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ORIGINAL RESEARCH ARTICLE

EFFECT OF MOISTURE CONTENT AND GRAIN VARIETY ON FRICTIONAL PROPERTIES AND SPECIFIC HEAT CAPACITY OF ACHA (FONIO) GRAINS

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ABSTRACT

There are many varieties of acha, but the most prominent two are white acha (*Digitaria exilis*) and brown acha (*Digitaria iburua*). This study was undertaken to determine the static coefficient of friction, kinetic coefficient of friction and specific heat of the grains as influenced by moisture content. The moisture levels considered were 5, 11, 23 and 28% db for the white variety and 5, 9, 21 and 30% db. The study revealed that increase in moisture content resulted to increase in the value of the properties considered for both varieties, with the white acha showing the highest values. Static coefficient of friction increased linearly with moisture content and had maximum values of 0.49 - 0.62 for the brown variety and 0.52-0.66 for the white variety all on steel sheet, while the minimum values for both varieties were on glass surface. Kinetic coefficient of friction increased linearly with moisture content and the highest value was obtained on hessian bag material (0.62-0.66) with the least being on steel sheet (0.58-0.64) for the two acha grain varieties. The study further revealed that, specific heat capacity of acha grains increased with increase in moisture content from 2.93 – 11.29 kJ/kgK (5 – 28% db) for the white variety and from 2.33 – 13.88 kJ/kgK (5 – 30% db) for brown variety. This study concludes that variety and changes in moisture content significantly affected the determined properties of acha.

1.0 Introduction

Acha is a cereal crop of West African origin belonging to the family graminaea (Gibon and Pain 1985), it is a great grain - available, inexpensive, gluten free, easy to cook and super nutritious. The plant is an important crop in Southern Mali, Western Burkina Faso, Eastern Senegal, Northern Guinea, North-Eastern Nigeria, and Southern Niger (Harlan, 1993; Jideani, 1999; Chukwu and Abdul-Kadir, 2008). There are many varieties of acha, but the most prominent two are brown acha (*Digitaria iburua*) and white acha (*Digitaria exilis*) as shown in Figures 1 and 2. In Nigeria, Chukwu and Abdul-Kadir (2008) reported that, the white acha is grown more widely.

Figure 1: Brown Acha grains *(Digitaria iburua)*

Figure 2: White acha grains *(Digitaria exilis)*

Acha contains at least 85 % dry matter, of which about 10 % is starch (Morales - Payan et al., 2002), 5 % is mineral and 7% is crude protein (Temple and Bassa, 1991). The protein of acha is higher compared to that of other grains (Chukwu and Abdul-Kadir, 2008), and is reputed to contain almost twice as much methionine as egg protein does (Temple and Bassa, 1991). In gross nutritional composition, acha differs little from wheat. In white acha (D. exilis) sample, the husked grain contained 8 % protein and 1 % fat. In a sample of brown acha (D. Iburua), a protein content of 11.8 % was recorded. Thus, acha has important potential not only as survival food but as a complement for standard diets. Acha is also known as one of the best diets for diabetic patients (Dury et al., 2006). Philip and Itodo (2006) highlighted the traditional tools and manual techniques currently used in West Africa for acha cultivation, harvesting and post harvest process operations such as threshing, winnowing, hulling and de-stoning. The authors noted the tedium and drudgery associated with the manual methods, and opined that acha production had to be stimulated by initiating research activities to address its mechanization constraints.

Inspite of its nutritional and economic importance, not much scientific data are available on the engineering (frictional and thermal) properties of acha for the design of equipment for its harvesting and processing operations. Literatute has shown that the physical and mechanical properties of many cereals have extensively been investigated. These include the study of Fathollahzadeh et al., (2008) who listed among others, gram, hazel nuts, okra seed and chick pea seed. Nwakonobi and Onwualu (2009) conducted a study on the effect of moisture content and types of structural surfaces on coefficient of friction of millet and sorghum. They reported that the coefficient of friction for the grains increased linearly with increase in moisture content.

It was reported by Adesola and Theresa (2012) that, mechanization of acha processing has been limited by dearth of data on engineering properties to aid design of equiptment for its post harvest operation. Due to lack of knowledge of the interplay between its properties and these factors, design and fabrication of machine for acha have been fortuitous. It was reported by Davies and El-Okene (2009) that designing the seed processing without considering engineering specifications may yield poor results. Some problems associated with the processing of acha (Digitaria exilis and Digitaria Iburua) that has limited its proper production and utilization are seen in harvesting, de-hulling, winnowing, threshing, de-stoning and processing in general. Therefore, this study was aimed to investigate the effect of moisture content and grain variety on some engineering properties of two acha varieties. These include static and kinetic coefficient of friction on different structural surfaces and specific heat at different moisture contents.

2. Materials and Methods

2.1 Sample procurement and preparation

The acha grains used for this study was un-de-hulled white and brown acha varieties (Digitania exilis and Digitania iburua) respectively. The bulk quantity of white and brown coloured acha grains was obtained from the Wadata market, Makurdi, Benue State, Nigeria. ASAE Standards S.352.2 (ASAE, 1998) for moisture content of seed determination was used to determine the storage moisture content of the acha grains. This method involved oven drying of sample at 105o for 8 hours with weight loss monitored to give an idea of the time at which the weight began to remain constant. This was carried out in three replicates and the average value recorded. The bulk of the grain mass of each variety was divided into four lots. The first lot was left at the market moisture content, while the remaining lots were conditioned by adding an amount of water to obtained the desire moisture content levels. The amount of water added to the samples was obtained using the equation of Solomon and Zewdu (2009):

$$Q = \frac{W_s(M_f - M_i)}{100 - M_f} \tag{1}$$

where:

Q = Quantity of water to be added, g

M_i = initial moisture content, %

M_f = final moisture content, %

W_s = weight of samples, g.

2.2 Moisture content determination

To investigate the physical properties of acha as affected by moisture content and grain varieties, the samples conditioned to different moisture levels were weighed with an electronic weighing balance (0.001 g accuracy) and oven dried at 105°C with weight loss noted on hourly basis. The samples were found to have a constant mass after oven drying for 5 hours. The moisture content was calculated from the relation used by Aviara et al., (2005) on sheanut as:

$$M_{w.b} = \left(\frac{W_i - W_f}{W_i}\right) \times 100 \tag{2}$$

where: M_{wb} = moisture content (%)

W_i = initial weight (g)

W_f = final weight (g)

This was converted to dry basis moisture content by using the equation:

$$M_{d.b} = \left(\frac{M_{w.b}}{1 - M_{w.b}}\right) \times 100 \tag{3}$$

where: Mdb = Dry basis moisture content (%)

2.3 Determination of static coefficient of friction

The static coefficient of friction was evaluated on four different surfaces namely: plywood, hessian bag material, fiberglass and steel. The inclined plane method was used as described by Dutta et al., (1998). This involved placing of an open-ended box of dimensions (50mm×100mm×100mm) on an adjustable tilting surface which was formed with structural surface. The box was then filled with grains and its content on top of the structural surface was gradually raised using a screw device until the box started to slide down and the corresponding tilting angle α was recorded. The value of static coefficient friction was calculated using Koocheki et al., (2007) formula.

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$$\mu = \tan\alpha \tag{4}$$

Where: μ = static coefficient of friction, and α = tilting angle

2.4 Determination of kinetic coefficient of friction

In determining the kinetic coefficient of friction, the open-ended box used in determining the static coefficient of friction was placed on a horizontal surface. The four surfaces used in the determination of the kinematic coefficient of friction were plywood, fibreglass, hessian bag material and steel. The fibre box was filled with grains. 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 relationship:

$$\mu = \frac{W_p + W_i}{W_b + W_s} \tag{5}$$

where: μ = Kinetic coefficient of friction.

Wp = Weight of pan (kg)

Wi = Weight placed in pan (kg)

Wb = Weight of box (kg)

Ws = Weight of sample (kg)

2.5 Determination of specific heat

The specific heat of the grains was determined using a copper calorimeter placed inside a flask by the method of mixture as described by Ogunjimi et al., (2002). A sample of known weight and temperature was poured into the calorimeters containing water of known weight and temperature. The mixture was stirred with a copper stirrer until equilibrium was attained. The final temperature was noted and the specific heat of the sample was calculated using the equation:

$$C_s = \frac{(M_c C_c + M_w C_w)(T_w - T_e)}{M_s(T_e - T_s)} \tag{6}$$

where:

Cc = Specific heat of calorimeter (J/kgK)

Cs = Specific heat of sample (J/kgK)

Cw = Specific heat of water (J/kg/K)

Mc = Mass of calorimeter (kg)

Ms = Mass of sample (kg)

Mw = Mass of water (kg)

Te = Equilibrium temperature of mixture (K)

Ts = Temperature of ample (K)

Tw = Temperature of water (K)

3. Results and Discussion

3.1 Grain moisture content

The initial moisture content of white and brown acha (Digitaria exilis and Digitaria iburua) grains was found to be 5 and 5% d.b respectively. The three other moisture levels obtained after conditioning the grains were 11, 23 and 28% for the white variety and 9, 21 and 30% for the brown variety. The investigations were carried out at the four different moisture levels above for each variety to determine the effect of moisture content on the frictional and thermal properties of acha varieties. These are static coefficient of friction, kinetic coefficient of friction and specific heat of the seeds.

3.2 Static coefficient of friction

The static coefficients of friction obtained experimentally on four structural surfaces against moisture content are presented in Figures 2a and 2b. It showed, that, the static coefficient of friction of the two varieties of acha grains increased linearly with increase in their respective moisture content ranges. The highest value was obtained when using steel and followed by hessian bag, wood and glass respectively for both varieties of acha considered in this study.

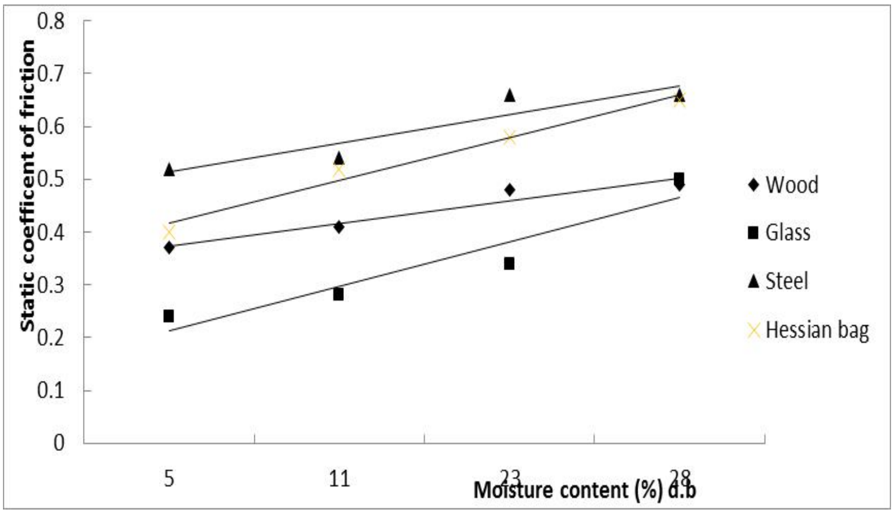

Figure 2a: The effect of moisture content on the static coefficient of friction of white acha grains

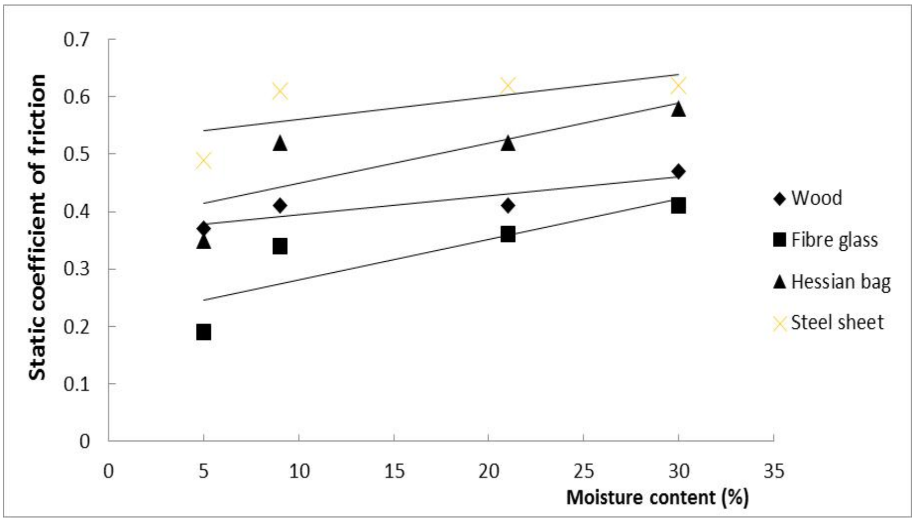

Figure 2b: The effect of moisture content on the static coefficient of friction of brown acha grains

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The static coefficient of friction varied according to the surface used. It could be said that at higher moisture content, the seeds became rough thereby increasing friction characteristics and the structural surface roughness also had decisive influence. The static coefficient of friction was maximum on steel (0.52 - 0.66) and (0.49 - 0.62), followed by hessian bag (0.40 - 0.65) and (0.35 - 0.58), wood (0.37 - 0.49) and (0.37 - 0.47) and was minimum on fibre glass (0.24 - 0.50) and (0.19 - 0.41) for the white and brown varieties respectively. The relationship existing between moisture content and the static coefficient of friction of acha grains for different structural surfaces was found to be linear and expressed in equation form as:

$$\mu s = x_1 M + y_1 \quad (7)$$

where: μs = Static coefficient of friction

x_1 and y_1 are constants.

M = Moisture content (%)

Singh and Goswani (1996) and Milani et al., (2007) reported linearly increasing trends on the static coefficient of friction for cumin seed, cucurbit seed and wheat respectively. This property is very useful in the product movements during processing. In the design of silos, bins and other storage containers for the seed, the vertical load on the walls of the structure or equipment is determined by the friction coefficient.

3.3 Kinetic coefficient of friction

The kinetic coefficients of friction obtained experimentally on four structural surfaces against moisture content are presented in Figures 3a and 3b. This shows that the kinetic coefficient increased with increase in moisture content. It also varies with structural surface used in the study.The highest friction was recorded on hessian bag (0.62 - 0.66) and (0.58 - 0.64), followed by wood (0.37 - 0.52) and (0.41 - 0.49) and galvanised steel sheet (0.32 - 0.54) and (0.34 - 0.53), while the least was recorded for glass (0.29 - 0.57) and (0.25 - 0.49) for the white and brown varieties respectively. This could be due to the surface characteristics of the seeds with increasing moisture content. It was also seen that for the white variety, the kinetic coefficient of friction on glass was initially lower than that of wood and steel but as the moisture content increased it rose higher than that of wood and steel.

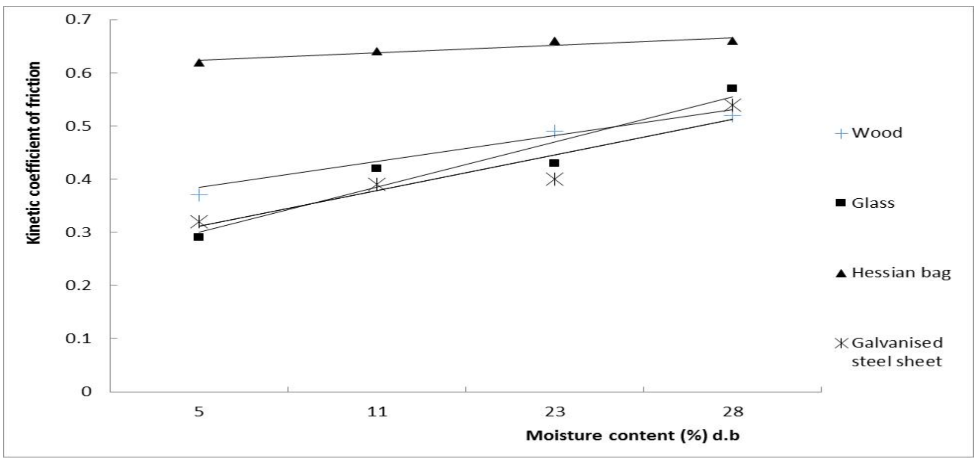

Figure 3a: The effect of moisture content on the kinetic coefficient of friction of white acha grains

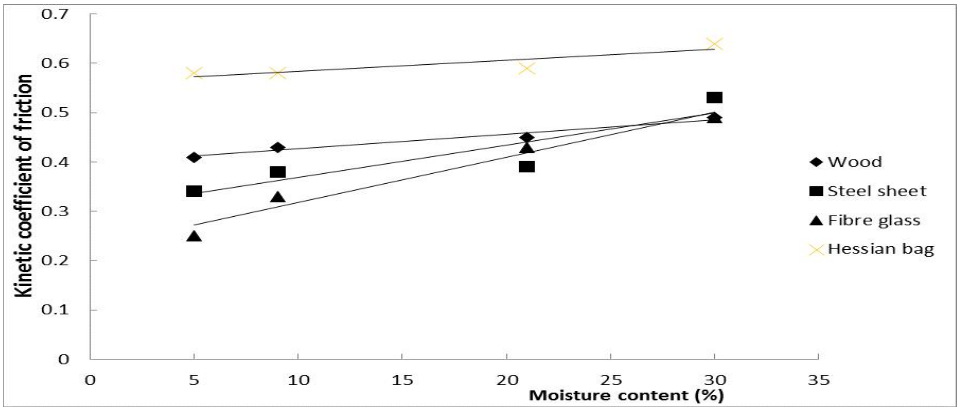

Figure 3b: The effect of moisture content on the kinetic coefficient of friction of brown acha grains

The relationship existing between moisture content and the kinetic coefficient of friction of the two varieties of acha grains on different structural surfaces was found to be linear as expressed in the equation:

$$\mu k = x_2 M + y_2 \quad (8)$$

where: μk = Kinetic coefficient of friction

x_2 and y_2 are constants

M = Moisture content (%).

Carman (1996) reported a linear increase of friction for lentil seed. It was also reported by Sessiz et al., (2007) that a linear relationship was obtained when moisture content was studied against kinematic coefficient of friction for capper fruit seeds. The kinetic coefficient of friction is needed before the power requirements for continued flow of granular or uncosolidated materials can be estimated.

3.4 Specific heat

The variation of specific heat of two varieties of acha grains at four moisture levels are presented in Figures 4a and 4b. It was observed that the specific heat of acha increased linearly with increases in moisture content from 2.33 - 13.88 KJ/kgK as the moisture content increased from 5 - 30% for the brown variety and from 2.93 - 11.29 KJ/kgK in the moisture range of 5 - 28% for the white variety. The relationship between moisture content and the specific heat capacity of the seeds was found to be:

$$C_{sw} = 0.30M + 1065.1 \quad (9)$$

$$C_{sb} = 0.41M + 861.94 \quad (10)$$

With the value for the coefficients of determination, R^2 = 0.7408 and 0.7718 for white and brown acha respectively.

where: C_s = Specific heat capacity of the seeds (kJ/kgK)

M = Moisture content (%).

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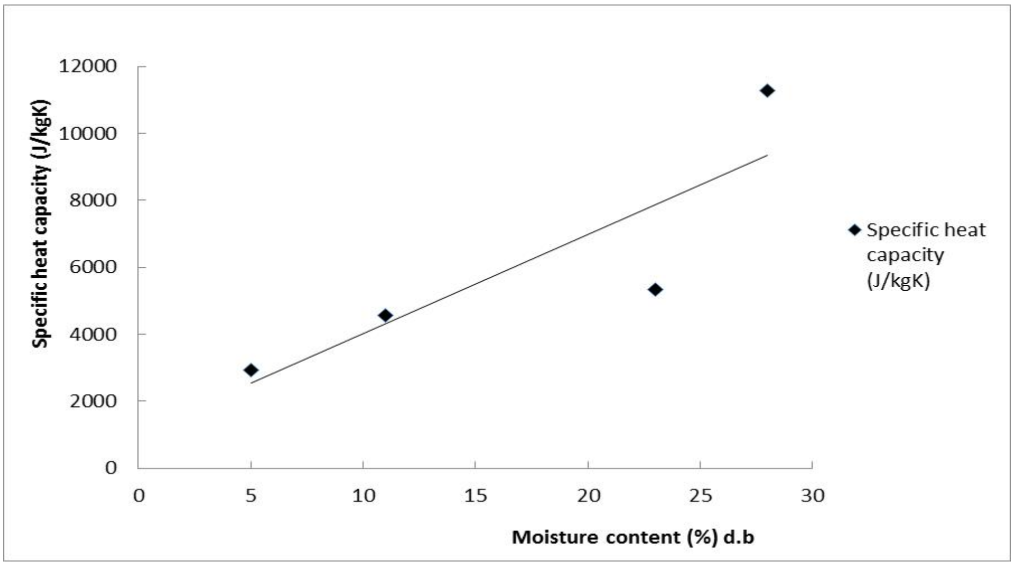

Figure 4a: The effect of moisture content on the specific heat capacity of white acha

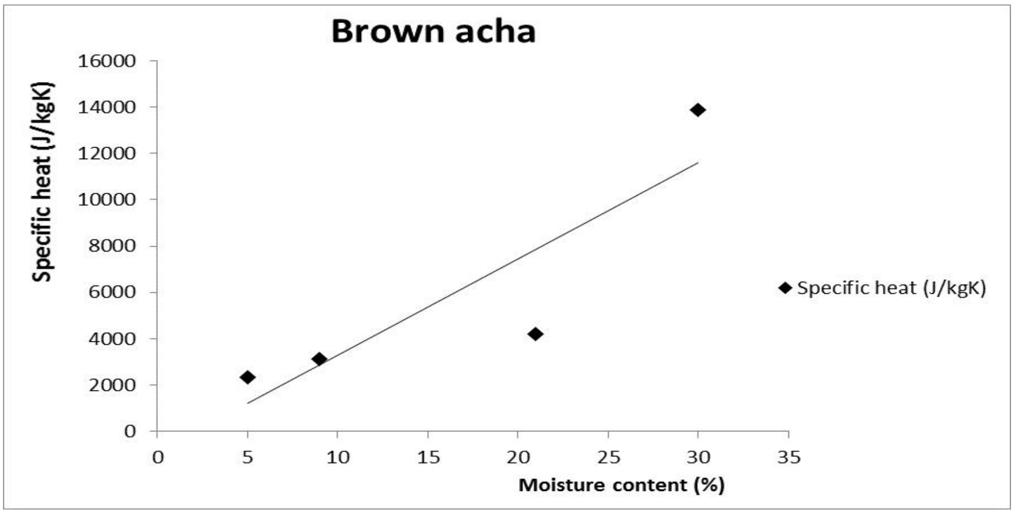

Figure 4b: The effect of moisture content on the specific heat capacity of brown acha

Aviara and Haque (2000) reported a similar trend of linear increase for guna seeds. The increasing trend in specific heat with moisture content correlated with works done by many other reseachers on different agricultural crops. Hsu et al., (1991) reported linear variation of specific heat with moisture content for pistachios. Isa et al., (2014) studied the thermal properties of some selected species of egusi melon in moisture range of 5.79 - 41.80% and reported that, specific heat increased linearly from 1.39 to 3.42 kJ/kg°C for Colocynthis citrulius variety. Knowledge of the specific heat of seeds as well as the effect of moisture content and temperature on it is essential for the design of thermal processing systems, as varying moisture content and temperature could form some of the process conditions.

The thermal properties of the seed are also essential in the development of processes and equipment needed in drying and storage. The values of constants obtained using equations 7 and 8 against different surfaces for each variety of acha is presented in Tables 1 and 2.

Table 1: Values of the constants for the static coefficient of friction on different structural surfaces

Varieties of acha	Structural surfaces	Constants		R^2
		x_1	y_1	
White	Wood	0.043	0.33	0.9362
	Hessian bag	0.081	0.335	0.9742
	Steel sheet	0.054	0.46	0.8526
	Fibre glass	0.084	0.1309	0.9
Brown	Wood	0.0033	0.362	0.8157
	Hessian bag	0.007	0.3787	0.6507
	Steel sheet	0.0039	0.5212	0.4983
	Fibre glass	0.007	0.2108	0.7169

Table 2: Values of the constants for kinetic coefficient of friction of acha grains on different structural surfaces

Varieties of acha	Structural surfaces	Constants		R^2
		x_2	y_2	
White	Wood	0.049	0.335	0.9471
	Hessian bag	0.014	0.61	0.8909
	Steel sheet	0.067	0.245	0.8811
	Fibre glass	0.085	0.215	0.9198
Brown	Wood	0.0029	0.3974	0.9586
	Hessian bag	0.0022	0.5612	0.7871
	Steel sheet	0.0066	0.3035	0.8142
	Fibre glass	0.0091	0.2263	0.9648

4. Conclusions

The moisture dependence of some physical properties of *D. exilis* and *D. iburua* grains in the moisture range of 5 to 28% and 5 to 30% respectively on the frictional and thermal properties was determined. The study revealed that, the static coefficient of friction of the grains increased with increase in moisture content and varied on structural surface used. The highest value was recorded in hessian bag (0.4 – 0.65), followed by galvanized steel sheet (0.52 – 0.65), wood (0.37 – 0.49) and the least on fiber glass (0.24 – 0.5) for the white variety and for the brown variety the highest was found when using galvanized steel sheet (0.49 – 0.62), followed by hessian bag (0.35 – 0.58), wood (0.37 – 0.47) and the least on fiber glass (0.19 – 0.41). The kinetic coefficient of acha grains increased with increase in moisture content and varied on structural surfaces. It was seen that for hessian bag the kinetic coefficient of friction increased from 0.62 – 0.66 and 0.58 – 0.64, 0.37 – 0.52 and 0.41 – 0.49 on wood, 0.29 – 0.57 and 0.25 – 0.49 on fiber glass, 0.32 – 0.54 and 0.34 – 0.53 on galvanized steel sheet for the white and brown varieties respectively. The specific heat capacity of acha grains increased with increase in moisture content from 2.93 – 11.29 kJ/kgK in the moisture range of 5 – 28% d.b for the white variety and from 2.33 – 13.88 kJ/kgK in the moisture range of 5 – 30% d.b for brown variety.

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