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EFFECTS OF VARIETY AND MOISTURE CONTENT ON THE COEFFICIENT OF SLIDING FRICTION OF PALM KERNEL AND SHELL ON LEATHER TARPAULIN

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ABSTRACT

One of the means of separating palm kernel and shell mixture is the coefficient of sliding friction which distinguishes the textural patterns of separating materials and its medium of separation. A thorough study of factors that can affect textural properties should be considered for an effective separation of palm kernel and shell. The effects of moisture content of two varieties of palm kernel and shell on the coefficient of sliding friction of two faces (front and back) of leather tarpaulin material was determined. The moisture content of both *tenera* and *dura* palm kernel and shell were determined according to the ASAE standards (1998) for oil seeds. The moisture content was adjusted to the desired value by adding a calculated volume of distilled water. The moisture content of *dura* and *tenera* varieties were 17.4 and 18.2% (w.b.) respectively, which were individually adjusted to 9.0, 13.0 and 17.0% (wet basis) by adding 76.3, 39.8 and 3.3 g; and 82.3, 46.4 and 10.6 g distilled water, respectively. The coefficient of sliding friction of sample variety was determined through an angle of repose apparatus. The coefficient of sliding friction for *dura* kernel and shell on the two faces (face A - front and face B - back) of the leather tarpaulin ranged from 0.41-0.49 for 9% moisture content; 0.44-0.51 for 13% moisture content; and 0.45-0.52 for 17% moisture content. The coefficient of sliding friction for *tenera* kernel and shell on the two faces of the leather tarpaulin ranged from 0.43-0.66 for 9% moisture content; 0.42-0.66 for 13% moisture content; and 0.42-0.73 for 17% moisture content. The moisture content of palm kernel and shell of either *dura* or *tenera* variety had no significant effect on the coefficient of sliding friction on any face of the leather tarpaulin except *tenera* shell, on face B of the leather tarpaulin.

Keywords: textural pattern; kinetic friction; mixture separation; sliding friction

INTRODUCTION

Sliding friction can also be referred as kinetic friction which is a force that opposes the sliding motion of two surfaces moving relative with each other. In dissimilitude, static friction is a force of friction between two surfaces that are pushing against each other, but not sliding relative to each other. Therefore, the force applied before the sliding begins, is opposed by static friction. The static friction involves higher resistance than sliding friction. The constant of proportionality is a unitless quantity called the coefficient of friction which proportionately depends on the surfaces in contact. The definition given by Chakraverty (1972) about the coefficient of friction between granular materials as the tangent of the angle of internal friction for material which was in accordance with the Equation 1. It was iterated that the coefficient of friction depends on grain shape, surface characteristics and grain moisture content.

$$\mu = tan\theta \qquad .... (1)$$

Where μ is the coefficient of friction and θ is the angle of internal friction.

An important process in the industrial utilization of the palm kernel and shell in the downstream is the effective separation of the kernel and shell. Palm kernel nut cracking results into a mixture of kernel and broken shell of irregular shapes and incomparable sizes depending on the method of cracking. Therefore, the need to separate the kernel from the mixture bestows a major challenge in the palm kernel oil extraction process for other downstream industrial usage (Olasumboye and Koya, 2014).

Two techniques are employed in the separation of the mixture of palm kernel and shell: wet and dry methods. The wet method is a separation in a liquid medium, based on the difference in specific gravities of the constituents. Industrially, palm kernel/shell mixture is separated by wet method which uses one of brine solution, clay-bath or hydro cyclone and aerodynamic properties (Olasumboye and Koya, 2014). However, the use of the wet method has some challenges: requirement of large volume of water for the separation; the disposal of water after using the clay bath; ability to maintain the solution within the appropriate density range; and energy and time required for re-drying the kernels. The dry method requires no liquid medium for its separation but gravity, speed variation, relative motion, coefficient of friction and shape of the separating materials. Some of the dry methods investigated earlier include handpicking, inclined table separators with or without induced vibration (Akubuo and Eje, 2002; Koya and Faborode, 2011; Aderinlewo *et al.*, 2018), winnowing column (Halim *et al.*, 2009), dispatch of kernel and shell from a spinning disc (Koya and Faborode, 2006) and rotary separator (Olasumboye and Koya, 2014). All these methods had various limitations and are not very suitable for industrial applications. Another machine was developed by Adepoju (2019) called kernel and shell inclined draper separator that uses the principle of coefficient of sliding friction and shape. The separator uses the texture of canvas materials and shape of sample variety to effect separation. According to Antia *et al.*, 2014, listed moisture content as one of the factors that can affect the separation of palm kernel from palm shell.

This research therefore, investigated the effects of moisture content on the coefficient of sliding friction of two varieties of palm kernel and shell on the coefficient of sliding friction of two faces (front and back) of leather tarpaulin material that can be used on the palm kernel and shell inclined draper separator.

MATERIALS AND METHODS

Materials

The materials used to determine the moisture content and coefficient of sliding friction of palm kernel and shell were: oven, *dura* palm kernel and shell, *tenera* palm kernel and shell, angle of repose apparatus, desiccator (180 ml), digital weighing balance (Scout Pro (SPU2001) electronic balance with accuracy 0.1 g) and centrifugal cracker.

Methods

Sample collection

The *tenera* nuts used in this study were acquired from the Directorate of University Farms (DUFARMS), Federal University of Agriculture, Abeokuta (FUNAAB) while *dura* nuts were collected from Ogun State Ministry of Agriculture, Eweje, Odeda, Abeokuta, Ogun State.

Sample preparation

The nuts of *dura* and *tenera* were manually cleaned from unwanted materials such as cell debris, stones and dirt. Then, the nuts were cracked using a centrifugal cracker to obtain a mixture palm kernels and shells.

Determination of moisture content

The moisture content of the palm kernel and shell were determined for *dura* and *tenera* varieties of palm kernel and shell in the Agricultural and Bio-Resources Engineering Crop Processing Laboratory, College of Engineering, Federal University of Agriculture, Abeokuta (FUNAAB). An ASAE standards (1998) for oil seeds as described by Orhevba *et al*., (2013) was used to determine the initial moisture content of the cracked mixture of palm kernels and shells of the two varieties. A mass of 1.20 kg of palm kernels and shells of the two varieties was measured individually and put in an oven at 105^{o}C for the first six (6) hours after which it was put in a desiccator (180 ml) to allow them to cool down before measuring the individual mass with a digital weighing balance (Scout Pro(SPU2001), an electronic balance with accuracy 0.1 g and to avoid the palm kernel and shell absorbing moisture when brought out of the oven. Subsequently, the mass of either palm kernels or palm shells was checked at every one (1) hour in order to get a constant mass. Immediately the mass of either palm kernel or palm shell was constant, the final mass was weighed and the Equation (2) was used to compute the initial moisture content. Each of palm kernel and palm shell for the two varieties was divided into three (3) portions for moisture adjustment.

$$mc = \frac{w_{1-w_2}}{w_1}$$ … (2) (Adepoju *et al*., 2023)

Where: mc is the moisture content (%wet basis), w_1 is the initial mass (g)and w_2 is the final mass (g).

Moisture content adjustment

A calculated amount of distilled water was added to the six (6) samples of the mixture of palm kernels and shells of the two varieties to bring them to the desired moisture contents of 9, 13 and 17% wet basis (w.b.) using the Equation (3) as described by Olayanju (2002) and sealed in separate polythene bags. Afterwards, the polythene was kept in refrigerator at 5°C temperature for at least one week to ensure moisture uniform distribution according to Davies and Zibokere (2011).

$$Q = \frac{A(b - a)}{(100 - b)}$$ … (3)

Where: A is Initial mass of the sample, g; a is initial moisture content of the sample, % (w.b.); b is final (desired) moisture content of sample % (w.b.); Q is mass of water added, g.

Determination of coefficient of sliding friction

Each variety of palm kernels and shells were loaded in turns into a bottomless four-sided cardboard made box of dimension 100 50 30 mm on the tilting board (Plate 1). In order to allow free movement of the sample, one of the edges of the box was not fixed in order to allow for movement of the crop product component on the board surface covered with leather tarpaulin material (Plate 2). An adjustable screw jack was positioned under the apparatus for controlling the angle of inclination. The box was loaded in turns with the two varieties of kernels and shells. The tilt angle at initial sliding of the box was noted for five readings and averaged. The coefficient of sliding friction was calculated with the Equation (4).

$$\mu = tan\theta \quad ...(4)$$

Where μ is the coefficient of sliding friction and θ is the angle of inclination (degree).

Plate 1: Angle of repose apparatus

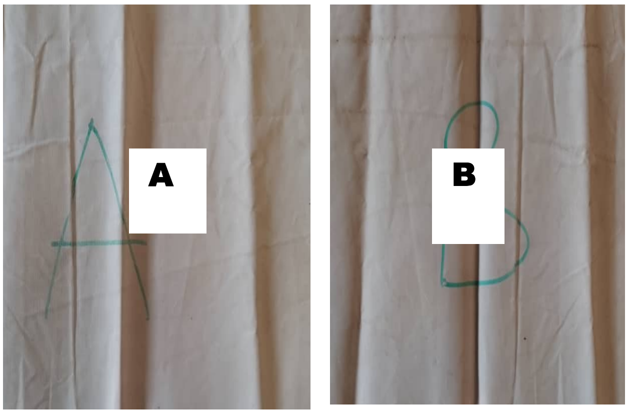

Plate 2: Leather tarpaulin for the two faces

Experimental design

The experimental design used was 3×2×2×2 factorial experiment where three (3) moisture contents were used for two (2) varieties of two (2) samples (palm kernel and shell) on two (2) faces of leather tarpaulin material (face A- front and face B - back) at five (5) replicates (Table 1). The total runs for the determination of coefficient of sliding friction was one hundred and twenty (120).

Table 1: Parameter Measurement

S/N	Parameter	Level	Values
1	Moisture content	3	9, 13 and 17% w.b.
2	Variety	2	Dura and tenera
3	Sample	2	Palm kernel and palm shell
4	Faces of the leather tarpaulin material	2	Face A-front and face B-back

Data analysis

The coefficient of sliding friction obtained for the three (3) moisture content of two (2) varieties of two (2) samples on two (2) faces of leather tarpaulin material (face A and face B) at five (5) replicates were analyzed using the analysis of variance (ANOVA). Separation of means was carried out by the use of Tukey Method.

RESULTS AND DISCUSSION

The moisture contents of dura and tenera varieties were 17.4 and 18.2% w.b. They were adjusted to 9, 13 and 17% w.b. by adding 76.3, 39.8 and 3.3 g; and 82.3, 46.4 and 10.6g distilled water respectively.

The dura kernel coefficients of sliding friction for 9, 13 and 17% moisture contents (w.b.) for face A and face B were 0.409, 0.458 and 0.450; and 0.471, 0.445 and 0.480 respectively. It was observed that the coefficient of sliding friction increased as the moisture content increased from 9 to 13% but decreased as the moisture content increased from 13 to 17% for the face A while the coefficient of sliding friction obtained decreased as the moisture content increased from 9 to 13% but increased as the moisture content increased from 13 to 17% for face B. The coefficient of sliding friction for face B was higher than coefficient of sliding friction for face A except at 13% moisture content (Table 2).

The dura shell coefficients of sliding friction for 9, 13 and 17% moisture contents (w.b.) for face A and face B were 0.488, 0.490 and 0.523; and 0.493, 0.515 and 0.510, respectively. It was observed that the coefficient of sliding friction increased as the moisture content increased from 9 to 17% for the face A while the coefficient of sliding friction obtained increased as the moisture content increased from 9 to 13% but decreased as the moisture content increased from 13 to 17% for face B. The coefficient of sliding friction for face B was higher than coefficient of sliding friction for face A except at 17% moisture content (Table 2); meaning that the textural pattern of the two faces was not exactly the same.

The coefficients of sliding friction of palm shell were higher than the coefficients of sliding friction of palm kernel on leather tarpaulin at the moisture contents used; meaning that the textural surface of palm shell is rougher than that of palm kernel.

Table 2: Moisture content and coefficient of sliding friction of *dura* palm kernel and shell on leather tarpaulin materials

Moisture content (%)	*Dura* palm kernel			
	Face A		Face B	
	θ°	μ	θ°	μ
9	22.2±2.17	0.409±0.04	25.2±1.64	0.471±0.03
13	24.6±1.34	0.458±0.03	24.0±1.41	0.445±0.03
17	24.4±1.52	0.454±0.03	25.6±1.82	0.480±0.04
Moisture content (%)	***Dura* palm shell**			
	Face A		Face B	
	θ°	μ	θ°	μ
9	26.0±1.58	0.488±0.03	26.2±1.79	0.493±0.04
13	26.2±1.79	0.493±0.04	27.2±1.92	0.515±0.04
17	27.6±1.95	0.523±0.04	27.0±1.87	0.510±0.04

The *tenera* kernel coefficients of sliding friction for 9, 13 and 17% moisture contents (w.b.) for face A and face B were 0.441, 0.433 and 0.437; and 0.429, 0.421 and 0.421, respectively (Table 3). The coefficient of sliding friction decreased as the moisture content increased from 9 to 13% but increased slightly as the moisture content increased from 13 to 17% for the face A while the coefficient of sliding friction obtained decreased as the moisture content increased from 9 to 13% but remained the same as the moisture content increased from 13 to 17% for face B. The coefficient of sliding friction for face A was higher than coefficient of sliding friction for face B (Table 3); meaning that the two faces were different in terms of their textural pattern.

The *tenera* shell coefficients of sliding friction for 9, 13 and 17% moisture contents (w.b.) for face A and face B were 0.660, 0.660 and 0.616; and 0.573, 0.606 and 0.727, respectively. The coefficient of sliding friction remained the same as the moisture content increased from 9 to 13% but decreased as the moisture content increased from 13 to 17% for the face A and the coefficient of sliding friction obtained increased as the moisture content increased from 9 to 17% for face B. The coefficient of sliding friction for face A was higher than coefficient of sliding friction for face B except at 17% (Table 3); meaning that the two faces were different in their textural pattern.

The coefficients of sliding friction of palm shell were higher than the coefficients of sliding friction of palm kernel on leather tarpaulin at the range of 9-17% (w.b.) moisture content. This means that the textural surface of palm shell is rougher than that of palm kernel. This observation was corroborated by Adepoju *et al.* (2023). The coefficients of sliding friction of *tenera* variety of either palm kernel or shell were higher than the coefficients of sliding friction of *dura* variety at the range of moisture content used and at the two faces of the leather tarpaulin. Adepoju *et al.* (2023) had earlier observed that because of the mass of *dura* variety of either palm kernel or palm shell which was higher than that of *tenera* variety, the force of gravity would be higher on the *dura* variety. Therefore, *dura* variety of either palm kernel or palm shell would have higher force to overcome the force that wanted to stop it from rolling or sliding as compared to *tenera* variety and that would connote that *dura* variety would roll or slide at a lower angle of inclination.

Table 3: Moisture content and coefficient of sliding friction of tenera palm kernel and shell on leather tarpaulin materials

Moisture content (%)	*Tenera* palm kernel			
	Face A		Face B	
	θ°	μ	θ°	μ
9	23.8±0.84	0.441±0.02	23.2±1.10	0.429±0.02
13	23.4±1.14	0.433±0.02	22.8±1.30	0.421±0.03
17	23.6±0.89	0.437±0.02	22.8±1.10	0.421±0.02

Moisture content (%)	*Tenera* palm shell			
	Face A		Face B	
	θ°	μ	θ°	μ
9	33.4±1.82	0.660±0.05	29.8±0.84	0.573±0.02
13	33.4±1.52	0.660±0.04	31.2±1.30	0.606±0.03
17	31.6±1.82	0.616±0.04	36.0±1.00	0.727±0.03

The moisture content of the *dura* palm kernel and *tenera* palm kernel had no significant effect on the coefficient of sliding friction for both face A and face B of leather tarpaulin (Table 4); meaning that, at the range of moisture content of palm kernel of *dura* and *tenera* used, the coefficient of sliding friction on both face A and face B of leather tarpaulin would be the same. This could be because of the nature of palm kernel's surface and the smoothness of the textural pattern on leather tarpaulin. Both the surfaces of palm kernel and leather tarpaulin were smooth, which in turn would reduce the force required to overcome the sliding friction of the palm kernel on the leather tarpaulin.

Table 4: Summary of analysis of variance of the effect of moisture content of the two varieties of palm kernel on coefficient of sliding friction for the two faces of the leather tarpaulin

	Source	DF	SS	MS	F-Value	P-Value
Dura kernel on face A	Moisture Content	2	0.007522	0.003761	2.97	0.090
	Error	12	0.015222	0.001268		
	Total	14	0.022744			
Dura kernel on face B	Moisture Content	2	0.003145	0.001572	1.30	0.308
	Error	12	0.014484	0.001207		
	Total	14	0.017629			
Tenera kernel on face A	Moisture Content	2	0.000170	0.000085	0.21	0.814
	Error	12	0.004863	0.000405		
	Total	14	0.005033			
Tenera kernel on face B	Moisture Content	2	0.000225	0.000113	0.19	0.825
	Error	12	0.006930	0.000578		
	Total	14	0.007155			

The moisture content of the palm shell of either *dura* or *tenera* variety had no significant effect on the coefficient of sliding friction for both face A and face B of the leather tarpaulin except *tenera* palm shell on the face B of the leather tarpaulin that was significant (Table 5). This means that at the range of moisture content used, the coefficient of sliding friction on the face A and face B of the leather tarpaulin would be the same except for *tenera* palm shell on face B. This observed no significant effect of the moisture content of palm shell of either *dura* and *tenera* on the coefficient of sliding friction, could be as a result of the nature of the surfaces of palm shell and leather tarpaulin. The surface of *dura* shell was smoother than the surface of *tenera* shell and this could have been the reason why the *tenera* palm shell was significant on the face B of the tarpaulin because the coefficients of sliding friction of the two faces were similar (Tables 2 and 3).

Table 5: Summary of analysis of variance of the effect of moisture content of the two varieties of palm shell on coefficient of sliding friction for the two faces of the leather tarpaulin

	Source	DF	SS	MS	F-Value	P-Value
Dura shell on face A	Moisture Content	2	0.003698	0.001849	1.22	0.330
	Error	12	0.018202	0.001517		
	Total	14	0.021900			
Dura shell on face B	Moisture Content	2	0.001351	0.000676	0.40	0.676
	Error	12	0.020052	0.001671		
	Total	14	0.021403			
Tenera shell on face A	Moisture Content	2	0.006488	0.003244	1.80	0.207
	Error	12	0.021579	0.001798		
	Total	14	0.028067			
Tenera shell on face B	Moisture Content	2	0.065684	0.032842	47.67	0.000
	Error	12	0.008267	0.000689		
	Total	14	0.073951			

The coefficients of sliding friction of *tenera* shell on leather tarpaulin (Face B) were similar at 9% and 13% moisture contents. However, both were significantly lower than the coefficient of sliding friction measured at 17% moisture (Table 6).

Table 6: Summary of separation of means using Tukey Method for the coefficient of sliding friction of *tenera* shell on leather tarpaulin

Moisture Content (%)	*Tenera* shell B
17	0.727 ± 0.03^{a}
13	0.606 ± 0.03^{b}
9	0.573 ± 0.02^{b}

Means with different letters are significantly different at $p<0.05$

CONCLUSION

This study obtained values for coefficient of sliding friction as affected by the moisture content of the sample on two faces of leather tarpaulin material which are needed to understudy canvas materials for frictional separation. The following conclusions were drawn from the study:

For both *dura* and *tenera* varieties, the coefficients of sliding friction of palm kernel and shell on the two faces of a leather tarpaulin fluctuated with moisture content. Overall, the coefficient of sliding friction of shells was higher than that of kernels.

Also, the *tenera* variety exhibited a higher coefficient of sliding friction than the *dura* for both kernel and shell at the tested moisture levels.

Moisture content was found to have an insignificant effect on coefficients of sliding friction for most combinations, with the sole exception of the *tenera* shell on face B of the leather tarpaulin, where it had a significant impact.

REFERENCES

Adepoju, V. O. 2019. Design and Fabrication of a Draper Separator for Palm Kernel and Shell, Unpublished Master of Engineering Thesis, Department of Agricultural and Bio-Resources Engineering, Federal University of Agriculture, Abeokuta. Pp 68 – 103.

Adepoju, V. O., Aderinlewo, A. A., Dairo, O. U., Adetunji, O. R., and Babalola, A. A. 2023. Determination of some physical properties of palm kernel and shell in relation to frictional separation. *Journal of Natural Science, Engineering and Technology*, 22(1):39-52.

Aderinlewo, A. A., Agboola, A. A., Adeosun, O. J., Ajisegiri, E. S. A. and Adisa, A. F. 2018. Investigation of Separation of Palm Kernel and Shell on an Inclined Plane Separator. *Acta Technica Corviniensis-Bulletin of Engineering* 2:135 – 137.

Akubuo C. O. and Eje B. E. 2002. Palm kernel and shell separator. *Biosystems Engineering,* 81(2): 193-199, doi: 10.1016/j-biosystemseng. 2001.0029.

Antia, O. O., Olosunde, W. and Offiong A. 2014. Determination of Optimum Moisture Content of Palm Nut Cracking for Efficient Production of Whole Kernel. *Nigerian Journal of Technological Development* 11(2):27-30.

American Society of Agricultural Engineers (ASAE) Standards 1998. Moisture measurement – unground grain and seeds. *American Society of Agricultural Engineers (ASAE),* S352.2:551.

Chakraverty, A. 1972. Post-Harvest Technology of Cereals. Co Pvt, LTD, New Delhi, Bombay, Calcutta.

Davies, R. M., and Zibokere, D.S. 2011. Effect of moisture content on some physical and mechanical properties of three varieties of cowpea (*Vigna unguiculata L. Walp*). *Agric Eng Int: CIGR Journal*, 13(1):1-8.

Halim, R. M., Bakar, N. A, Wahid, M. B., May, C. Y, Ramli, R., Ngan, Ma Ah, M, R. 2009. Maximizing the Recovery of Dry Kernel and Shell via a Four Stage Winnowing Column. *MPOB Information Series* (MPOB TT No. 427).

Koya O. A., and Faborode M. O. 2011. Influence of Nut Cracking Methods on Kernel Quality and Separability of Product. *Ife Journal of Technology,* 20(1):1115-9782.

Koya, O. A. and Faborode, M. O. 2006. Separation Theory for Palm Kernel and Shell Mixture on a Spinning Disc. *Biosystems Engineering*, 95(3):405–412, doi.10.1016/j.biosystemseng.2006.07.005.

Olasumboye, A. and Koya, O. 2014. A Rotary Separator for the Dry Mixture of Palm Kernel and Shell. *Innovative Systems Design and Engineering,* 5(7):32-41.

Olayanju, T. M. A. 2002. Design, Fabrication and Evaluation of a Beniseed (Sesamum Indicum L.) Oil Expeller. An Unpublished Ph.D. Thesis at the Department of Agricultural Engineering, University of Ibadan, Nigeria. Pp 68 – 101.

Orhevba, B. A., Chukwu, O., Osunde, Z. D., and Ogwuagwu, V. 2013. Influence of moisture content of the yield of mechanically expressed neem seed kernel oil. *Academic Research International*, 4 (5): 252 – 257.

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