Effect of Moisture Content and Types of Structural Surfaces on Coefficient of Friction of Two Nigerian Food Grains: Sorghum (*Sorghum bicolor*) and Millet (*Pennisetum glaucum*)

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ABSTRACT

The knowledge of coefficient of friction of food grains on various structural surfaces is important in analysis and design of post harvest handling, food processing and storage equipment. Measurements were made to determine the coefficient of friction of two local food grains (sorghum and millet). Effects of various structural surfaces and different moisture content levels on the measured parameters (coefficient of friction) were determined. Both factors examined had a high significant effect ($P < 0.01$) on the coefficient of friction of the grains. The coefficient of friction obtained for sorghum ranged from 0.43 ± 0.05 to 0.71 ± 0.12 over a moisture content range of 22.9 to 33.3 % (wb). That of millet ranged from 0.19 ± 0.04 to 0.46 ± 0.08 over a moisture range of 21 % to 34.7 % (wb). For sorghum, the highest values of coefficient of friction were obtained with concrete followed by steel, wood and plastic. Coefficient of friction for the grains increased linearly with increase in moisture content. For millet, the highest values of coefficient of friction were obtained with concrete surfaces, followed by steel, plastic and wood.

Keywords: Coefficient of friction, structural surfaces, grain handling, sorghum, millet Nigeria.

1. INTRODUCTION

Sorghum and millet are of great importance as staple foods in many parts of Nigeria and the West African sub-region. They constitute major sources of energy and protein in these countries. Many countries rely upon sorghum and millet as their principal raw materials for beverages. Sorghum contains about 71 % carbohydrate and 10 % protein while millet contains about 73 % carbohydrate and 11 % protein. Other nutrients such as fibre, vitamins and minerals are present in lesser quantities.

The knowledge of coefficient of friction of the food grains on various structural surfaces is necessary in analysis and design of post-harvest grain handling, processing and storage equipment such as grain bins, silos, conveyors, flow of food grain from bins by gravity or loaded auger and other machines. A machine can only be started or stopped if forces of static friction or dynamic friction are overcome by a power source. Therefore, information on both static and dynamic coefficient of friction is vital in estimating the power requirement of machines.

Efforts have been made to determine the coefficient of friction of some agricultural products using different methods (Mohsenin, 1980; Singh and Goswami, 1996; Shinoj and Viswanathan, 2006). Kramer (1944) employed the method of inclined plane to study the coefficient of friction of rough rice. The method, based on moving a given surface against the material, has been used by several investigators (Buelow, 1961; Brubaker and Pos, 1965; Snyder et al., 1967). In this method, the contact driven surface is either mounted on a revolving circular disc or on a horizontal table. In most cases, the static friction coefficient is measured on a slope of adjustable angle usually given by the tangent of the angle at which the material starts to slide down the slope (Sitkei, 1986). Ghosh (1966) used the conventional tilting table. This was found to be inaccurate and subject to error as it involved manual lifting. Coefficient of friction of apples on several surfaces was measured by Vis et al (1968). These investigators held the apples in a special mechanism equipped with a load cell and moved the test surfaces, mounted on a horizontal platform driven by an electric motor at a given speed. Correa et al (2007) employed a digital roughness measurement apparatus to study the static friction coefficient of rice in processing.

A different friction apparatus was used in carrying out friction study reported in this paper. This made use of a Joggle Jack whose major design consideration was the selection of a suitable pitch and diameter of spindle screw. To eliminate errors and ensure accuracy, a fine threaded spindle to raise the inclined surface by a minimum pitch of 1.0 mm on M6 diameter was required. Other design details were documented by Agida (1995). The apparatus has been used to study the angle of friction of maize and rice (Obetta and Onwualu, 1999). This property has not been determined for many other Nigerian grains including sorghum and millet.

The main objective of this paper is to describe the measuring apparatus and generate data on coefficient of friction of sorghum and millet. The work also determined the effect of moisture content and different structural material surfaces on friction coefficient of these two local grain crops.

2. MATERIAL AND METHODS

2.1 Test Apparatus

The friction measuring apparatus is illustrated in Figure 1. It consists of a Joggle Jack (6), with accessories, including a protractor (1), test surface (2), surface plate (3), absorber (4), lever arm (5), base plate (7), glass cover (8), screw, bolt, nuts, ball bearing, and pins. Other component parts include interchangeable surfaces, cover plate, hinges, and structural frame as shown in Figure 1.

The lever arm is rotated in a clockwise direction; and one revolution of a Joggle Jack raises the platform base, giving a pitch of 1.00 mm and test surface inclination of 0.5°. At the contact point between the Joggle Jack and the testing surface plate holder, a damper material is fitted into the arrangement to minimize vibration.

The protractor registers any little change in the inclination of the test surface up to an angle of 45° which is within the range of angle of friction for most biological materials. The device provides stable and reliable readings and errors may only result from wrong reading of the calibrated values of the protractor.

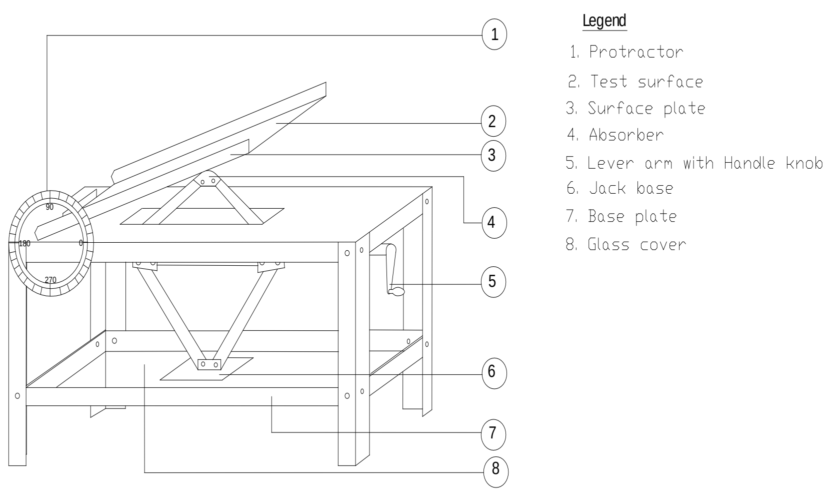

Figure 1: Friction Measuring Apparatus

2.2 Test Procedure

The grain crops used in this study were sorghum (*Sorghum bicolor*) and millet (*Pennisetum glaucum*) and were obtained from a local market in Benue State, Nigeria. The various structural material surfaces studied were concrete (Steel trowel finish), Plastic, Steel and Plywood. These were selected based on their use in construction of storage structures and handling equipment in the locality.

The samples of the two different grain crops were conditioned to obtain samples at five different moisture levels. For sorghum grains, the moisture content of 22.9, 26.6, 31, 32.9 and 33.3 percent on a wet weight basis were achieved, while for millet crop, moisture content of 21, 23.6, 27.5, 29.4 and 34.7 percent wet basis were obtained. These ranges of moisture were selected to coincide with the normal moisture content of the crops at harvest.

The test sample was carefully loaded and the Joggle Jack spindle rotated while the test sample was observed for sliding. The rotation of the Joggle Jack handle was done gradually and steadily for an accurate result; and the angle at which the material started to slide down the test surface was read from the protractor. The tangent of this angle gave the static coefficient of friction of the grains on the test surfaces.

2.3 Experimental Design and Data Analysis

The tests were carried out using a randomized complete block factorial design to study the effect of moisture content and different structural surfaces on the static coefficient of friction. The moisture levels formed the levels of one factor while the structural surfaces formed the levels of the other factor. The two factors had four and five observations per experimental cell. A total of 100 observations were made for each grain type. Data obtained were subjected to Analysis of Variance (ANOVA) to detect treatment effects, and regression analysis to obtain empirical predictive equations.

3. RESULTS AND DISCUSSION

3.1 Coefficient of Friction of the Food Grains

Tables 1 and 2 show the results of the determination of coefficient of friction of sorghum and millet respectively at different moisture content levels and various structural surfaces.

Table 1. Coefficient of friction of sorghum grain at different moisture content and structural surfaces

Moisture content % wet basis	Coefficient of friction(μ)			
	Concrete	Plastic	Steel	Wood
22.9	0.58±0.05	0.43±0.05	0.48±0.04	0.45±0.08
26.6	0.61±0.11	0.46±0.17	0.53±0.06	0.48±0.11
31.0	0.65±0.09	0.48±0.08	0.58±0.08	0.51±0.10
32.9	0.68±0.08	0.51±0.06	0.62±0.09	0.53±0.05
33.3	0.71±0.12	0.54±0.13	0.64±0.02	0.55±0.09

Table 2. Coefficient of friction of millet grain at different moisture content and structural surfaces

Moisture content % Wet basis	Coefficient of friction(μ)			
	Concrete	Plastic	Steel	Wood
21.0	0.35±0.08	0.22±0.02	0.26±0.06	0.19±0.04
23.6	0.37±0.07	0.24±0.04	0.27±0.09	0.22±0.03
27.5	0.40±0.10	0.27±0.03	0.30±0.04	0.24±0.08
29.4	0.43±0.08	0.29±0.05	0.32±0.02	0.26±0.01
34.7	0.46±0.08	0.30±0.02	0.35±0.07	0.28±0.03

The analysis of variance for coefficient of friction for both sorghum and millet was carried out with moisture content and structural surfaces as factors. Moisture content and structural surfaces were found to have high significant effect (P = 0.01). The interaction of moisture content and structural surfaces was also found to be highly significant (P = 0.01). The summary of the results of analysis of variance for coefficient of friction for the two grain crops are shown in Tables 3 and 4.

Table 3. Analysis of variance table for sorghum

Source of Variation	Df	SS	MS	Fcal	Ftab 1%
Blocks	4	0.000756	0.000189	2.46^{ns}	3.60
Moisture content	4	0.192866	0.048216	627.043*	3.60
Structural surface	3	0.40778	0.1359286	1767.69*	4.08
Interaction	12	0.00923	0.000769	10.0028*	2.46
Error	76	0.005844	0.0000768		
Total	99	0.616476			

Df = degree of freedom; SS = sum of squares; MS = Mean square; Fcal = Calculated F
Ftab = Tabulated F; ns = not significant; * = Significant effect

Table 4. Analysis of variance table for millet

Source of Variation	Df	SS	MS	Fcal	Ftab 1%
Blocks	4	0.000266	0.0000665	1.177^{ns}	3.60
Moisture content	4	0.10706	0.256765	454.45*	3.60
Structural surface	3	0.385523	0.128507	2274.47*	4.00
Interaction	12	0.002702	0.00022516	3.98*	2.46
Error	76	0.004294	0.0000565		
Total	99	0.49549			

Df = degree of freedom; SS = sum of squares; MS = Mean square; Fcal = Calculated F
Ftab = Tabulated F; ns = not significant; * = Significant effect

3.2 Effect of Moisture Content on Coefficient of Friction

Figure 2 shows the effect of moisture content on the coefficient of friction of sorghum grains. It is observed from the figure that the coefficient of friction increased with an increase in moisture content for all the structural surfaces tested. For sorghum, the coefficient of friction varied from 0.43±0.05 to 0.71±0.12 over a moisture range of 22.9 % to 33.3 %. The results obtained for sorghum showed higher values than that of millet. The higher values may be attributed to the higher bulk density of sorghum and also the inter-particulate cohesion of these grains among themselves. The corresponding regression equations with their corresponding correlation coefficients for sorghum are shown on Table 5. The table shows that there is a linear relationship between moisture content and coefficient of friction.

Figure 3 shows the effect of moisture content on coefficient of friction for millet grain. The figure indicates that the coefficient of friction increased with increase in moisture content for all the structural surfaces tested. It ranged from 0.19±0.04 to 0.46±0.08 over a moisture range of 21 % to 34.7 %. The results of the regression analysis carried out between the coefficient of friction and moisture content for all the structural surfaces tested with their corresponding correlation coefficients are presented on Table 6 for millet.

Table 5. Regression equations for predicting coefficient of friction from moisture content for sorghum grain

Structural surface	Regression equation	Correlation coefficient
Concrete	$\mu = 0.314 + 0.011M$	0.936
Plastic	$\mu = 0.219 + 0.009M$	0.887
Steel	$\mu = 0.144 + 0.014M$	0.978
Wood	$\mu = 0.248 + 0.008M$	0.963

μ = coefficient of friction; M = moisture content %(wb)

Table 6. Regression equations for predicting coefficient of friction from moisture content for millet grain

Structural surface	Regression equation	Correlation coefficient
Concrete	$\mu = 0.176 + 0.008M$	0.982
Plastic	$\mu = 0.097 + 0.006M$	0.930
Steel	$\mu = 0.112 + 0.006M$	0.988
Wood	$\mu = 0.062 + 0.006M$	0.960

μ = coefficient of friction; M = moisture content %(wb)

3.3 Effect of different Structural Surfaces on Coefficient of Friction

The results (Tables 1-6, Figs. 2 and 3) show that the coefficient of friction of food grains does not only depend on the moisture content of the grain but also on the structural surfaces in contact with the grain. The highest values of coefficient of friction for sorghum (0.58 ± 0.05 to 0.71 ± 0.12 over a moisture range of 22.9 to 33.3 %) were obtained with concrete. This was followed by steel (0.48 ± 0.4 to 0.64 ± 0.02), wood (0.45 ± 0.08 to 0.55 ± 0.09) and plastic (0.43 ± 0.05 to 0.54 ± 0.13). For millet, the highest values were obtained with concrete (0.35 ± 0.08 to 0.46 ± 0.08, over a moisture range of 21 % to 34.7 %). This was followed by steel (0.26 ± 0.06 to 0.35 ± 0.07), plastic (0.22 ± 0.02 to 0.3 ± 0.02) and wood (0.19 ± 0.04 to 0.28 ± 0.03). These have implications for the choice of these materials in design of handling, processing and storage equipment for these grains in particular and other grains in general.

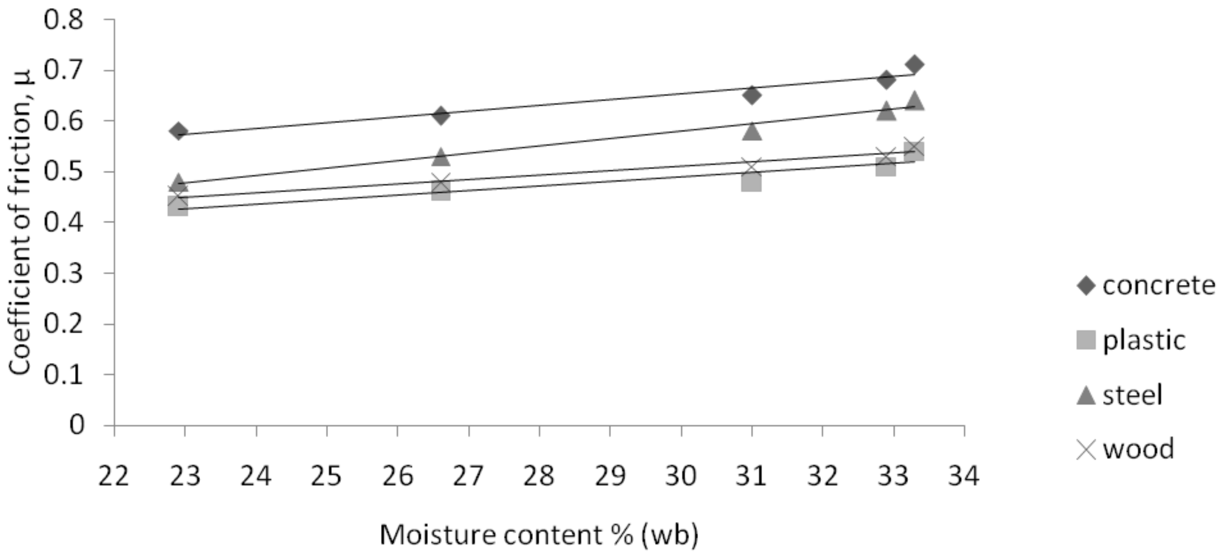

Figure 2: Effect of moisture content on coefficient of friction of sorghum grain

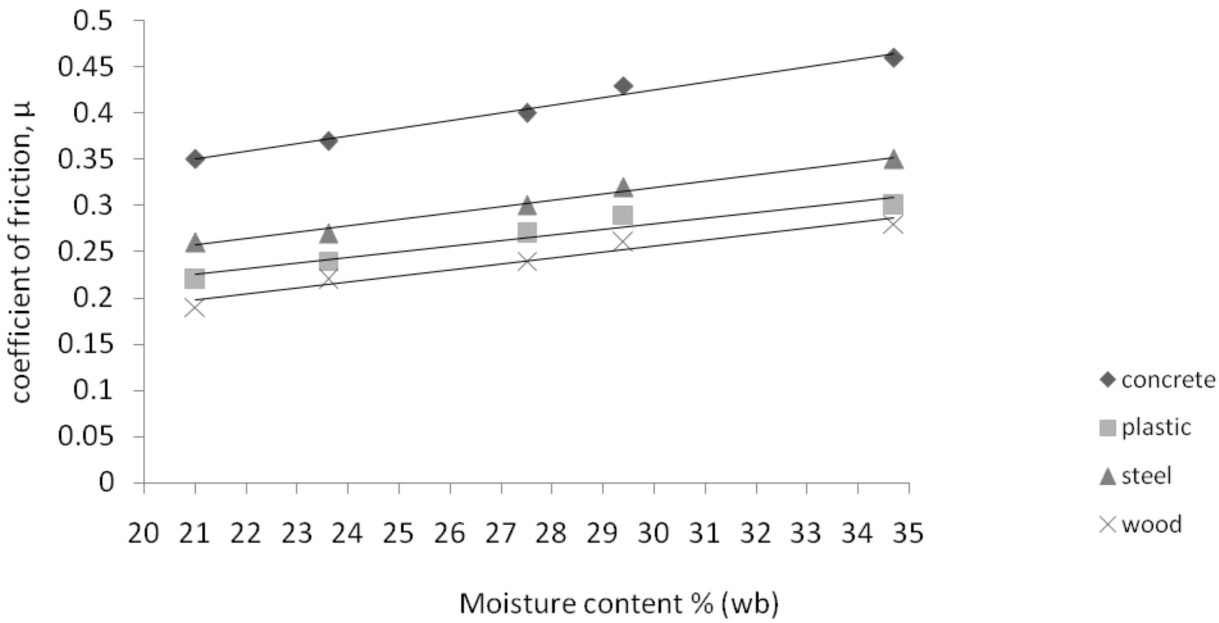

Figure 3: Effect of moisture content on coefficient of friction of millet grain

4. CONCLUSIONS

The method and procedure reported in this paper are adoptable and reliable means of measuring coefficient of friction of food grains on various structural surfaces. Moisture content and structural surfaces significantly affected coefficient of friction of sorghum and millet. For sorghum and millet grains, the coefficient of friction increased linearly with increase in moisture content for all the structural surfaces tested. For sorghum, the highest values of coefficient of friction were obtained with concrete followed by steel, wood and plastic. For millet, the order of variation was concrete, steel, plastic and wood. The results of the analysis indicate that moisture content and structural surfaces are factors to consider in the design of facilities for material handling, processing and storage.

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