FRICTION COEFFICIENT OF MAIZE, COWPEA AND GROUNDNUTS ON DIFFERENT STRUCTURAL SURFACES

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ABSTRACT

The coefficient of friction of food grains and seeds which are necessary for the design of equipment for handling, transport, processing and storage of 'mamaba', 'asetenapa' and 'chinese' varieties of maize, cowpea and groundnut respectively have been evaluated as a function of grain moisture content varying from 10% to 28% (wb). In this moisture range, the coefficient of friction increased from 0.223 to 0.674. There was an increase in the coefficient of friction from 0.223 to 0.453 for 'asetenapa' variety, 0.260 to 0.522 for 'mamaba' variety and 0.288 to 0.577 for 'chinese' variety on rubber surface in the moisture content range of 10% to 28% (wb). Also on galvanized steel at the moisture content range of 10% to 28 %(wb), the coefficient of friction increased for 'asetenapa' variety from 0.259 to 0.498, 'mamaba' variety from 0.284 to 0.558 and 'chinese' variety from 0.309 to 0.619 and on plywood, 'asetenapa' variety had coefficient of friction increasing from 0.279 to 0.579, 'mamaba' variety 0.311 to 0.624 and for 'chinese' variety from 0.356 to 0.674. 'Chinese' variety of groundnuts had the highest coefficient of friction on all the three surfaces studied with values ranging between 0.288 and 0.674 as against values of 0.223 to 0.579 for 'asetenapa' variety which had the lowest values. Moisture effects on the coefficient of friction for the products studied were highly significant at 1%. From the study it can be said that product specification is necessary in the selection of materials for the construction of handling systems, dryers and silos.

Keywords: *'mamaba' maize, 'asetenapa' cowpea, 'chinese' groundnut, moisture content, coefficient of friction.*

INTRODUCTION

Cowpea (*Vigna unguiculata*), is of major importance to the livelihoods of millions of relatively poor people in less developed countries of the tropics as it provides a cheap and nutritious source of food for rural to relatively poor urban communities. In the fresh form, the young leaves, immature pods and seeds are used as vegetables, while several snacks and main meal dishes are prepared from the grain. The cowpea grain contains an average of 23 – 25% protein and 50 – 67% starch (Singh, 1997). Going beyond its importance for food and feed, cowpea can arguably be regarded as the fulcrum of sustainable farming in semiarid lands especially in West and Central Africa (Singh, 1997).

Groundnut (*Arachis hypogaea*) also known as monkey nut, peanut and goober pea is believed to have originated from Bolivia, South America. It is now grown extensively in West Africa, India and China. The crop is primarily grown for oil extraction as the kennels contain 40 – 50% edible oil. The butter is a highly nutritious food containing about 29% protein, 47% fat and 17% carbohydrate (Yayock *et. al.*, 1988).

As a subsistence crop, groundnuts are eaten fresh or boiled, or they are roasted and ground into flour. The cake produced after oil extraction is fed to livestock as a good source of protein. The groundnut crop is a major export crop in the moderate rainfall areas (500 – 1400mm) of West Africa lying between latitude 8° and 13°N (Yayock *et. al.*, 1988).

Maize (*Zea mays*) originated from tropical America, but is now one of the world's most widely cultivated food crops. It has a remarkably adaptable physiology and is rightly described as both a tropical and temperate crop. The Maize grain is used to produce a variety of food stuffs, including corn flour, ground maize, cornflakes and corn oil. Industrial products manufactured from maize grains include glucose, starch, alcohol and acetone (Yayock *et. al.*, 1988). Maize is highly nutritious both as human and animal food. Compared with other grains, it has a high fat content. Although this presents a major problem in corn milling, this fat is of great nutritional value and has low cholesterol content (Yayock *et. al.*, 1988). Depending on the variety, age and area in which it is grown, the fat content of the whole kernel (grain) is about 3.5 to 6% and the total protein content of the kernel is about 9 – 12% (Yayock *et. al.*, 1988).

Two types of friction may be identified for granular products, namely: friction of the kernels against the walls of storage structures and conveying systems referred to as the static wall friction and the friction of the kernels against each other called grain internal friction or angle of repose (Boumans, 1985).

In the storage and processing of ensiled products, the variations in the coefficient of static friction of the products have a very significant influence on the calculation of stresses developed on silo walls. Grain pressures in shallow and deep silos were first studied with Rankine and Janssen's equations which contain angle of internal friction and the wall friction coefficient (Reimbert and Reimbert, 1976).

The classical grain pressure as developed by Janssen is given by the equation:

$$L = \frac{\rho R}{\mu' k}[1 - e^{(-\mu' k h)/R}] \qquad (1)$$

where,

P_l = unit vertical pressure

R = "hydraulic radius" - area of bin floor divided by the perimeter in m.

k = ratio of lateral to vertical pressure in the grain

ρ = grain bulk density in kg/m^3.

h = height of grain in m

μ′ = wall friction coefficient (Reimbert and Reimbert, 1976).

The equation developed by Rankine is given by:

$$P_l = \frac{\rho h(1 - \sin \phi)}{1 + \sin \varphi} \qquad (2)$$

Where,

P_l = lateral pressure in kg/m^2.

ρ= grain bulk density in kg/m^3.

Φ= angle of internal friction or the angle of repose.

h= depth of the grain in m.

Friction coefficient together with the angle of repose influences the flow of ensiled materials in hoppers and outlet chutes. Flowability of materials which is characterised by the angle of repose and the co-efficient of friction on a particular surface determines the type of handling system and its components (Reimbert and Reimbert, 1976).

The friction co-efficient depends on the physical properties of the product and the roughness or smoothness of the walls on which the product is in contact with. The frictional resistance, which is different for each product, is also strongly determined by the type and roughness of the wall surface, pressure by the weight on top of the materials and the moisture content of the product as well as the surface. Non easy flowing products are characterised by internal friction and higher cohesion than easy flowing products (Boumans, 1985).

Methods used in static friction studies include the use of a bottomless cylindrical grain container connected by a string running over a frictionless pulley on a frame with a loading pan (Visvanathan *et. al.*, 1996: Chandrasekar and Visvanathan, 1999). The weight of the grains and the added weights comprise the normal force (N) and frictional force (F) respectively. Here the coefficient of static friction (μ) is determined as the ratio

$$\mu = \frac{F}{N} \qquad (3)$$

The coefficient of friction on various structural surfaces have been determined using this approach for wheat (Platonov and Poltorak, 1969; Thompson and Ross, 1984; Thompson *et. al.*, 1988; Moore *et. al.*, 1984 and Snyder *et. al.*, 1967), for coffee (Chandrasekar and Viswanathan, 1999) and for neem nut (Visvanathan *et. al.*, 1996).

Several researchers in the determination of static coefficient of friction however used the tilting table test technique or the inclined plane method with respect to many surfaces such as galvanized steel, mild steel, stainless steel, wood, aluminium, polythene, glass and jute (Baryeh, 2002; Baryeh, 2001; Bart-Plange and Baryeh, 2003; Singh and Goswami, 1996; Gupta and Das, 1998; Joshi *et. al.*, 1997; Suthar and Das, 1996; Shepherd and Bhardwaj, 1986). These are common materials used for the handling and processing of grains and construction of storage and drying bins.

Baryeh (2001) reported the highest coefficient of friction for Bambara groundnuts on plywood, followed by galvanized steel and aluminium. The values of coefficient of friction were found to increase linearly from 0.52 to 0.71, 0.45 to 0.65 and 0.21 to 0.28 for plywood, galvanized steel and rubber respectively for cocoa beans by Bart-Plange and Baryeh (2002).

Data available indicates that coefficient of friction increases with increasing moisture content for products such as soybean and pumpkin by Deshpande *et al* (1993) and Joshi *et al* (1992) respectively. This was carried out on plywood, mild steel and rubber surfaces. The tilting table test technique is a simple and frequently used test method for determining the coefficient of friction of grain on structural materials. Versavel and Brittan (1986) used the tilting table test method and obtained mean values of the coefficient of friction for wheat (12% moisture content) on smooth galvanised steel to be 0.298. Brubaker and Pos (1965) also used the tilting table technique to report the friction values of 0.10 at 10% moisture content for wheat on smooth galvanized steel.

Data on the physical properties of various new varieties of grains and nuts are essential for the design and selection of appropriate technologies for the handling, storage and processing of products after harvest. These new varieties come in different sizes and shapes and are moisture dependent. Research especially on the coefficient of friction of food grains and nuts available locally has not been extensively carried out on most design surfaces, though knowledge of the magnitude of the coefficient of friction of such surfaces is important for design engineers. It is therefore necessary to have a baseline data on the coefficient of friction and its variation with moisture for these varieties.

The objective of this study was to determine the coefficient of friction of "mamaba" variety of maize, "asetenapa" variety of cowpea and "chinese" variety of groundnut on different structural surfaces and their variation with moisture.

MATERIALS AND METHODS

Sample Preparation

Grain samples of maize, cowpea and groundnut were obtained from the Grain Development Board, Kumasi. Different moisture contents of the samples were used in the study. Test samples were from the 2004 growing season. For each variety, moisture content was determined using 5 ground samples each of mass 5g on wet basis. The ground samples were heated in an oven at a temperature of 130+/-2 °C for 2 hours to vaporise the moisture. The dried samples were reweighed and the weight difference caused by drying taken as weight of the water contained in the sample. Moisture content on wet basis was determined by dividing the mass of water evaporated by the initial weight of sample and the averages recorded.

After the determination of the initial moisture content of the various samples, the samples were then conditioned to four other moisture levels. The desired moisture content for the higher values was obtained by adding a calculated amount of distilled water to the samples using the relation:

$$Mw = \frac{M_s(m_f - m_i)}{100 - m_f} \qquad (4)$$

where

M_w - quantity of distilled water (kg)
m_i - initial moisture content (%)
m_f - desired final moisture content (%)
M_s - mass of sample to be conditioned (kg)

The samples were then sealed in airtight polythene bags after which they were put in a refrigerator at a temperature of 5°C for one week to avoid the growth of micro organisms and also allow the moisture to distribute uniformly throughout the samples. The investigation of the various samples were carried out in the moisture content range of 10-28% since handling and storage of the products studied are mostly done in this moisture content range.

Determination of Coefficient of Friction

The coefficient of friction for each of the samples was measured against three structural materials, namely rubber, plywood and galvanized steel. A PVC cylinder of diameter 100mm and height 50mm was filled with the sample to be measured and placed on the friction surface. The PVC cylinder was pulled up slightly (about 2mm) so as not to touch the friction surface. The friction surface which is part of a special construction was hinged at one end so that it can be lifted gradually at the end which is unhinged by means of a bolt and nut arrangement (Figure 1).

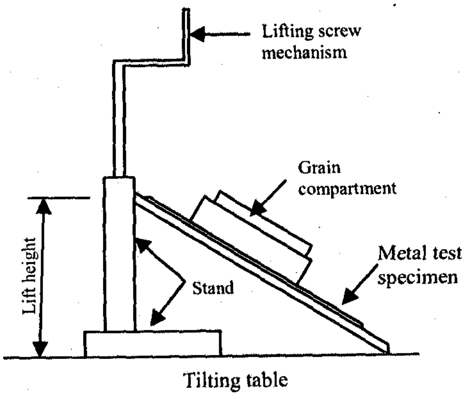

Fig. 1: **Tilting table apparatus for the determination of friction coefficient**

The friction surface with the cylinder resting on was gradually lifted (inclined) with the bolt and nut arrangement until the cylinder, along with the sample just began to slide down. At this point, the bolt adjustment was stopped and the angle which was made (angle of tilt) read using the graduated scale of an adjustable drawing setsquare.

The coefficient of friction (μ) was then calculated from the equation:

$$\mu = \tan\Phi \quad \text{where } \Phi = \text{angle of tilt.} \qquad (5)$$

For each surface, the procedure was replicated five times and the averages recorded for the five different moisture levels.

Statistical Analysis

Statistical analysis using the F-test by Gomez and Gomez (1986) was used for the analysis of variance to determine significant differences between moisture variation and the properties studied. The ranges of coefficient of variation values which give a good index of the reliability of the experiment were determined.

RESULTS AND DISCUSSIONS

Coefficient of friction on Plywood

Figure 2 shows the effect of moisture content on the coefficient of friction on plywood for the three products studied. The values for the coefficient of friction ranged from 0.279 to 0.674 in the moisture content range of 10% to 28% for the three products studied.

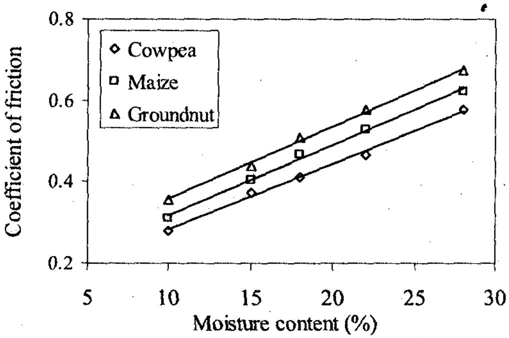

Fig. 2: Variation of coefficient of friction with moisture content on plywood

Figure 2 shows a linear increase in coefficient of friction as moisture content increases for all products studied, with the highest increase being exhibited by groundnut. Coefficient of friction values increased from 0.356 to 0.674 as moisture content increased from 10% to 28% for groundnut.

This can be compared to values of 0.311 to 0.624 for maize and 0.279 to 0.579 for cowpea in the moisture content range of 10% to 28% respectively. The increase in the coefficient values with increase in moisture may be attributed to the fact that when the grains get wet and heavy, they are not able to slide down easily. The relationships may be expressed mathematically for cowpea, maize and groundnut on plywood as:

$$\mu_{cowpea} = 0.0162M + 0.1205 \quad (R^2=0.9946) \qquad (6)$$

$$\mu_{maize} = 0.0174M + 0.1431 \quad (R^2=0.9966) \qquad (7)$$

$$\mu_{groundnut} = 0.0179M + 0.1793 \quad (R^2=0.9973) \qquad (8)$$

The results of the statistical analysis, as seen in table 1, indicate that the effects of moisture on coefficient of friction on plywood for the three products were highly significant at 1% levels. Significant differences existed among the three products as shown in the analysis of their means.

Table 1: Analysis of variance for plywood

Source	Degree of freedom	Sum of squares	Mean square	F-value	Probability
Crops	2	0.02	0.010	110.15	0.0000
MC	4	0.17	0.041	456.49	0.0000
Error	8	0.00	0.000	-	-
Total	14	0.19	-	-	-

Grand mean=0.467
Grand sum=7.003
Total count=15
Coefficient of variation=2.04%

Coefficient of Friction on Galvanised Steel

Figure 3 depicts the effect of moisture content on the coefficient of friction on galvanized steel. The range of values was from 0.259 to 0.620 for the coefficient of friction in a moisture content range of 10% to 28%. There was also a linear increase in the coefficient of friction as moisture content increased for the three products studied which was similar to that found for plywood.

Figure 3 shows the highest coefficient of friction values again being exhibited by groundnuts, which was followed by maize and then cowpea. There was an increase from 0.309 to 0.620 for groundnut, 0.284 to 0.498 for maize and 0.259 to 0.498 for cowpea in the moisture content range of 10% to 28%.

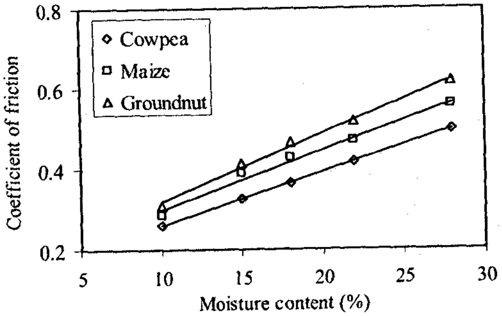

Fig. 3: Variation of coefficient of friction with moisture content of galvanised steel

The relationship between the coefficient of friction and moisture content on the various products on galvanized steel is given in the following equation:

$$\mu_{cowpea} = 0.0132M + 0.1263 \quad (R^2=0.998) \qquad (9)$$

$$\mu_{maize} = 0.0147M + 0.1521 \quad (R^2=0.9848) \qquad (10)$$

$$\mu_{groundnut} = 0.0168M + 0.1515 \quad (R^2=0.9937) \qquad (11)$$

The statistical analysis here indicated that the effects of moisture on coefficient of friction on galvanized steel for the three products were highly significant at 1% levels. Significant differences did exist among the three products following the analysis of variance, which gave a coefficient of variation of 3.393.

Coefficient of Friction on Rubber

The variation of the coefficient of friction with moisture content for rubber for the varieties studied is shown in figure 4

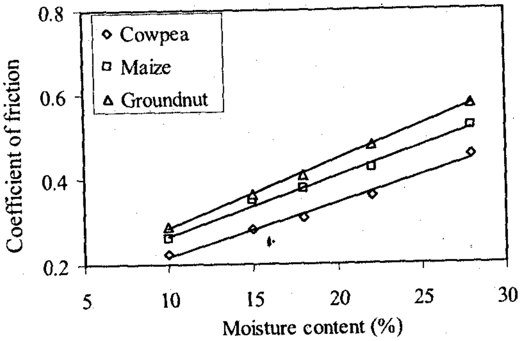

Fig. 4: Variation of coefficient of friction with moisture content on rubber

The range of values is from 0.233 to 0.577 for a moisture content range of 10% to 28% respectively. These figures show an increase in the coefficient of friction on rubber with an increase in moisture content, and this increase can be said to be linear as shown from figure 4.0. Groundnut showed the highest increase followed by maize and cowpea in that order. The relationship between the coefficient of friction and moisture content on the various products on rubber is given in the following equation:

$$\mu_{cowpea} = 0.0126M + 0.0904 \quad (R^2=0.0.9916) \qquad (12)$$

$$\mu_{maize} = 0.014M + 0.1251 \quad (R^2=0.9904) \qquad (13)$$

$$\mu_{groundnut} = 0.0161M + 0.1231 \quad (R^2=0.999) \qquad (14)$$

The statistical analysis results indicate that the effects of moisture on coefficient of friction on rubber for the three products were highly significant at 1% levels and significant differences existed among the products studied.

General Comments

From the results it can be inferred that when the same handling system is used for the three products studied, cowpea would generally flow easily than the other products as it had the lowest coefficient of friction on all the surfaces studied. Knowledge of the coefficient of friction of various local materials for construction of hoppers, silos and systems used in handling the products is essential and rubber which generally gave the lowest values for coefficient of friction for the various products studied will also offer lowest resistance to product flow. The low coefficient of friction values for rubber can be attributed mainly to the slippery nature of the rubber surface as against the other surfaces studied as the grains get wetter. The study has shown that it is important to specify the products to use as well as the materials of construction required in the design of storage structures and material handling systems.

CONCLUSION

The investigation of the coefficient of friction of cowpea, maize and groundnut on plywood, galvanized steel and rubber, revealed the following: The coefficient of friction of the products increased linearly with increasing moisture content for all the three surfaces namely plywood, galvanized steel and rubber.

The highest coefficient of friction was exhibited on plywood by groundnut with values of 0.356 to 0.674 for moisture content range of 10% to 28%w.b. as compared to the lower value for rubber which ranged from 0.288 to 0.577 at moisture content 10% to 28%w.b. for the same groundnut. Plywood had the highest coefficient of friction values, followed by galvanized steel and rubber. From the statistical analysis done, there were significant differences among the coefficient of friction of the three products on the structural surfaces.

Statistical analysis also showed that the moisture effects on the coefficient of friction studied for the individual varieties were highly significant at 1%. The low coefficient of variability values (less than 4%) obtained indicates the reliability of the experiments.

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