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Production and cost analysis of a hybrid cocoa beans roasting and winnowing machine for small scale uses

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Abstract : *Human utilization of cocoa beans in different forms is increasing from time to time. This calls for different processing equipment of the beans. Cocoa nibs are the small grains collected from cocoa beans after drying and shell removal (winnowing). These nibs are further processed by roasting, alkalization, grinding, agitation, pressing to get the cocoa cake that is processed to cocoa powder by pulverization for our beverages, and the butter gotten when the liquor of the nibs is pressed. To get the nibs produced requires cleaning, sorting, roasting and winnowing. In all cocoa processing plants in Nigeria, three different machines are required for the listed nibs production activities. These caused much capital investment, increase in inventory cost, maintenance cost, and machine layout and manpower requirement. In order to reduce these problems, a hybrid machine capable of processing dry cocoa beans to the nibs level was designed. The different components of the machine were identified, designed, fabricated and coupled together. The machine is easy to operate and can be powered by a low horse-power prime mover with a processing capacity of 600 kg/h and cost of production of four hundred and thirty thousand naira (₦430,000) only.*

Key Words: *Cocoa beans, cocoa processing, cocoa products, production, machines.*

1. INTRODUCTION:

The crop processing industry of Nigeria like other African countries is dominated by the informal sector comprising mainly of small and medium scale rural enterprises owned and operated by men and women who depend solely on indigenous technology. Known as “food of the gods”, the cocoa tree (*Theobroma cacao L.*), of the Malvaceae family, is a tropical plant cultivated for its beans, from which cocoa powder and butter are extracted. Cocoa is produced by comparatively few countries; all of them tropical, but the product is processed and consumed mainly in temperate countries. The cocoa bean is greatly appreciated for its aroma and its nutrients (phosphorus, magnesium, iron, zinc, manganese, copper, potassium, selenium, vitamins B2 and B3). Cocoa is a popular raw material in the pharmaceutical, cosmetics, and the food industries. Studies show that the cocoa bean contains flavonoids with antioxidant properties that can reduce blood clot and the risk of stroke and cardiovascular attacks (1). Long before the oil boom of the mid-70s in Nigeria, cocoa has been a major source of revenue and still remains a large agricultural enterprise in the South-Western part of the country till today. Presently, fourteen of Nigeria’s 36 states grow cocoa of which more than 80% are from southwest geopolitical zone. Nigeria ranks among top cocoa producing countries in the world, occupying the fourth position after Côte d’Ivoire, Ghana and Indonesia (2). The inability of the Nigerian farmers to produce cocoa like Ghana and Côte d’Ivoire in Africa are attributed mainly to loss of soil fertility, world price fluctuation, aging plantation, and negligence of agriculture in favour of crude oil by government. The production of cocoa powder is an eleven unit operation comprising cleaning, roasting, winnowing, milling, alkalizing, blending, milling, pressing, butter packing, pulverizing and sifting. The dried fermented cocoa beans are cleaned by aspiration and de-stoning to remove dry pulp debris, stones and other extraneous materials including chaff and pod residue. The beans are roasted (at within a temperature range of 90-140°C for 90-95 minutes) to sterilize them, eliminate the acids formed during fermentation, make the beans amenable to fracture during decortication and enhance the development of the sensory attributes typical of chocolate (3). Home-scale roasting and winnower machine is developed to encourage farmers and smallholders to process raw cocoa beans from local farms and increase cocoa basic products produced by home-scale industries. Cocoa roasting can be done in many different ways some of which are roasting in a normal oven, in a coffee roaster, on the stove top in a pot or *comal* (griddle). You can also use a perforated sheet pan or a regular sheet pan. The most important thing is that the beans must be consistently roasted. Cocoa roasting are mainly in two patterns, light roasts and dark

roasts, depending on the choice of the individual taste. The dark roasts produce more fluidity during grinding, this is done at a temperature above 130ºC. Some roast until they hear the first beans pop; sounds like a popcorn, which can be above 140ºC.

Winnower machine separates roasted cocoa beans from shells, consequently roasted cocoa nibs can be processed into cocoa mass (4). In using winnower machine, it is expected that the shell texture is fragile, as a result, it is easier to break and separate. Roasted cocoa beans should also have low water content in order to get uniform fractions of roasted cocoa nibs. Another method to get uniform fractions of roasted cocoa nibs is by sieving the nibs (5).

It is expected that the winnower produces cocoa nibs with uniform size and there is not any tiny cocoa shell parchment mixed with the cocoa nibs (6). Processing of cocoa beans into confectionery products such as chocolate bar can be done in small-scale in order to get chocolate directly from cocoa beans instead of cocoa mass. Chocolate products made directly from cocoa beans have better flavor and aroma due to self-choosing cocoa beans quality by the operator (7).

The cocoa nibs are then milled to produce cocoa liquor (cocoa suspended in cocoa butter). Previous type of winnower machine consisted of double rolls with some space in-between for breaking down cocoa beans without grinding them and then sieving the broken beans. Other type was in form of serrated con cylinder installed to hallowed cone stator widely known as kibbing cones type (8). The machine was later developed by providing air suction and cyclone-shape funnel. Roasted cocoa beans are peeled using rotor-stator and then, they go to exhausted channel that is connected to suction fan, as a result, smaller fractions of cocoa shell parchment will be sucked out of the exhausted channel and the nibs are collected on the storage funnel (5). Another type of winnower machine to process roasted cocoa nibs was previously developed by Widyotomo *et al.* (9) for farmers-group scale and the capacity of the machine was 268kg/hour. Cocoa processing mechanization using less sophisticated machine is the most suitable for developing home or small-scale industries with relatively low processing cost.

The industrial machines studied for this research work is at JohnVents Cocoa Processing Plant, Ilesa-Owo expressway, Akure, Ondo State. In this plant, the cocoa beans are first passed through an oven on a conveyor belt at a temperature of 100ºC. This process is referred to as fast drying. The moisture content of the beans is reduced to between 7-8%. After this process, the beans are crushed in a crusher and then winnowed to separate the nibs from the shells by an aspirator. The nibs are moved to the roasting chamber where they are roasted at a temperature of 140ºC for a period of between 3-4 hours, with good agitation. The roasted nibs are cooled rapidly and the moisture content after roasting and cooling drops to between 3.80-4.30%.

In some other industrial machines, it is the cocoa beans that are roasted wholly and the product of this method is known as roasted cocoa beans. The roasted cocoa beans are sent to the crusher for crushing and then winnowed to separate the nibs from the shells. The most valuable part of cocoa bean is the nib.

In all the operations of these industrial machines, the roasting chamber is separated from the winnowing chamber. This research is aiming at combining these two processes in a single machine that is handy, cheap and can produce a product (cocoa nibs) that can compete favorably with that of an industrial machine and that can be used by a small scale cocoa processor. The objective of this study is to promote small-scale cocoa beans roasting and winnowing in accordance with chocolate processing in smallholders or even processing run by family farmers. Although, there had been different cocoa bean roasting and winnowing machines, but all these were separate machines, that is, drying machine is separated from winnower. This research work is aiming at combining the two operations on a single machine which can encourage more processing of the cocoa beans into downstream products for both local and international markets.

2 METHOD :

2.1 Machine Description and Operation

2.1.1 Description

The components of the machine include the main frame, the A.C electric motor, the hopper, the roasting chamber (roasting cylinder), the winnowing chamber, (this includes the cylinder housing the abrasive material), the blower (fan for separating cocoa nibs from shells due to difference in weight), D.C electric motor, the stirrer for stirring cocoa beans etc. Details of these components are subsequently presented

2.1.1.1 The main frame

Mild steel angle iron of dimensions 50 mm x 50 mm x 4 mm was used for the construction of the main frame for strength. This was cut to sizes and joined together by arc welding method for rigidity. The frame must be very strong for it to be able to bear all the loads that will be coming on it.

2.1.1.2 The hopper

The basic function of hoppers in industrial machines is to feed raw materials into the machine. The type of raw materials to be fed into the machine determine the design of the hopper to be used and how its passage may be designed. The hopper of this machine was made of stainless steel and it came in form of a pyramid. The angle of inclination of the hopper to the horizontal surface is 45^{o}, this is so to facilitate easy feeding. Stainless steel was chosen as material because it is corrosion resistant, since cocoa is acidic, stainless steel will be able to resist its corrosive nature on materials.

2.1.1.3 The drying chamber

This part consists of the heating chamber and the drying area with stirrer which is connected directly to an electric motor with a speed reduction gear for stirring the cocoa seeds during drying for even distribution of seeds to receive equal heat, thus preventing burning or under-drying of some seeds. The drying chamber is at the top of the heating element producing the heat. The stainless steel is a good conductor of heat. It conducts the heat generated from the heating element, and pass it onto the cocoa seeds for drying. An opening is provided for discharging the dried beans. The drying chamber must be lagged to prevent heat loss during drying.

2.1.1.4 The winnowing chamber

The winnowing chamber is cylindrical, housing the winnowing cylinder that is connected to it's own speed reduction geared electric motor. This part also has its own hopper for receiving the dried cocoa seeds ready for winnowing. This part was designed such that as it receives the dried beans, peeling is carried out on them by abrasion. The drum was wrapped with abrasive material which rubs on the cocoa seeds, thus effecting peeling of the dried beans. The abrasive material was wrapped on the drum in a helical form. This was done to prevent choking of the chamber with the beans. Also, any of the seeds that escapes peeling in the front will still get peeled before getting to the end of the drum. The chamber consists of two exit troughs. The first trough is the exit for shells while the other trough is for the nibs.

A fan was incorporated with the winnowing chamber. The fan performs two functions: (i) to cool the roasted beans that are coming directly from the roasting chamber into the winnowing chamber and (ii) to blow away or separate the nibs from the shells due to weight difference during winnowing.

2.2 Design analysis

The roasting chamber hopper of the machine was designed for 2 kg of cocoa beans. The density (ρ) of cocoa beans is 593 kg/M^3 (10). The roasting chamber cylinder (inner) was designed for 5 kg of cocoa beans while the outer part was designed to accommodate the insulating material (fiber glass) between it and the inner cylinder. The volume of the insulating material was also determined. The stirring shaft was designed against torsion and the effective diameter was determined.

0.5 hp (373 Watts) geared electric motor with gear reduction ratio of 50:1 was used for the stirring to achieve a desired speed of 25 rpm. This was done to achieve good roasting of the cocoa beans. The heating element needed to supply heat was also designed for. 1500 Watts coil was chosen. The total energy requirement of the roaster was calculated. The winnowing chamber's hopper's volume was designed for 5 kg of cocoa beans, while the winnowing chamber's volume was also designed for 5 kg. The winnowing shaft was designed against torsion and the diameter was calculated. 0.5 hp geared electric motor with gear reduction ratio of 50:1 was chosen and this was connected to the winnowing shaft through a flange coupling. In designing for the coupling, the hub shear stress, flange shear stress and the bolts were all calculated (11). The power needed to peel the beans was also determined using the equation of Akintade *et al*, (12).

2.3 Machine Operation

The mode of operation of the cocoa beans roaster is in this form: the cocoa beans are fed through the hopper, the discharge opening would have been shut before then, the heating element switched on, the temperature at which to roast is chosen and the timer set for the required time. The stirrer also should be switched on immediately with the heating element. As the temperature of the roasting chamber gets higher, the stirrer continues stirring the beans for even distribution of the beans to heat. This is to prevent burning of some of the beans while some at the center will not receive enough heat for even roasting. At the expiration of the time chosen, the beans are sampled for roasting, if satisfactory roasting is achieved, the heating element is switched off to conserve energy while the discharge opening is opened and the stirrer will stir all the roasted beans out of the chamber into the winnowing chamber hopper in preparation for winnowing operation. The winnowing chamber, having received the roasted cocoa beans, is switched on and the blower fan also switched on. The beans will be shelled and the fan will separate the nibs from the shells by difference in weight.

The nibs are collected at the first opening while the shells will be blown to the extreme end of the winnower where they are collected in a sack that will be provided for it.

3. RESULTS AND DISCUSSION :

3.1 Results.

The fabrication of the machine was carried out at the Mechanical Engineering departmental workshop of Rufus Giwa Polytechnic, Owo, Ondo State Nigeria. The machine is displayed thus;

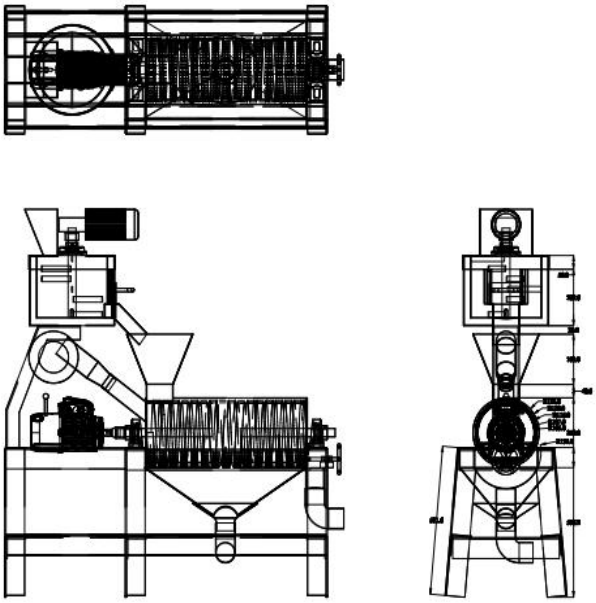

Figure 1: Orthographic View of the Drying and Winnowing Machine

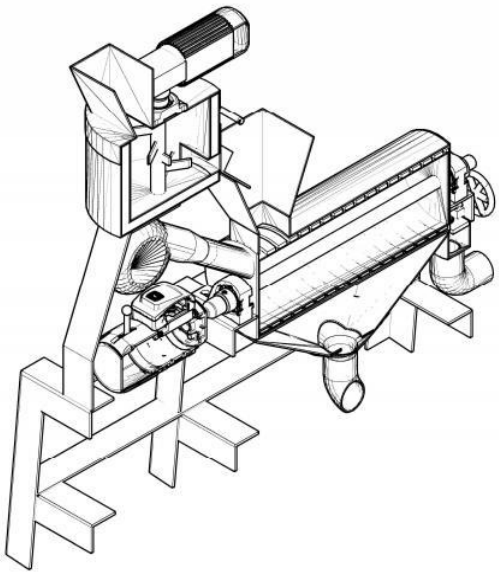

Fig 2: Cutaway View of the Drying and Winnowing Machine

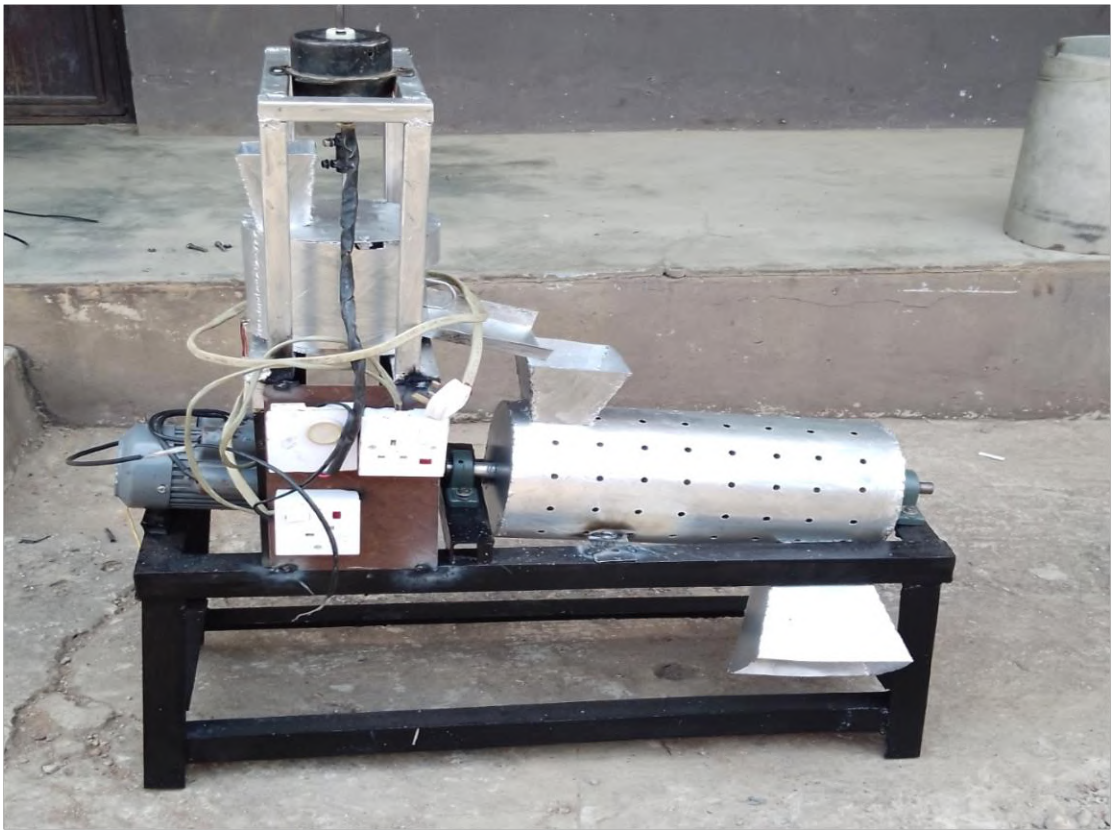

Fig 3: The locally fabricated cocoa drying and winnowing machine.

Table 1: Materials selection.

s/n	Component	Possible materials	Selected material	Reason for selection	Limitation of selected material
1	Hopper	Stainless steel, galvanized steel, mild steel.	Stainless steel	Corrosion resistant	It is expensive than the others.
2	Frame	Mild steel, galvanized steel, stainless steel.	Mild steel	It possesses good load-bearing strength and it is cheap.	
3	Shaft blades.	Stainless steel, galvanized steel and mild steel.	Stainless steel	Corrosion resistant	It is expensive
4	Shaft for drying section.	Stainless steel, galvanized steel and mild steel.	Stainless steel	Corrosion resistant and strength	It is expensive
5	Shaft for winnowing section.	Stainless steel, galvanized steel and mild steel.	Mild steel.	Strength and it is cheap.	
6	Coupling.	Mild steel, cast iron	Cast iron.	Strength and it is cheap	
7	Bolts and nuts.	Stainless steel and mild steel.	Mild steel	Strength and it is cheap	

3.2 Cost analysis

The results of the cost analysis of the components used in the production of the machine is presented in Table 1 below.

Table 2: Summary of the cost of producing the machine.

S/n	Description	Materials & Sizes	Quantity	Rate (₦)	Cost (₦)
1	Stainless steel plate	1.5 mm	1	70,000	70,000
2	Stainless steel shaft	Ø50 mm x 750 mm	1	25,000	25,000
3	Stainless steel perforated pipe	Ø170 mm x 800 mm	1	22,000	22,000
4	Stainless steel shaft	Ø20 mm x 300 mm	1	9,000	9,000
5	Stainless steel flange	Ø80 mm x 8 mm	1	5,800	5,800
6	Mild steel angle iron	(50x50x4) mm	3	5,000	15,000
7	Variable speed electric motor	220 V	1	150,000	150,000
8	D.C electric motor	110 V	1	10,000	10,000
9	Step down transformer	220 V-110 V	1	4,000	4,000
10	Heating element (1,200Amp)	Ø250 mm x 150 mm	1	12,000	12,000
11	Temperature regulator	-	1	8,500	8,500
12	Thermocouple	-	1	5,000	5,000
13	Fiber glass (insulator)	-		9,000	9,000
14	Pillow block bearing	P206	2	3,000	6,000
15	Circuit controller	-	1	20,000	20,000
16	Stainless steel electrodes	Gauge ‘12’	1packet	22,000	22,000
17	Mild steel electrodes	Gauge ‘12’	1packet	5,000	5,000
18	Cutting disc		3	1,500	4,500
19	Grinding disc		1	1,500	1,500
20	Paint		1gallon	5,000	5,000
21	Miscellaneous				20,000
	TOTAL				429,300

3.3 Discussion

The idea of developing a hybrid dual-purpose drying and winnowing machine for nibs production for small scale cocoa processing plant is to further encourage the local processing of cocoa beans into its different products through local technology. A review of the existing industrial cocoa processing (i.e drying and winnowing) machines was first carried out, the findings there was used to develop this machine that can be used for the processing of cocoa beans by small holders. The processing capacity of the machine is estimated at about 600 kg/h. The calculated average power consumption of this machine is about 2 hp (about 1.5 kW), this means that with a 5 kW petrol engine power generator, the small holder will be able to carry on with production compared with the heavy industrial machines that require much power to run. The production cost of this machine (₦430,000) is also within the reach of the average small holders.

4 CONCLUSION:

The following conclusions were drawn from this study;

- The components used for the production of this machine were chosen according to the conditions under which the machine will be used. Cocoa is corrosive and thereby needs corrosion resistant materials for the machine to be used for longer period.
- The materials used were all locally sourced and affordable even for the small holders.
- The machine is easy to operate and
- It can be powered by a low horse power prime mover.

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