is shown in Table 3. Each of the three axial diameters of the kernel was observed to increase with moisture content.

Roundness and sphericity

The shadowgraphs of shea-nut and kernel at three mutually perpendicular positions are shown schematically in Fig. 3. The values of roundness and sphericity calculated using Equations (1) and (2), for both the nut and kernel at each position of rest are presented in Table 4. These show that the roundness and sphericity of the nut are higher than those of the kernel at each position. It can also be seen from Table 4 that the nut has roundness and sphericity values above 70% while, for the kernel, they are above 60 and 70% respectively. The nut and kernel may, therefore, be treated as spheres in analyses requiring an approximation

Table 1. Some physical properties of shea-nut at 3.84% moisture content (db)

Properties	Values			
	Mean	Maximum	Minimum	Standard deviation
Axial dimensions:				
Major diameter, a_n (mm)	36.63	45.00	29.00	3.30
Intermediate diameter, b_n (mm)	29.30	37.50	23.60	2.40
Minor diameter, c_n (mm)	27.93	32.70	22.00	2.52
Relative mass of kernel (%)	60.16	80.00	37.00	15.00
Volume, V_n (mm^3)	18200	26000	14000	3500
True density ρ_{tn} (kg/m^3)	616.13	764	370	103.83
Bulk density, ρ_{bn} (kg/m^3)	282.52	282.90	282.10	0.31
Porosity, p_n (%)	54	____	____	____
Angle of repose, θ_n (degrees)	23.32	25.35	20.35	1.83

Table 2. Nut and Kernel dimensions ratio at 3.84% moisture content (db)

Particulars	Ratio				
	Mean Value	Maximum Value	Minimum Value	Standard deviation	Correlation Coefficient
a_n/b_n	1.254	1.69	0.867	0.114	0.5011**
a_n/c_n	1.318	1.69	0.902	0.126	0.5140**
a_n/m_n	3327.30	4518.62	2701.21	715.23	-0.0581
a_k/b_k	1.458	2.068	1.0732	0.176	0.3263**
a_k/c_k	1.636	2.76	1.211	0.253	0.2394*
a_k/m_k	3404.61	5011.76	2794.34	1024.18	0.310
a_n/a_k	1.244	1.738	1.005	0.195	0.0696
b_n/b_k	1.451	1.655	1.170	0.211	-0.0513
c_n/c_k	1.632	1.928	1.257	0.238	0.0770
m_n/m_k	1.800	2.581	1.168	0.540	0.0650

*Significant at 5% level.   **Significant at 1% level.

Table 3: Axial dimensions of shea-nut kernel at different moisture contents

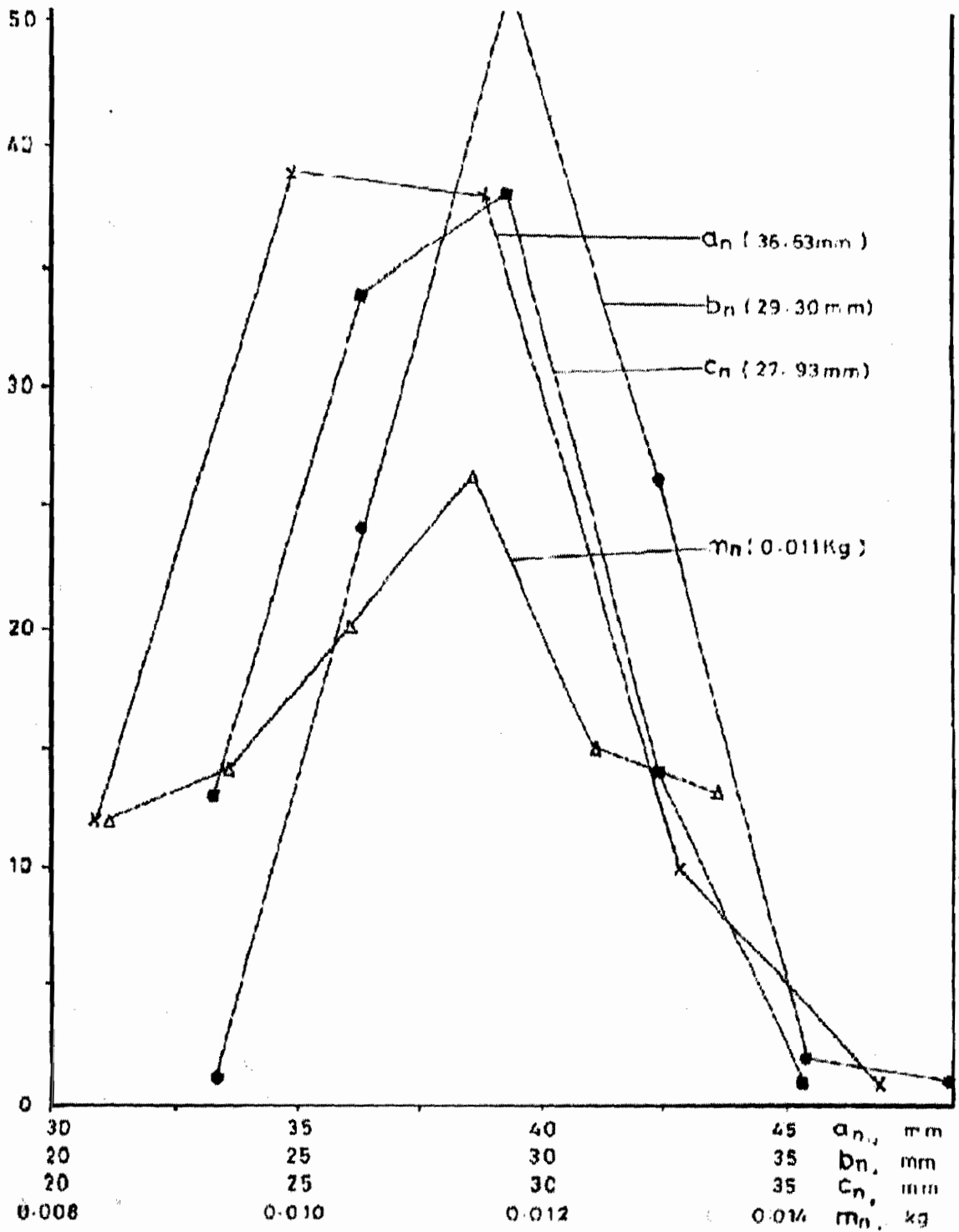| Moisture Content % (db)	Axial dimensions (mm)		
	Major diameter (a_k)	Intermediate diameter (b_k)	Minor diameter (c_k)
3.32	29.62 (4.20)	20.30 (2.23)	18.20 (2.26)
6.95	31.44 (3.70)	23.92 (3.80)	21.24 (4.30)
13.51	33.00 (4.30)	26.26 (3.90)	26.10 (4.40)
20.70	33.71 (3.98)	27.67 (4.39)	27.38 (4.60)

Values in parentheses are standard deviations.

Fig 2. Frequency distribution curves of nut dimensions at 3.84% moisture content
(The values in parentheses indicate mean value of parameter)

Volume

The volume of the nut at the moisture content of 3.84% (db), is given in Table 1. The variation of the volume of kernel in the moisture range of 3.32-20. 70% (db) is shown in Fig. 4. It was found that the kernel volume increased with moisture content. The relationship between kernel volume and moisture content was found to be linear and this can be expressed by the regression equation.

$$V_k = 5697.62+39.41 M \qquad (R^2 = 0.92) \qquad (7)$$

Particle and bulk densities

The particle and bulk densities of the nut at the moisture content of 3.84% (db) are given in Table 1, while those of the kernel and their variation with moisture content are presented in Fig. 4. The kernel particle density decreased from 1137 to 1088.53kg/m^3 as the moisture content increased from 3.32 to 20.70% (db). The variation of the kernel particle density with moisture content can be represented by the regression equation

$$\rho_{tk} = 1148.38-2.73M \qquad (R^2 = 0.96) \qquad (8)$$

The kernel bulk density increased from 482.51 to 595.60kg/m^3 in the above moisture range. The relationship existing between the kernel bulk density and moisture content can be represented by the equation

$$\rho_{bk} = 467.93 + 6.82 M \qquad (R^2 = 0.91) \qquad (9)$$

At the moisture content of 3.84% (db) the particle and bulk densities of the kernel were found to be significantly higher than those of the nut. This shows that the nut, kernel and shell can be separated using either density separators or air classifiers.

Porosity

The porosity of the nut calculated using Equation (3), at the moisture content of 3.84%

(db) is given in Table 1. The variation of the porosity of kernel with moisture content in the moisture range of 3.32-20.70% (db) is presented in Fig. 5. From Fig. 5, it can be seen that the porosity of the kernel decreased with increase in moisture content. The relationship between them was found to be linear and represented by the regression equation

$$P_k = 59.43 - 0.73 M \qquad (R^2 = 0.95) \qquad (10)$$

This shows that the kernel would exert higher resistance to airflow at higher moisture levels and should be of important consideration in the design of the storage, drying and aeration systems.

Angle of repose

The angle of repose of shea-nut at 3.84% (db) moisture content was found to be 23.32⁰ (Table 1), while that of kernel was observed to increase with moisture content in the moisture range of 3.32-20.70% (db) as shown in Fig. 5. The relationship existing between the kernel angle of repose and moisture content is expressed by the regression equation

$$\theta_k = 29.25 + 0.34M \qquad (R^2 = 0.98) \qquad (11)$$

This shows that the sides of the hopper that would be used to feed the nut and kernel into a handling equipment may not need to be steeply inclined.

Static and kinetic coefficients of friction

The static and kinetic coefficients of friction of shea-nut with respect to five structural surfaces are shown in Table 5. The static coefficients of friction of the kernel with respect to the same surfaces were observed to increase with moisture content as shown in Fig. 6. The coefficient of friction is a parameter in the determination of lateral pressure on walls of storage structures, as shown in the relationships for shallow and deep bins, so it will play an important role in the design of silos for the storage of shea-nut or kernel. The relationships between kernel static coefficient of friction on various structural sur-
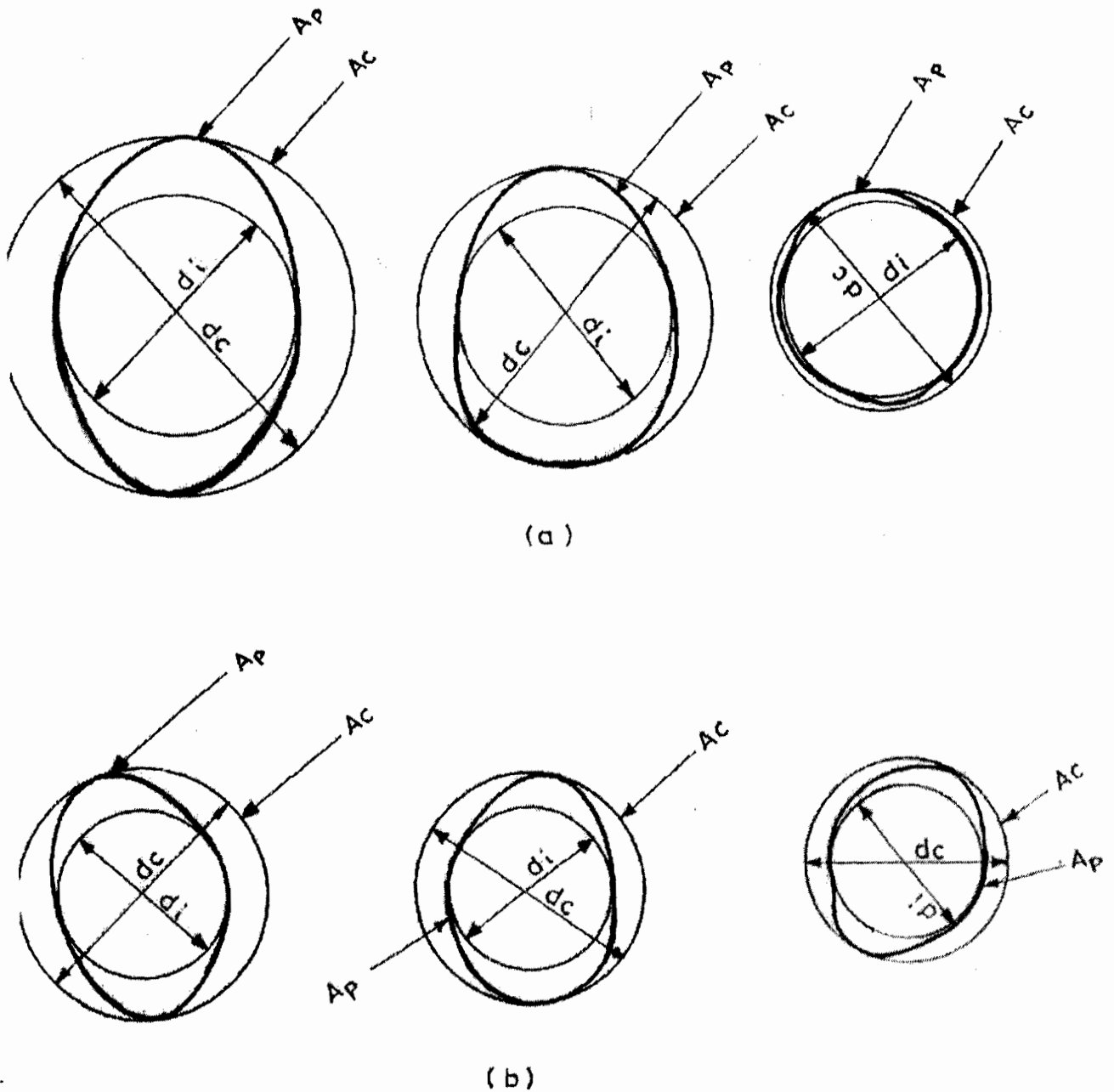
Fig.3. Shadow graphs of shea—nut, a, nut; b, kernel at a 3.84% moisture content,(db) and three mutually perpendicular positions(Left)Normal to minor axis, (middle) Normal to intermediate axis, (Right) Normal to major axis.
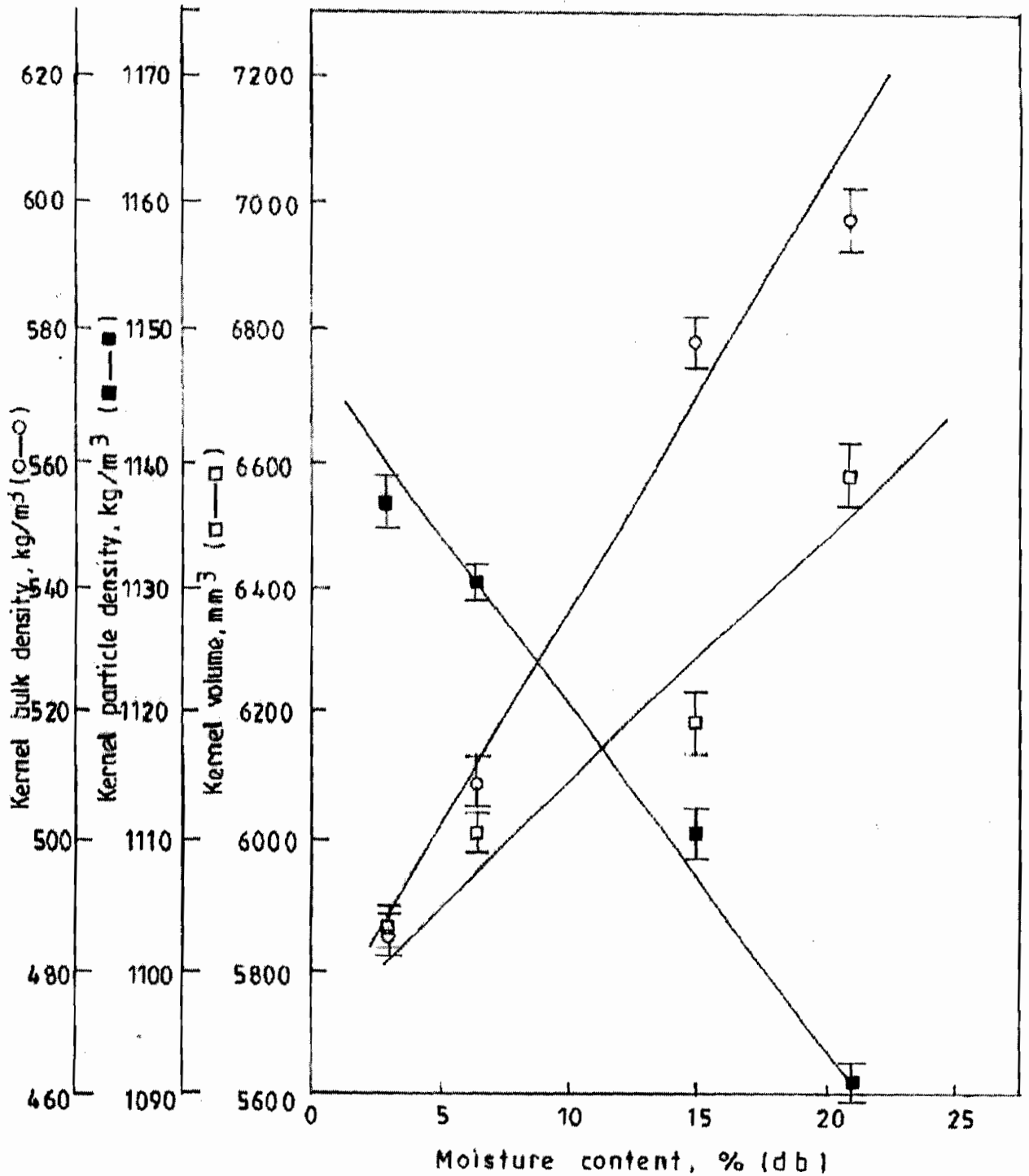
Fig. 4. Effect of moisture content on kernel volume, particle density and bulk density.

Table 4: Roundness and sphericity of sheanut and kernel at three mutually perpendicular positions and moisture content of 3.84% (db)

Rest Position	Nut		Kernel	
	Roundness	Sphericity	Roundness	Sphericity
Minor axis	0.68	0.79	0.59	0.71
	(0.076)	(0.089)	(0.087)	(0.064)
Normal to	0.71	0.78	0.62	0.68
Intermediate axis	(0.055)	(0.058)	(0.039)	(0.057)
Normal to Major	.81	.88	.69	.75
axis	(0.089)	(0.058)	(0.062)	(0.077)
Mean value	0.73	0.82	0.63	0.71
	(0.056)	(0.045)	(0.042)	(0.029)

Values in parentheses are standard deviations

Table 5: Static and Kinetic Coefficients of friction of Sheanut on different Structural surfaces at 3.84% moisture content (db)

Surface	Coefficient of friction	
	Static (f_n)	Kinetic (μ_n)
Galvanized steel sheet	0.305	0.286
	(0.0126)	(0.0041)
Glass	0.173	0.157
	(0.0072)	(0.010)
Hessian bag material	.0.445	0.412
	(0.0105)	(0.010)
Plywood with wood grains parallel to the direction of movement	0.367	0.82
	(0.003)	(0.005)
Plywood with wood grains perpendicular to the direction of movement	0.388	0.384
	(0.005)	(0.002)

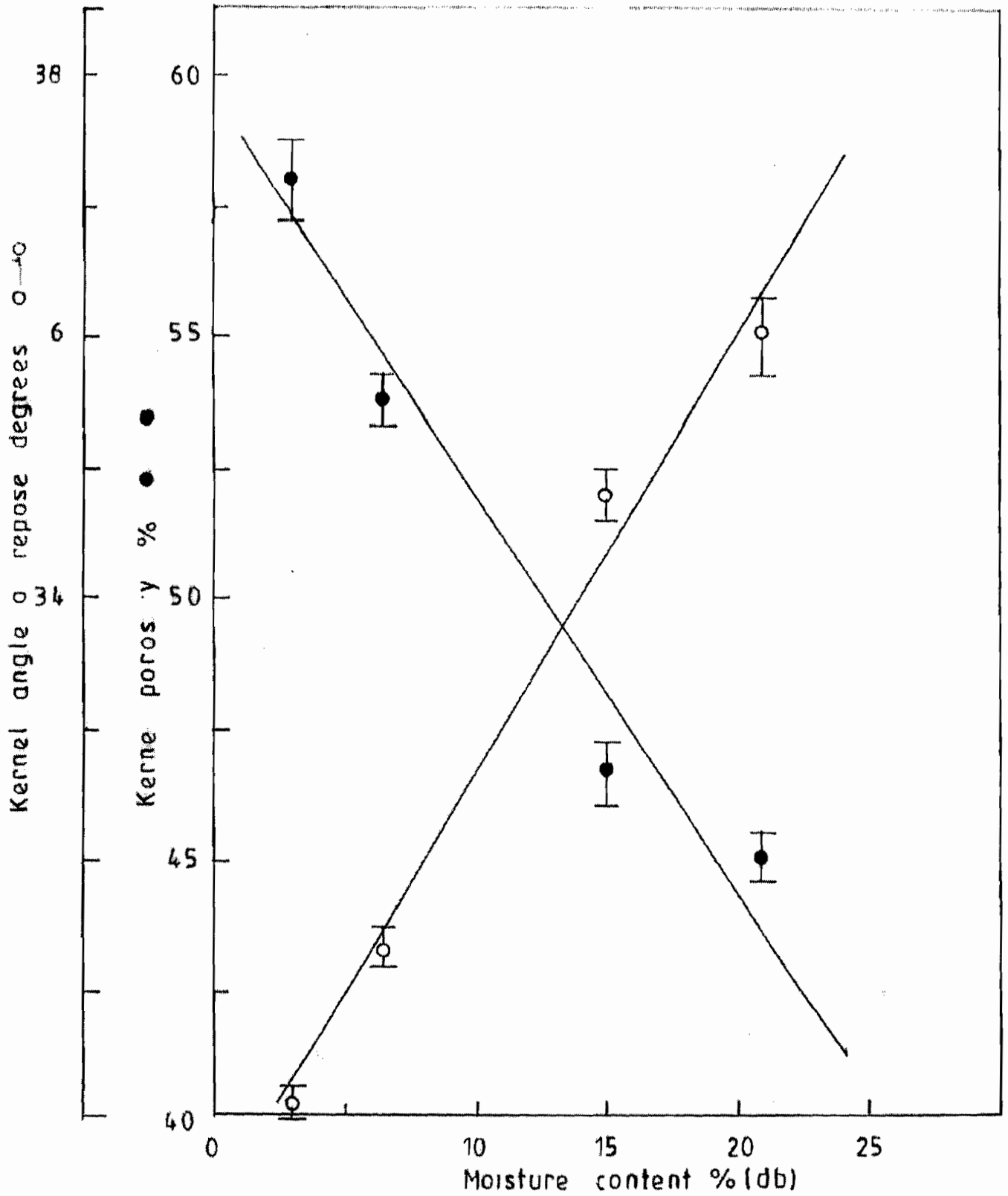*Values in parentheses are standard deviations*

Fig. 5   Effect of moisture content on kernel porosity and angle of repose
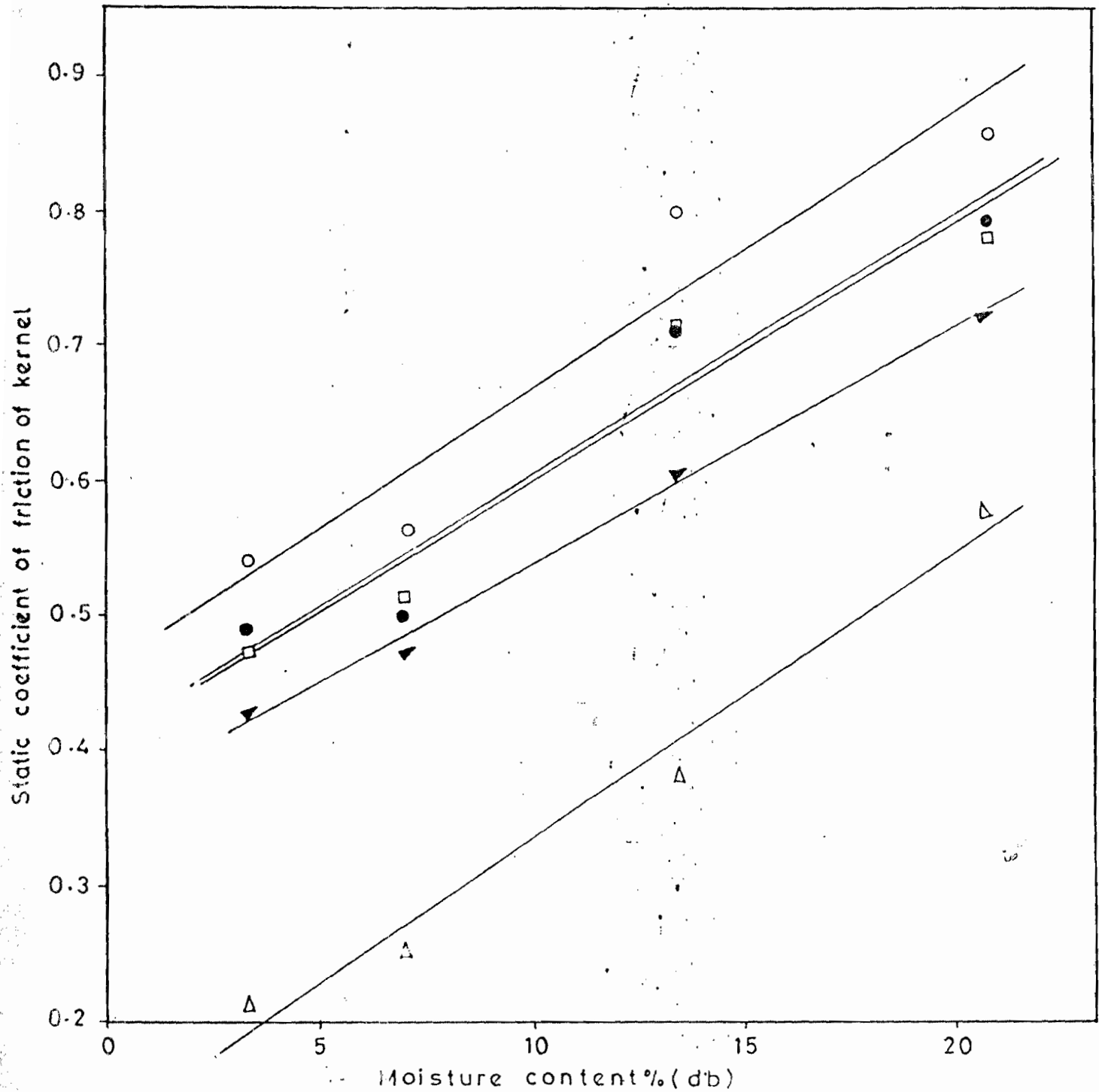
Fig.6. Effect of moisture content on static coefficient of friction of kernel: o—o plywood with grains perpendicular, ●—● plywood with grains parallel, □—□ Hessian bag material, ▼—▼ Galvanized steel △—△ Glass.
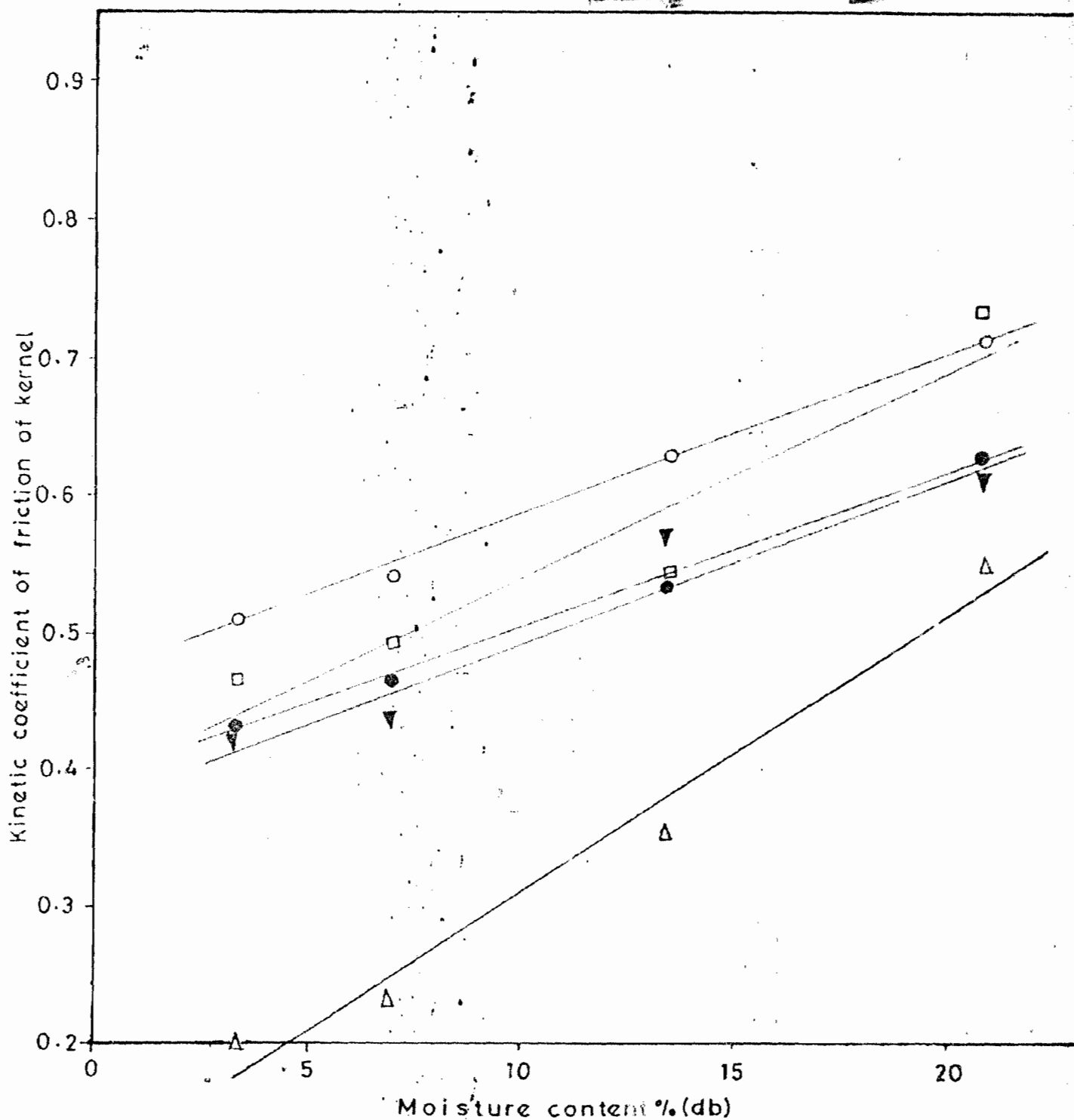
Fig. 7. Effect of moisture content on the kinetic coefficient of friction of kerne
o——o plywood with grains perpendicular, ●——● plywood with grains
parallel, □——□ Hessian bag material ▼——▼ Galvanized steel, ∆——∆ Glass.

faces and moisture contents are presented below

$$f_{ks} = 0.360 + 0.018 \, M \quad (R^2 = 0.99) \quad (12)$$

$$f_{kg} = 0.122 + 0.021 \, M \quad (R^2 = 0.98) \quad (13)$$

$$f_{kh} = 0.405 + 0.019 \, M \quad (R^2 = 0.95) \quad (14)$$

$$f_{kr} = 0.403 + 0.019 \, M \quad (R^2 = 0.94) \quad (15)$$

$$f_{kl} = 0.464 + 0.0204 \, M \quad (R^2 = 0.92) \quad (16)$$

The maximum value of the nut static coefficient of friction at the moisture content of 3.84% (db) was obtained on hessian bag material, while the minimum value was on glass surface. In the moisture range of 3.32 – 20.70% (db), the kernel static coefficient of friction showed maximum values on plywood with wood grains perpendicular to the direction of movement and minimum on glass. Similar trend was observed on the kinetic coefficient of friction. Fig. 7 shows that kernel kinetic coefficient of friction increased with moisture content and varied according to the surface on which the kernel moved. The relationships between the kernel kinetic coefficient of friction on various structural surfaces and moisture contents are presented as follows:

$$\mu_{ks} = 0.375 + 0.012M \quad (R^2 = 0.92) \quad (17)$$

$$\mu_{kg} = 0.107 + 0.0204M \quad (R^2 = 0.97) \quad (18)$$

$$\mu_{kh} = 0.392 + 0.015M \quad (R^2 = 0.90) \quad (19)$$

$$\mu_{kr} = 0.397 + 0.0104M \quad (R^2 = 0.99) \quad (20)$$

$$\mu_{kl} = 0.468 + 0.012M \quad (R^2 = 0.99) \quad (21)$$

Conclusions

The physical properties necessary in the design and development of machines and systems for post harvest handling and processing of shea nut were evaluated at a moisture content of 3.84% (db). These include the axial dimensions (major, intermediate and minor diameters), roundness, sphericity, particle and bulk densities, porosity, angle of repose and static and kinetic

coefficients of friction on different structural surfaces. The frequency distribution curves of axial dimensions tend toward normal. The intermediate and minor diameters show close relationship with the major diameter, and from the values of roundness and sphericity obtained the nut and kernel could be treated as spheres in analyses requiring an approximation of their shapes. At the above moisture content, the nut size, roundness, sphericity and volume are higher than those of the kernel, while the particle and bulk densities, porosity, angle of repose and static and kinetic coefficients of friction on the same structural surfaces are lower. These will be of important consideration in the design of the nut cracking machine, the discharge system and the separator for materials obtained from nut cracking operation.

The kernel properties were found to vary with moisture content. The axial dimensions of the kernel, volume, bulk density, angle of repose and static and kinetic coefficients of friction on different structural surfaces all increased with moisture content in the moisture range of 3.32 to 20.70% (db). The particle density and porosity of the kernel decreased with increase in moisture content in the above range.

Notation

A_c area of the smallest circumscribing circle, mm^2

A_p largest projected area, mm^2

a   major diameter, mm

b   intermediate diameter, mm

c   minor diameter, mm

d_c diameter of the smallest circumscribing circle, mm

d_i diameter of the largest inscribing circle, mm

M   moisture content, %

m   mass, kg

p   porosity, %

v   volume, mm^3

ρ_b bulk density, kg/m^3

ρ_t true density, kg/m^3

0   angle of repose, deg.

f   static coefficient of friction

μ kinetic coefficient of friction

Subscripts

g   glass

h   hessian bag material

k   kernel

l   plywood with wood grains parallel to the direction of movement

n   nut

r   plywood with wood grains perpendicular to the direction of movement

s   galvanized steel sheet.

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