APPLICATION OF COEFFICIENT OF FRICTION TO THE SEPARATION OF COCOA HUSK–BEANS MIXTURE

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ABSTRACT

Investigation was carried out on the application of coefficient of friction in the separation of cocoa beans–husk mixture. An inclined plane at angles 20, 25 and 35° rotating at different speeds (215, 250 and 260 rpm) and receiving the mixture at heights 30, 60 and 90 mm, was used for the study. The result indicates that within the range of factors considered, the separation efficiency of the beans from the mixture increases with increase in speed of rotation and height of fall, while it decreases with increase in angle of inclination. Statistical analysis shows that the effects of each of the factors and that of their interaction are significant at 99%. The best separation efficiency (99%) was observed at a speed of 250 rpm, an angle of inclination of 25° and a height fall of 90 mm.

PRACTICAL APPLICATIONS

Separation of cocoa beans from the husks has been a serious problem in cocoa processing. Handpicking is still being used to separate the mixture of cocoa beans–husk even with the mechanical pod breaker available. This therefore constitutes a tedious operation. An inclined plane mechanism tested for the separation of the mixture in this study can be incorporated into the design of the cocoa pod processor to reduce the drudgery involved in cocoa processing and improve the quality of the product.

INTRODUCTION

Cocoa (*Theobroma cacao*) is a delicate lowland tree plant believed to have originated from South and Central America, and was introduced by the Spanish

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to the Indonesian archipelago and West Africa in the 16th century. The cocoa tree is grown predominantly in West Africa, Latin America and Southeast Asia. It thrives in hot and rainy tropical climates within 20 degrees north and south of the equator (Wikipedia Encyclopedia 2006; World Cocoa Foundation 2006). The name "cacao" was first given by Swedish natural scientist Carl von Linné (1707–1778), who called it "theobroma cacao" or "food of the gods" (Wikipedia Encyclopedia 2006). Fabunmi (1994) reported that among the 22 known species of cocoa, *T. cacao* is the most widely known. The cocoa tree can grow to between 12 to 15 m high in the wild, and up to 4 to 5 m in cultivated form. It bears fruit or pods that contain cocoa beans, which when fermented and dried, provide valuable material for all chocolate-based products ranging from beverages and confectionaries to cosmetics. At maturity, it produces thousands of flowers among which very few develop into fruits (Lass and Wood 1985). The oval-shaped pods which vary in color (from yellow or green to red or violet) have the shape of miniature rugby balls and sprout directly from the trunk and the thicker branches of the tree. Most species of cocoa produce fruits twice in a year and can produce fruits for up to 75 to 100 years or more, under good cultivation practices. The area cultivated worldwide covers between 3.5 and 4.5 million hectares yielding over 3.6 million tons of cocoa beans in 2004. The leading producers of cocoa beans are Côte d'Ivoire, Ghana, Indonesia, Nigeria, Brazil, Cameroon and Ecuador. The production went from 1,556,484 MT in 1974 to 1,810,611 MT in 1984 to 2,672,173 MT in 1994 and 3,607,052 MT in 2004 (FAO 2006 in Wikipedia Encyclopedia 2006).

A cocoa pod is approximately 20 cm long and 10 cm wide. A section through the pod shows a rough leathery rind about 3 cm thick, filled with sweet (although not edible), slimy and pinkish pulp, enclosing from 30 to 50 large, soft, pink or purple almond-like seeds or beans. The physical structure of a longitudionally and transversely sectioned cocoa pod is shown in Figs. 1 and 2 (Fabunmi 2004). Among most commercial crops, cocoa is known to provide very high economic returns because of the wide range of domestic and industrial uses of the beans. Cocoa pulp juice is used in the production of soft drinks and alcohol. Cocoa husks, when properly processed, serve as animal feeds and can be burnt to produce potash for making soft soap (Adomako 1995; Spore 1998).

In most places, especially in Africa, harvesting is done manually with go-to-hell and is therefore a labor-intensive operation. Cocoa bean extraction (i.e., breaking the pods and separating the wet beans from the husks) is the first step in cocoa pod processing (see Fig. 3) which is traditionally manual. Pods are broken with objects such as wooden clubs, cutlasses and knives to hit or strike the pods or by knocking two pods against each other laterally. This often results in up to more than 5% mechanically damaged cocoa beans and increases their susceptibility to infestation by insects and fungi (Fabunmi

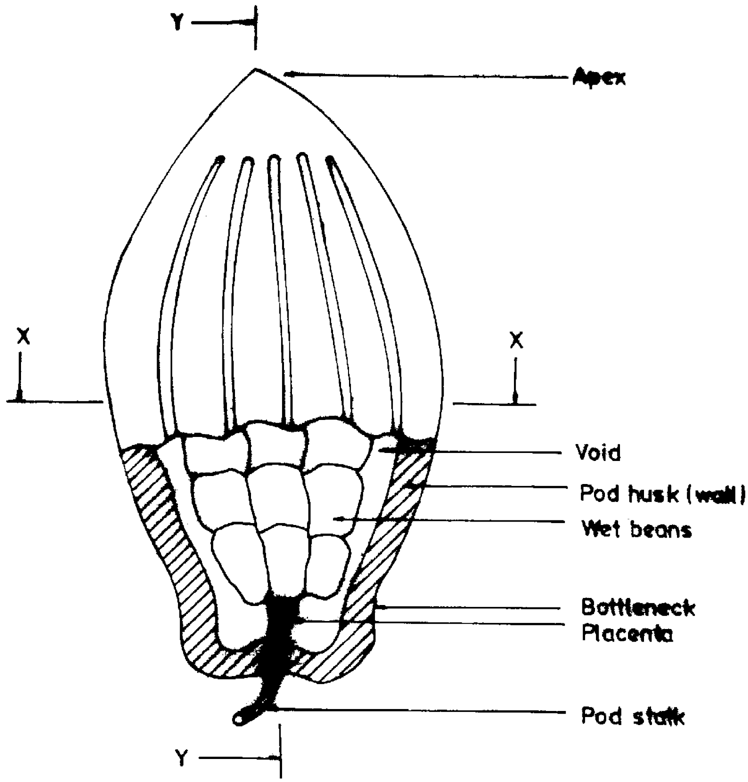


FIG. 1. LONGITUDINAL SECTION OF A COCOA POD SHOWING THE PHYSICAL FEATURES (SECTION Y-Y)
Source: Fabunmi (2004).

2004). The beans when extracted are piled in heaps, bins or on grates where, after several days of fermentation, the distinctive cocoa aroma is created and the color of the bean turns dark brown while the thick pulp thins and trickles off. These manual processing operations take up a great deal of time, require a large expenditure of labor and form a critical unit of operation during the primary processing of cocoa pods. Some researchers have worked on machines for pod breaking and bean extraction to reduce the drudgery, improve timeliness and enhance productivity (Maduako and Faborode 1990; Faborode and Oladosu 1991; Faborode and Dirinfo 1994). The pods were properly broken by most of the machines but the process of separating the husk–bean mixture has been a major problem. Manual efforts are still being made to do this. A separation technique based on the coefficient of friction of

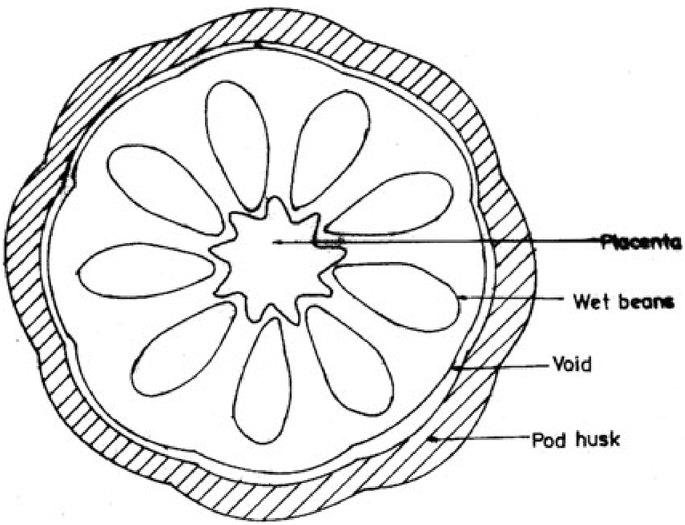


FIG. 2. TRANSVERSE SECTION OF A COCOA POD SHOWING THE PHYSICAL FEATURES (SECTION X-X)
Source: Fabunmi (2004).

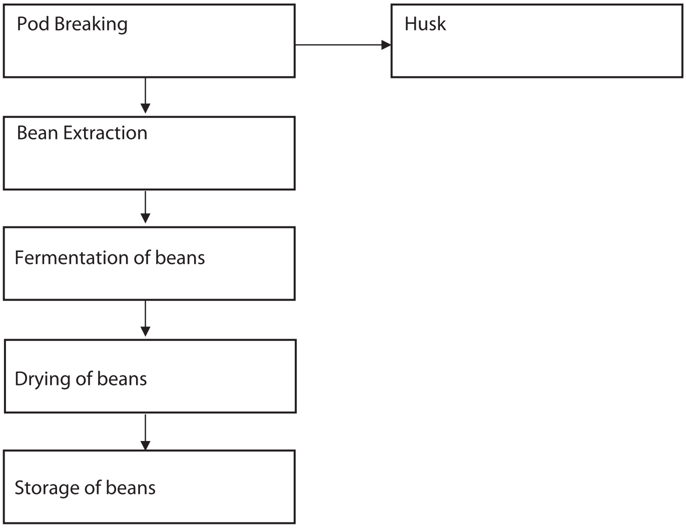


FIG. 3. FLOWCHART OF COCOA PROCESSING

the materials (beans and the husks) is being proposed using a modified inclined plane mechanism for separating palm nut from fiber (Adegbenjo 2002).

MATERIALS AND METHODS

Freshly harvested cocoa pods used for the experimental study were obtained from the Teaching and Research Farm of Obafemi Awolowo University, Ile-Ife, Nigeria. A preliminary experiment was conducted on the coefficient of friction of cocoa husks using an inclined plane (Mohsenin 1986). Ten pods were broken into bits and the coefficient of static friction test was carried out on the husks. The three categories of husk placement likely to be encountered during processing were considered for the test. These were:

(1) husk resting on the plane on its outer dry surface;
(2) husk resting on the plane on its outer but wet surface; and
(3) husk resting on its inner cut surface.

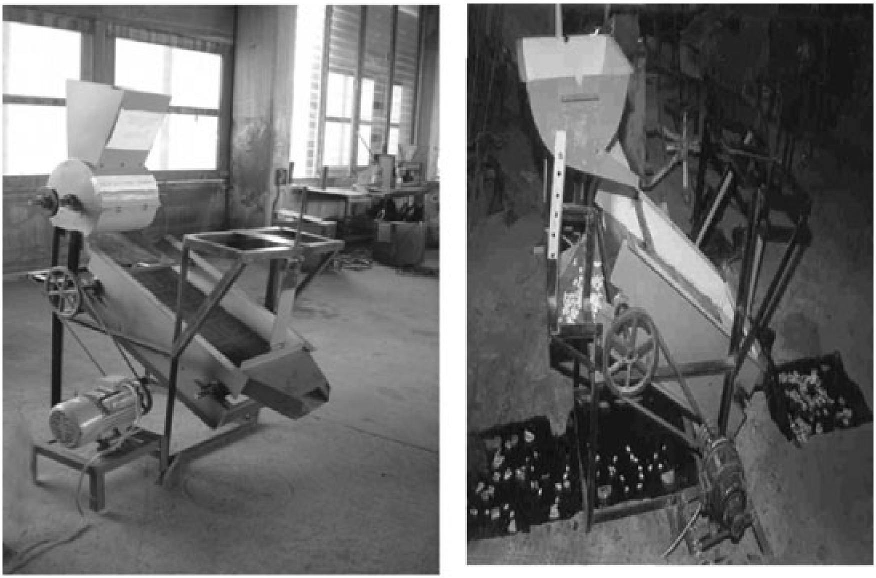
The experiment was carried out on two different surfaces: rubber (natural rubber-elastomer manufactured by Daylong Certificado Company, France – ISO 9001:2000) and carpet (made from mixture of polystreylene and polypropylene and manufactured by APEX, Thailand). The plane was covered with the appropriate material and the test sample placed on it. The angle of inclination was gradually varied from 0 to 60° until the test sample just began to slide. The angle at this point was recorded and the procedure repeated 20 times for each condition using each of the surface materials (i.e., rubber and carpet). The coefficient of friction was calculated by taking the tangent of the resulting angle as (Mohsenin 1986):

$$\tan\theta = \frac{h}{l} \tag{1}$$

where h = height of inclined plane at point of slide, and l = length of inclined plane.

The same surfaces were used in carrying out the coefficient of friction for wet cocoa beans. Interestingly, the beans remained stuck to the surface materials at all angles of inclination (the inclined plane was calibrated up to 60° only and this explains why some readings were reported as >60°).

Based on the results obtained from the preliminary experiments on static coefficient of friction, it became evident that the differences in the coefficient of friction could be a way of separating the beans from the husks. Carpet (specified earlier) was picked as the surface material for separation because of



a b

FIG. 4. (a) AN ISOMETRIC VIEW OF THE COCOA BEANS–HUSK MIXTURE INCLINED PLANE SEPARATOR AND (b) THE INCLINED PLANE SEPARATOR DURING ONE OF THE EXPERIMENTAL TRIALS

its availability, surface smoothness and flexibility. Three important design parameters considered in relation to the efficiency of separation were:

(1) the speed of the separating surface;
(2) the angle of inclination of the separating surface; and
(3) the height of fall of the broken mixture from the hopper onto the separating surface.

The adapted inclined plane mechanism used for the experimental work is shown in Fig. 4 while in operation during one of the experimental trials. The machine consisted mainly of the separating surface, the hopper (which is in the form of a frustum, 400 × 400 mm on top and 200 × 200 mm at the bottom), the scraper, a 1,440-rpm fractional horsepower electric motor, two pulleys and the body frame. The separating surface consisted of a length of carpet wrapped around two 100-mm-diameter rollers; one at the top and another at the bottom. The distance of travel down the surface was 1 m (i.e., the length of the surface). The width of the surface was about 450 mm. The angle of inclination of the surface was varied by adjusting the screw fitted at the front to the frame carrying the separating surface. The height of fall was varied by raising the hopper via the holes drilled along the bars carrying the hopper. The speed of the inclined plane was varied by changing the size of the pulley(s) of the belt drive. The choice of the height of fall and speed was arrived at after some trial experimental runs.

The electric motor drives the pulley on the inclined separating surface anticlockwise. As a result, materials falling from the hopper onto the inclined surface moved in the upward direction as the surface. The beans stuck onto the surface and discharged at the upper end whereas the husks slid down the surface and were collected at the lower end. Beans that were not thrown off the surface by centrifugal force as they turned around the upper roller were scraped off the surface using a scraper closely fitted to the surface below. The efficiency of this machine depended on the combination of the three parameters earlier stated: the height of fall, angle of inclination and the speed of the inclined surface. A 3^3 factorial experimental design consisting of angle of inclination (20, 25 and 35°), speed of rotation (215, 250 and 260 rpm) and height of fall (30, 60 and 90 mm) was used in the study. The separation efficiency was calculated in terms of percentage of beans separated as:

$$\text{Separation efficiency} = \frac{\text{Weight of beans separated}}{\text{Total weight of pod} - \text{bean mixture}} \tag{2}$$

RESULTS AND DISCUSSION

The results of the coefficient of static friction test carried out on the husks are shown in Table 1, and Table 2 shows the average separation efficiency of cocoa beans from pods at the different processing conditions. It could be observed that increase in the angle of inclination at the three speed and height

TABLE 1.
COEFFICIENT OF STATIC FRICTION OF BROKEN HUSKS

Material	Husk resting on its outer dry surface		Husk resting on its outer but wet surface		Husk resting on its inner cut surface	
	Carpet	Rubber	Carpet	Rubber	Carpet	Rubber
Angle of inclination (θ°)	30.47	39.91	26.98	32.28	41.69	>60 and <90
Coefficient of friction (μ)	0.59	0.84	0.51	0.63	0.89	–

TABLE 2.
AVERAGE SEPARATION EFFICIENCY UNDER DIFFERENT CONDITIONS

Speed (rpm)	Height (mm)	Angle of inclination (degrees)		
		20	25	35
215	30	84.58	80.46	50.68
	60	74.12	76.34	61.45
	90	80.12	79.42	55.03
250	30	97.91	97.73	86.51
	60	97.66	83.14	84.02
	90	91.84	99.00	74.25
260	30	96.80	87.21	75.36
	60	86.12	89.57	51.66
	90	88.83	86.60	59.15

Mean = 80.58; SD = 14.25.

levels reduces the separation efficiency. This is because the ease of sliding increases with increase in angle of inclination, and as a result, more of the beans rolled down with the husks to husks-collection end while few stuck to the carpet surface to be collected at the other end. The efficiency, however, decreases with the increase in speed from 215 to 250 rpm, and reduces slightly at 260 rpm. The increase in separation efficiency with the speed could be attributed to the fact that there is an increase in agitation as speed increases, thereby enabling more of the husks to separate from the beans and roll down the carpet surface. The slight reduction may be due to the possibility of some of the beans being detached from the mixture and thrown off as a result of velocity increase. Increase in height of fall from 30 to 60 mm increases the separation efficiency, especially at speeds of 215 and 250 rpm, but later reduces at a speed of 260 rpm. The best separation efficiency (99.0%) was observed at 250 rpm, height of 90 mm and angle of inclination of 25°. The statistical analysis of the effect of the factors considered on separation efficiency using the statistical package (SAS 1987) indicates that the effects of all the factors are significant at 99%. The interactive effects of all the factors (i.e., speed and height; speed and angle; height and angle; and speed, height and angle) are also significant at 99%.

CONCLUSION

Separating cocoa beans from cocoa husk–beans mixture has remained a critical bottleneck in the processing of cocoa. A lot of attempts have been made to tackle this problem with very little success. This study investigated the possibility of applying the frictional properties of the cocoa husk and beans in the separation of the mixture. A separation of up to 99.0% was recorded in the experiment. The results obtained here indicate that it is easier to apply this method as higher separation efficiency was recorded.

With this result, it is now possible to incorporate an inclined plane separating unit into cocoa pod process line. Thus, the problem of separating cocoa beans from the husk after pod breaking will be solved. This will enhance the production and processing of cocoa.

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