Modification of a cocoa pod divergent roller grader

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Abstract: Grading the cocoa pods to uniform size is required to adjust the knife settings of the pod breakers and achieve improved performance. A gravity fed divergent roller type grader was developed for grading cocoa pods according to the breadth into six grades. Fiveround mild steel pipes of 40 mm outer diameter and 3 mm thickness for 1500 mm length were arranged with divergent of 65 to 100 mm between two rollers towards tail end with slope in the range of 22.5 to 25.5°. The grader, grades cocoa pods into six grades as, less than 70 mm, 70-80 mm, 80-85 mm, 85-90 mm, 90-100 mm and above 100 mm. The grader was evaluated for capacity and effectiveness at 22.5, 24 and 25.5° slopes of operation. The capacity of the grader and the effectiveness of grading are found significant with slope of operation. The capacity of the grader was 253.1, 268.9 and 277.7 kgh^{-1} at operating slopes of 22.5, 24 and 25.5°, respectively and the effectiveness of grader was 0.767, 0.787 and 0.745. Operating at 24°slope yielded the highest effectiveness of 0.787 and a capacity of 268.9 kgh^{-1}. According to these size grades of the pods, the breaking mechanism can be adjusted to achieve efficient pod breaking.

Keywords: cocoa pods, size distribution, divergent type grader, capacity, effectiveness.

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1 Introduction

Cocoa (*Theobroma cacao* L.) forms the chief ingredient in making chocolates, health drinks, cosmetics and even pharmaceuticals. Cocoa is identified as a crop of native to Amazon basin and is spread to other countries *viz*., Ivory Coast, Ghana, Nigeria, Cameroon Mexico, Central America, Caribbean Islands, South America, West Africa and South East Asia, where the climatic conditions are favorable for cultivation (Shahbandeh, 2020). Cocoa pod at its maturity, ripe and tuned three quarters yellow in colour, is harvested individually using machete, pruning pole, pruning shears or sickle (Adabe and Ngo-Samnick, 2014). As shown in Figure 1, the cocoa pod comprisesthe husk having the surface with ridges and furrows. The pod stalk with placenta holds the wet beans and white coloured mucilage. Immediately after the harvest of ripe cocoa pods or followed by a brief storage of pods, pods are broken using a knife or wooden mallet or cutlass, *etc.* with little or no damage to the beans. The beans are removed and subjected to fermentation followed by drying, often called as "curing", which are generally carried out at the farm level (Adabe and Ngo-Samnick, 2014). These operations are carried out at farm level using larger number of labourers.

The geometry and size of cocoa pods vary with agro climatic regions, varieties, cultivation practices, *etc.* Partial mechanization of handling, grading, pod breaking, *etc.,* will reduce the drudgery to the laborer and increase the efficiency of the process. For efficient using the breaking

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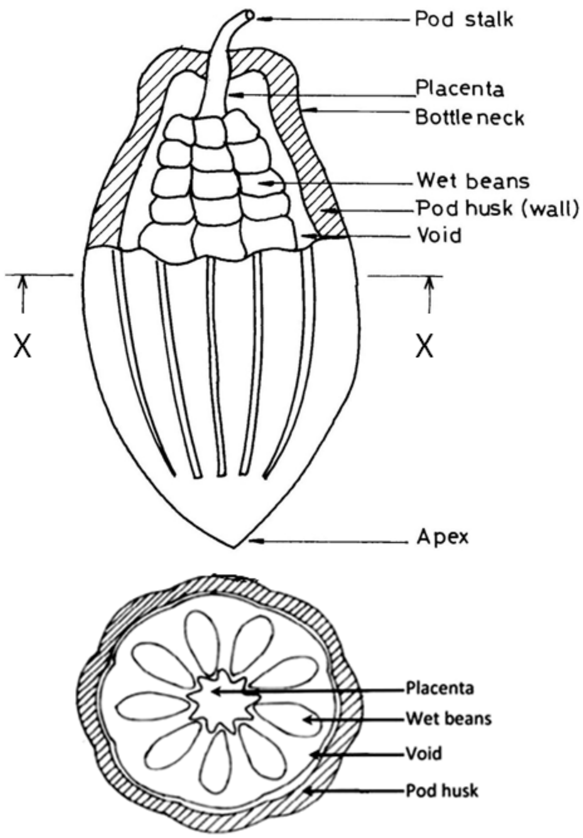
tool, adjustment in the mechanism may be required according to the size of the pods, which envisages the requirement of a pod grader at farm level.



Section at X-X

Figure 1 Geometry of cocoa pod

Punched sieves and meshes of various shapes and size of perforations are used for grading the agricultural producers of small to medium sizes. Hand and power operated rotary type graders were developed for fruits and vegetables (Ghuman and Kumar, 2005), tomato (Preetha et al., 2016) and onion bulbs (Karthik et al., 2018). Stepwise expanding pitch type fruit grader (Mangaraj et al., 2005), oscillating sieve type grader for rose onions (Gayathri et al., 2016) and weight basedgraders for fruits and vegetables (Omre and Saxena, 2003) were developed. Roller type mechanisms are developed, commonly known as divergent roller type with pair of rollers having varying clearance along the length, used to grade the produces, mostly round to elliptical shape, where the produce can roll or slide, when the rollers rotate opposite outward. During the movement of the produce along the length of the roller with varying clearance, the produce passes through the roller clearance appropriate to its diameter or breadth.

A number of divergent roller type graders were developed by the earlier researchers for tomato, potato and onion (Shahir and Thirupathi, 2009), sapota fruits (Ukey and Unde, 2010), onions (Londhe et al., 2013), almond (Ghanbarian et al.,2015) and apple (Muzamil et al., 2018). The divergent roller type grader requires power to rotate the rollers and facilitate movement of produce and thereby grading. The divergent rollers fitted permanentlywith inclination and not rotating also provide the appropriate clearance for grading the produces and do not require power for its operation (Londhe et al., 2013). This type of divergent roller graders working without power, will be much useful at the plantations for grading cocoa pods.

For the development of such graders, information on size distribution, friction, rolling characteristics, *etc.*, are required. Some of the earlier researchers, Bart-Plange and Baryeh (2003), Bamgboye and Odima-Ojoh (2004), Adewumi and Fatusin (2006), Adzimah et al. (2010), Aliu and Ebunilo (2011) and Muzamil et al. (2018) have determined the various physical properties of cocoa pods. However, the information on the properties of the pods of Indian cultivar will be much useful for the development of grader. Hence, some of the important physical properties of cocoa pods were determined as related to development of pod grader anda gravity flow divergent type pod grader was developed and reported.

2 Materials and methods

2.1 Raw materials and moisture content of cocoa pod, husk and beans

The freshly harvested mature whole cocoa pods of mixed F1 progeny varieties were obtained during November – December 2019, from a local farmer in Coimbatore, India (latitudeof 11°1'0.64"N; longitude of 76°57'21"E and altitude of 411 m above MSL). Pods having crack or skin injuries and infestation were rejected by physical observation. Harvested pods were collected in gunny bags and transported with care to the laboratory. In the laboratory, pods were stored open at ambient condition (30°C±1°C and 65% to 70% relative humidity) and used in the experiments within 3 days.The method of moisture measurement of peanut (ASAE S410.1 DEC97,1998) was modified and the moisture content of whole cocoa pods was determined. Husk, wet beans, placenta and pod stalk were manually separated from 5 fruits and pooled. Five samples of each of them weighing about 100 g were placed in a ventilated oven at 130°C till constant weight is reached. It took about 12-16 hours to reach complete dry. The moisture content of the husk and bean were determined from their individual initial and final weights. Moisture content of whole pod was determined from the sum of the initial and final weights of the individual components. All the samples were weighed in a digital balance of 0.01 g accuracy (Ohaus Corporation, New Jersey, USA) and the mean moisture contents were expressed in percentage on dry basis. This method was modified and used for moisture estimation of false banana fibre (Mizera et al., 2017).

2.2 Size distribution

Considering cocoa pods as prolate spheroid/ elliptical in shape, from the samples lot, 1000 whole ripe cocoa pods were selected and for each fruit, breadth (diameter at minor axis) was measured using a digital vernier caliper (Mitayo Instrument, Japan) reading to 0.01 mm. The length of the pod was measured along its longitudinal axis (diameter at major axis) using a height gauge with least count of 0.05 mm. With the length and breadth of the pods the distribution curve was drawn and percentage contribution on the size was assessed.

2.3 Geometric mean, sphericity and aspect ratio

The geometric mean diameter (D_g, mm) of the cocoa pod (Josué et al., 2019) was determined using the Equation 1from the main principal physical dimensions, length and breadth.

$$D_g = (ab^2)^{1/3} \tag{1}$$

Sphericity(S,decimal) was determined using the following formula (Josué et al., 2019).

$$S = \frac{\sqrt[3]{ab^2}}{a} \tag{2}$$

The aspect ratio (R_a) was calculated using the length 'a' and the breadth 'b' of the sample (Josué et al., 2019).

$$R_a = \frac{b}{a} \tag{3}$$

where, $a$is the length of the pod, mm; $b$is the breadth of the pod, mm.

The measurement was replicated with at least hundred pods selected in random from the whole lot and also from each grade.

2.4 Coefficient of friction

The experimental apparatus used in the static friction studies consisted of a frictionless pulley fitted on a frame, an open-ended rectangular container (200 mm × 100 mm × 75 mm) to hold the sample, loading pan and test surfaces. The container was placed on the test surface and filled with two or three cocoa pods of known mass. Weights were then added to the loading pan until the container began to slide. The mass of the pods and the added weights comprise the normal force and frictional force, respectively. The coefficient of static friction was calculated as the ratio (Zhang, 2016):

$$\mu = \frac{F}{N} \tag{4}$$

where, μ is the coefficient of static friction; $N$is the normal force in static friction, N; F is the frictional force in static friction, N.

The experiment was performed using the different test surfaces of mild steel, galvanised iron, aluminium and stainless steel with five replications. For each replication, the pods in the sample container were emptied and refilled with a different sample. The earlier researchers used this type of set up with circular containerto determine the coefficient of friction for minor millets (Balasubramanian and Viswanathan, 2010), ginger (Jayashree and Visvanathan, 2011) and cocoa pod (Josué et al., 2019).

2.5 Rolling angle and rolling resistance

Rolling angle (ϕ) is the slope of the surface required to facilitate rolling of the object. The action of rolling for the cocoa pods may be required in grading the pods. The rolling angle of fruits was measured by placing a cocoa pod on a flat surface hinged to the frame horizontally and provided with a circular angle measuring system (0 to 90°). With the fruit placed on the horizontal surface was gradually raised till the fruit begin to roll (Ebaid et al., 2012). This inclination required for rolling is the rolling angle.

Rolling resistance, also called as rolling friction or rolling drag, is the force resisting the motion when a body (such as a ball, tire, or wheel) rolls on a surface. The rolling resistance was calculated (Wargula et al., 2019) using Equations 5 and 6:

$$R = F_r \frac{N}{b} \quad (5)$$

$$F_r = tan\, ø \quad (6)$$

where, R is the rolling resistance, kg cm^{-1}; F_r is the co-efficient of rolling friction (tan ϕ), decimal; N is the normal force (mass of pod), kg; b is the rolling radius (breadth of pod), cm; ϕ is the rolling angle,°.

2.6 Fabrication of cocoa pod grader

A gravity fed divergent type grader was fabricated for grading cocoa pods according to the breadth. The divergent roller set consisted of five round mild steel pipes having outer diameter of 40 mm and thickness 3 mm for 1500 mm length. They were arranged in parallel to each other with a divergent towards the tail end. The variation in the clearance between two pipes varied from 65 mm at feeding end to 100 mm at the tail end, based on the mid diameter or size of the pods, which is the most useful in determining the size of the breaking chamber (Aliu and Ebunilo, 2011).

The clearance varied with the length of the pipes as given in the Table 1. This pipe assembly with five pipes arranged with 65 mm and 100 mm clearance at the head end and tail end were welded on the frame. The main frame of the grader was fabricated using 40 ×40 × 5 mm mild steel angle section and the size of the frame was 1540 × 1300 × 540 mm. The legs in the tail end were provided with adjustments to vary the slope of the grader in the range of 22 to 26°.

The feeding unit was fabricated using 1 mm thick mild steel sheet to an overall dimension of 800 mm × 500 mm ×75 mm and arranged with 30°inclination such that the pods delivered at the hopper will be diverted to the grading pipes. The five mild steel pipes, provide four divergent passages as per the clearance specified in Table 1. The cocoa pod reaching the divergent clearance starts sliding and exhibit friction between the pod surface and the pipe surface. The friction is overcome by the inclination provided for the pipe with the increase in the friction force.

Table 1 Length and spacing range of divergent pipe grader for cocoa pods

Sl. No.	Grade Type	Length range, mm	Spacing range between two separators, mm
1	VI	0 to 305	65-70
2	V	305 to 545	70-80
3	IV	545 to 850	80-85
4	III	850 to 1050	85-90
5	II	1050 to 1450	90-100
6	I	Moving away from the pipe.	Above 100 mm

During the sliding of the cocoa pods, the possibilities of turning of the pods and rolling along the pipes, may occur and they are prevented by providing stoppers (30 mm long and 3 mm diameter) projecting from the surface of the pipe. Also during the operation, no clogging or jamming of the pods was noted due to the slope of the rollers. When the cocoa pods slide along the divergent and reached the clearance appropriate to its breadth (minor axis), it passes through the passage and reach the partition provide below the pipe assembly. Below the pipe assembly, five partitions, which act as collection chamber of size 450 mm × 500 mm, are provided to receive the pods as pass through the five clearance ranges. The largest size, above 100 mm will slide along the divergent pipe and collected outside as the largest size (Grade I). The pods received in the chamber can be collected manually or in bags through the inclined outlets. A view of the gravity flow divergent type cocoa pod grader developed in this study is shown in Figure 2.

Figure 2 A gravity fed divergent type cocoa pod grader

1. Feeding Tray; 2.Guiding channel; 3.Dividers; 4.Outlet for oversize pod; 5.Shutter; 6.MainFrame; 7. Feeding slope adjustment; 8. Collection chamber; 9. Mild steel pipe

2.7 Effectiveness of size grader

The cocoa pod grader separates the pods of different sizes into six fractions as grade - VI (65-70 mm), grade - V (70-80 mm), grade – IV (80-85 mm), grade – III (85-90 mm), grade - II (90-100 mm) and grade - I (above 100 mm). Let W_t be the total number of pods and W_1, W_2, W_3, W_4, W_5 and W_6 are the individual fractions (in numbers) of the feed material corresponding to gap S_1 (65- 70 mm), S_2 (70-80 mm), S_3 (80-85 mm), S_4 (85-90 mm), S_5 (90-100 mm) and above S_5 (above 100 mm) used in the unit as shown in Figure 3.

After the grading, the fraction of feed material obtained through the six product outlets are correspondingly, Q_1, Q_2, Q_3, Q_4, Q_5 and Q_6.

Thus, material balance,

$$W_1 + W_2 + W_3 + W_4 + W_5 + W_6 = W_t \quad (7)$$

$$Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 = Q_t \quad (8)$$

Let q_1 be the number of pods received through opening S_1, other than the size belong to this size opening available in the fraction Q_1. Similarly, q_2, q_3, q_4, q_5 and q_6 are the fractions available in Q_2, Q_3, Q_4, Q_5 and Q_6.

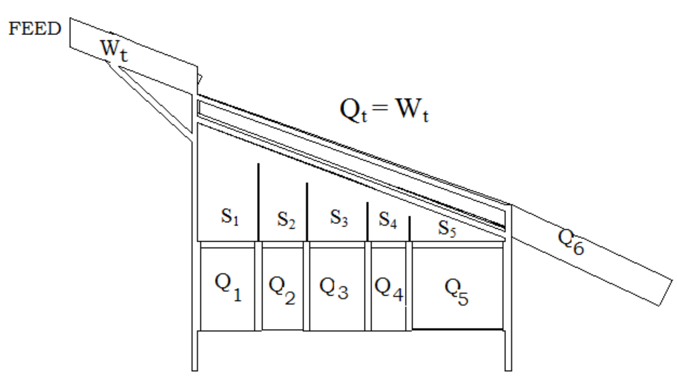


Figure 3 Schematics of divergent roller type cocoa pod grader

Hence, the purity of the product obtained at each outlet after grading is,

$$P_1 = \frac{Q_1 - q_1}{Q_1} \quad (9)$$

$$P_2 = \frac{Q_2 - q_2}{Q_2} \quad (10)$$

$$P_3 = \frac{Q_3 - q_3}{Q_3} \quad (11)$$

$$P_4 = \frac{Q_4 - q_4}{Q_4} \quad (12)$$

$$P_5 = \frac{Q_5 - q_5}{Q_5} \quad (13)$$

and $$P_6 = \frac{Q_6 - q_6}{Q_6} \quad (14)$$

The fraction yield i.e. the ratios of material in the fractions to the mixture obtained through the outlets are,

$$Fr_1 = \frac{Q_1}{W_t} \quad (15)$$

$$Fr_2 = \frac{Q_2}{W_t} \quad (16)$$

$$Fr_3 = \frac{Q_3}{W_t} \quad (17)$$

$$Fr_4 = \frac{Q_4}{W_t} \quad (18)$$

$$Fr_5 = \frac{Q_5}{W_t} \quad (19)$$

$$Fr_6 = \frac{Q_6}{W_t} \quad (20)$$

Let a_1, a_2, a_3, a_4, a_5 and a_6 be the fractions of each size corresponding to gaps S_1, S_2, S_3, S_4, S_5 and above S_5 in the total feed as,

$$a_1 = \frac{W_1}{W_t} \quad (21)$$

$$a_2 = \frac{W_2}{W_t} \quad (22)$$

$$a_3 = \frac{W_3}{W_t} \quad (23)$$

$$a_4 = \frac{W_4}{W_t} \quad (24)$$

$$a_5 = \frac{W_5}{W_t} \quad (25)$$

$$a_6 = \frac{W_6}{W_t} \quad (26)$$

Therefore, the degree of extraction, ratio of component in the yield fraction of same component in the initial mixture given by,

$$Ex_1 = \frac{Q_1 - q_1}{W_1} = P_1 \frac{Q_1}{W_1} \quad (27)$$

Dividing numerator and denominator by Q_1 and Wt yields,

$$Ex_1 = \frac{(Q_1 - q_1)Q_1 W_t}{W_1 Q_1 W_t} = P_1 \frac{(Q_1 / W_t)}{(W_1 / W_t)} \quad (28)$$

Thus Equation 28 yields,

$$Ex_1 = P_1 \frac{Fr_1}{a_1} \quad (29)$$

$$Ex_2 = P_2 \frac{Fr_2}{a_2} \quad (30)$$

$$Ex_3 = P_3 \frac{Fr_3}{a_3} \quad (31)$$

$$Ex_4 = P_4 \frac{Fr_4}{a_4} \quad (32)$$

$$Ex_5 = P_5 \frac{Fr_5}{a_5} \quad (33)$$

$$Ex_6 = P_6 \frac{Fr_6}{a_6} \quad (34)$$

The effectiveness was evaluated by the completeness of the extraction of each component in pure form as given by Dhas et al. (2004).

$$E = Fr \frac{(P - a)}{(1 - a)} \quad (35)$$

The overall effectiveness for the 6 component mixture graded into 6 fractions was determined as,

$$E = \sum_{i=0}^{n} Fri \; \frac{(P_i - a_i)}{(1 - a_i)} \quad (36)$$

This method was followed for the evaluation of the graders to separate mixtures into more than 2 fractions in pepper (Dhas et al.,2004) and pepper and cardamom (Balakrishnan et al.,2010).

2.8 Evaluation of grader

The gravity fed divergent pipe type grader was evaluated in a cocoa plantation in Coimbatore, India. During the evaluation trials, the grader was placed in a level surface. About 150 to 200 numbers of cocoa pods from the fresh harvest were randomly taken for evaluation. Each pod was measured at its breadth using a caliper and grouped according to size range of 65- 70, 70-80, 80-85, 85-90, 90-100 and above 100 mm. Normally during evaluation of graders, the earlier researchers used the mass of the materials present in each size. Howeverin the present study, since the raw material is large enough in size to count and take in numbers, the number of pods was counted. The number of pods present in each size range in the taken lot was counted and taken as W_1, W_2, W_3, W_4, W_5 and W_6. Also this lot was weighed. The fractions of these sizes a_1, a_2, a_3, a_4, a_5 and a_6 corresponding to gaps S_1, S_2, S_3, S_4, S_5 *and above* S_5 are calculated using the Equations 21 to 26. The separated materials were pooled and graded by delivering in the feeding chute. From the feeding chute the pods flow by gravity along the divergent rollers and flow though the gap when reach the clearance according to the breadth and collected at the respective outlets.

The pods collected in each outlet were counted as Q_1, Q_2, Q_3, Q_4, Q_5 and Q_6. From each of this lot, the pods of size other than corresponding to the clearance were separated by measuring each pod and counted as q_1, q_2, q_3, q_4, q_5 and q_6. Using the values of Q and q, the purity of separation was calculated for all the outlets using the Equations 9 to 14. Factional yields, Fr, the ratios of material in the fractions to the mixtures obtained through the outlets were calculated using the Equations 15 to 20. With the availability of all the data, the effectiveness was estimated using the Equation 36 for each opening range and the overall effectiveness was arrived by summing up of all the openings. After each experiment, the same lot of the pods was used and the graded pods collected through the outlets were measured and the calculations were made. As seen from the values of rolling angles determined and preliminary trials, the grader was found to work satisfactorily in the slope range of 22° to 26°, the unit was evaluated at 22.5°, 24° and 25.5° slopes by adjusting the height of the frame in the tail end. The grader was operated continuously with known mass of pods and the time taken was noted and the capacity of the grading process was calculated.

In each slope, six trials were conducted as per completely randomised block design and the mean of the effectiveness and capacity in kg per hour were reported. One way analysis of variance was performed using SPSS 16 to assess the significance of the slope of operation with capacity and effectiveness of grading.

3 Results and discussion

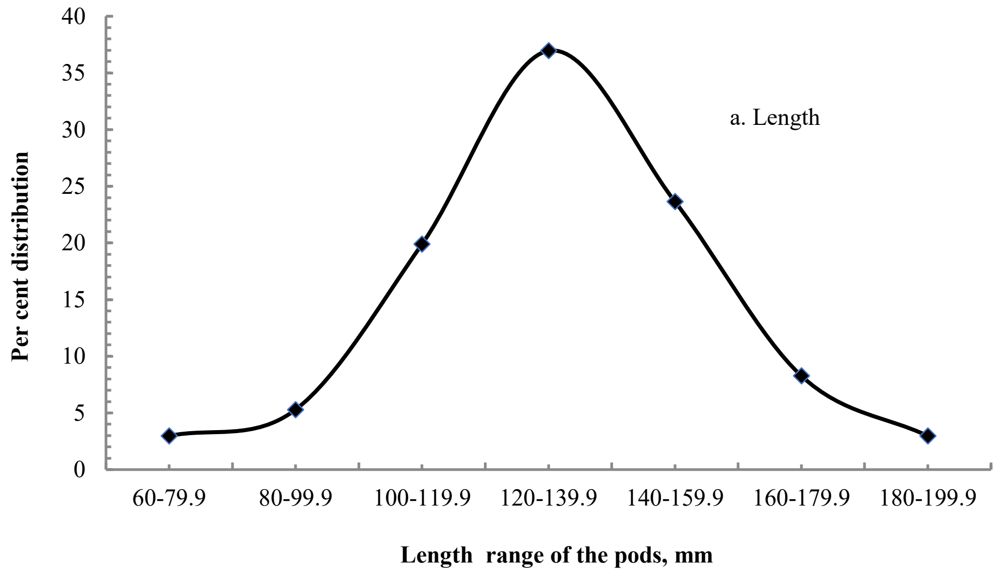
3.1 Moisture content of cocoa pod, husk and beans

The average moisture content of the harvested whole cocoa pod was 294.94%± 2.51% (d.b.). After two days of pod storage, the average moisture content of pods reduced to 274.82%±9.22% (d.b.). The average moisture content of fresh cocoa pod husk and fresh beans were 7.69%±1.07% (d.b.) and 52.70%±2.19% (d.b.), respectively. The cocoa beans extracted from the pods were fermented and sun dried by the farmers to safe moisture level. The moisture contents estimated after fermentation and drying were 128.68%±5.46% and 8.48%±1.26% (d.b.), respectively.

3.2 Size distribution

The measurement of size and mass was replicated with a minimum of hundred pods selected in random from the whole lot and also from each grade. The cocoa pod can be regarded as prolate spheroid (elliptical) in shape with nearing sharp ends. The dimensions measured along the major axis and minor axis are reported as length and breadth. The average length and breadth of the cocoa pods are 147.50±13.9 and 74.19±13.05 mm, respectively.The percentage distribution of length and breadth of cocoa pod are shown in Figure 4a and b. From the distribution curve for length, the size was categorized as less than 120 mm, 120 to 140 mm and above 140 mm, which were 28%, 37% and 35% of the whole lot and graded as small, medium and large size, respectively. As seen in Figure 4b, breadth varied from 60 mm to 110 mm and the major contribution was 18%, 28%, 36%, 12%, 4% and 2% for the ranges, below 70 mm, 70-80 mm, 80-85 mm, 85-90 mm, 90-100 mm and 100-110 mm, respectively. A direct proportion between the length and breadth was noted. For the small, medium and large size pods, the average length were110.66±07.05, 130.05±05.46 and 152.03±11.53 mm and breadth were 65.43±3.41, 77.98±5.26 and 95.12±4.44 mm, respectively.

The thickness of husk at the ridge and furrow varied as 4 to 21 mm and 3 to 17 mm, with mean values of 9.65±2.27 and 7.80±2.19 mm, respectively. The mean thickness of the husk in ridge side for small, medium and large pods are 7.24±1.6, 8.44±2.4 and 10.83±2.7 mm, and in furrow side is 5.75±1.5, 6.81±2.1 and 8.82±2.7 mm, respectively. It is expected that during pod breaking, the breaking edge will most of the time hit the pod at the ridge. Hence for the design of pod breaking mechanism, breaking the husk at ridge is probably more important than at the furrow (Bamgboye and Odima-Ojoh, 2004).



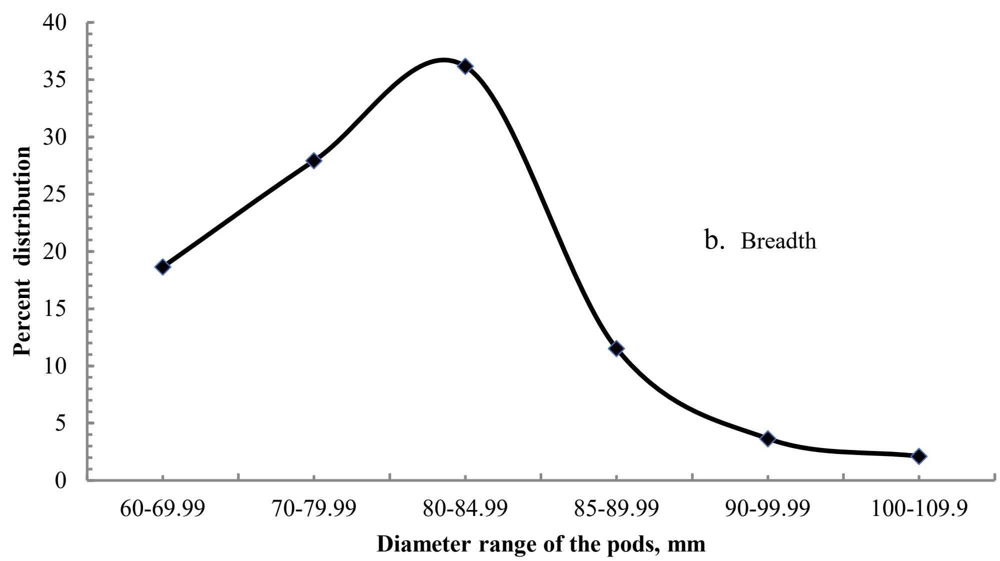


Figure 4 Percent distribution of length and breadth of cocoa pod (a. length; b. breadth)

Bamgboye and Odima-Ojoh (2004) also reported that the average length of whole cocoa pods of F3 Amezon variety was 153.7±5 mm. Average diameter of small, medium and large pod was 65.43±3.4, 77.98±5.2 and 95.12±4.4 mm, respectively. Similar results were also reported by Adewumi and Fatusin (2006). In the above moisture range between 5% and 24% (w.b), the mean cocoa bean length, width and thickness increased from 22.41 to 22.5 mm, 12.2 to 12.86 mm and 7.36 to 7.70 mm, respectively. At the moisture content of 8.6% (w.b), 87% of the beans had lengths between 20.0 and 26.0 mm, 87% had their width between 10.0 and 14.0 mm and 95% had their thickness between 6.0 and 10.0 mm (Bart-Plangeand Baryeh, 2003).

3.3 Geometric mean, sphericity and aspect ratio

The geometric mean diameterof the pods was 94.75±8.6 mm for the ungraded pods and were 85.45±6.2, 93.23±9.1

and 105.59±10.5 mm for small, medium and large pods, respectively. Thickness of the husk, both in ridge and furrow increased with increase in pod size. Though cocoa pods are regarded as prolate spheroid in shape, determination of sphericity shows that the small size pods are with mean sphericity of 0.68±0.05 and the medium and large pods are with 0.61±0.01 and 0.54±0.04, respectively. The mean aspect ratio was 0.57±0.10, 0.48±0.10 and 0.40±0.04 for small, medium and large size pods, respectively. The smaller size pods had higher sphericity and aspect ratio, due to the situation of shorter length. Burubai et al. (2007) reported that the fairly high sphericity values show features favourable to rolling of the pods and therefore have a practical application in handling such as conveying and grading. The sphericity of cocoa bean varied from 0.57 to 0.58 in the moisture content range of 8.6% to 24% (w.b) (Bart-Plangeand Baryeh, 2003). Similar results were observed in case of African nutmeg and fresh oil palm fruit (Owolarafe et al., 2007).

3.4 Coefficient of static friction

The coefficient of static friction of cocoa pods against various surfaces, namely, mild steel, galvanized iron, aluminum and stainless steel, varied in the range of 0.681 to 0.738 on mild steel surface, 0.652 to 0.717 on galvanized iron surface, from 0.512 to 0.579 on aluminium surface and 0.503 to 0.526 on stainless steel with the moisture content of the pod husk, in the range of 7.53% to 20.95% (d.b.).

The reason for increased coefficient of static friction at higher moisture content may be due to higher cohesive force between pods at higher moisture content and the surface. Similar results were reported by Aviara et al.(2007) for guna seeds and Josué et al. (2019) for cocoa pods. Also, Jayashree and Visvanathan (2011) reported the higher values of friction coefficients for harvested ginger (81.7% w.b) on various surfaces than the dry ginger (8.85% w.b).

3.5 Rolling angle and rolling resistance

The rolling angle of cocoa pods on mild steel, stainless steel, galvanized iron and cardboard surfaces for all three size of pods (small, medium and large) has not shown any significant difference with respect to surfaces and size. The rolling angle ranged 15.6±3.7 to 19.7±2.7. The average rolling angle increased linearly from 18° to 24° at moisture content of pod husk in the range of 7.53% to 20.95% (d.b.).Similar result was observed by Bahnasawy et al. (2004) for three varieties of onion.

From the rolling resistance as calculated using Equation4 for different surfaces, the maximum value was found for mild steel surface followed by galvanized iron, aluminium and stainless steel surfaces; the mean values were found to be 0.179, 0.208, 0.165 and 0.199 $kg_f cm^{-1}$, respectively.

3.6 Evaluation of grader

The gravity fed divergent type grader for cocoa pods was evaluated as per the procedure explained in Section 2.8. The model calculation of effectiveness at slopes 22.5°, 24° and 25.5°, as calculated following Equation 36 are given in Table 2.

Table 2 Model calculation of effectiveness of grading in divergent type cocoa pod grader

Sl. No.	Opening size, mm	W_i	Q_i	q_i	a_i	P_i	Fr_i	Effectiveness, Ei $Ei=Fri\,\frac{(Pi-ai)}{(1-ai)}$
Slope of operation: 22.5°								
1	65- 70	29	11	-	0.224	1.00	0.085	0.085
2	70-80	36	44	11	0.277	0.75	0.338	0.221
3	80-85	48	57	7	0.369	0.84	0.438	0.329
4	85-90	11	12	2	0.085	0.92	0.092	0.084
5	90-100	5	5	1	0.039	1.00	0.038	0.038
6	>100	1	1	-	0.008	1.00	0.008	0.008
Overall Effectiveness, $E=\sum_{i=1}^{6} Fri\,\frac{(Pi-ai)}{(1-ai)}$								0.765
Slope of operation: 24°								

1	65- 70	29	15	-	0.224	1.00	0.085	0.085
2	70-80	36	44	9	0.277	0.75	0.338	0.221
3	80-85	48	54	6	0.369	0.84	0.415	0.307
4	85-90	11	11	-	0.085	0.92	0.092	0.084
5	90-100	5	5	-	0.039	1.00	0.038	0.038
6	>100	1	1	-	0.008	1.00	0.008	0.008
Overall Effectiveness, $E = \sum_{i=1}^{6} Fri \frac{(Pi-ai)}{(1-ai)}$								0.743
Slope of operation: 25.5°								
1	65- 70	29	12	-	0.224	1.00	0.069	0.069
2	70-80	36	43	12	0.277	0.72	0.331	0.203
3	80-85	48	56	11	0.369	0.80	0.431	0.298
4	85-90	11	13	2	0.085	0.85	0.100	0.083
5	90-100	5	5	-	0.039	1.00	0.038	0.039
6	>100	1	1	-	0.008	1.00	0.008	0.008
Overall Effectiveness, $E = \sum_{i=1}^{6} Fri \frac{(Pi-ai)}{(1-ai)}$								0.700

The analysis of variance of capacity of the grader and the effectiveness of grading with slope of operation is given in Table 3. From the table, it is seen that the capacity of the grader and the effectiveness of grading are significant with slope of operation.

The mean values of capacity of the grader were 253.1, 268.9 and 277.7 kgh^{-1} at operating slopes of 22.5°, 24° and 25.5°, respectively as given in Table 4. For these operating slopes, the effectiveness of grader was 0.767, 0.787 and 0.745, respectively. It is seen that the grading capacity increased with slope of operation, as the slope facilitate the faster movement of the pods along the divergent pipes. The mean comparison of the capacity of the grader indicated the values are different with slope of operation. The effectiveness of grading with slope of operation from 22.5° to 24° increased from 0.767 to 0.787 and further decreased to 0.745 at 25.5°slope. The mean comparison indicated that the effectiveness of grading was at par at slopes 22.5° and 24° and different between slopes 22.5° and 25.5°.

Table 3 Analysis of variance of slope of operation on grading capacity and effectiveness.

Source	df	SS	MS	F_a
Grading capacity				
Experiment	17	3852.16	226.59	
Grading capacity	05	1735.16	347.03	
Slope	02	1856.06	928.03	35.56**
Error	10	0260.94	026.09	
Total	34	7704.32	1527.75	
SED	CD (0.01)	CD (0.05)	CV%	F_{crit}
2.949	6.571	9.347	1.92	4.26
Effectiveness of grading				
Experiment	17	0.0283	0.0016	
Effectiveness of grading	05	0.0117	0.0023	
Slope	02	0.0102	0.0051	7.99**
Error	10	0.0063	0.0006	
Total	34	0.0565	0.0153	
SED	CD (0.01)	CD (0.05)	CV%	F_{crit}
0.0146	0.046	0.032	3.34	3.68

Note: ** Significance at 1 per cent level.

Table 4 Capacity and effectiveness of divergent type cocoa pod grader

Slope,°	Capacity, kgh^{-1}	Effectiveness
22.5	253.1 (12.3)	0.767 (0.0106)*
24.0	268.9 (10.4)	0.787 (0.0102)
25.5	277.7 (11.8)	0.745 (0.0141)

Note: * Values given in parenthesis are the standard deviation of six replications.

At higher slopes, the faster movement of the pods gives less contact time on the divergent pipes and thus the grading effectiveness is less compared to the other lower slopes. Thusoperating at slope of 24° yields the highest effectiveness of 0.787 at a capacity of 268.9 kgh^{-1}.

4 Conclusions

A gravity fed divergent type grader was developed to grade the cocoa pods in to six grades. The highest effectiveness and capacity were, 0.787 and 268.9 kgh^{-1} at operating slope of 24°.

References

Adabe, K. E., and E. L. Ngo-Samnick. 2014. *Cocoa Production and Processing*. Wageningen, Netherlands: The Pro-Agro Collection.

Adewumi, B. A., and A. B. Fatusin. 2006. Design, fabrication and testing of an impact-type hand operated cocoa pod breaker. *CIGR Journal*,8: Manuscript PM 06 022.

Adzimah, S.K., E.K. Asiam, and I. A. Adetunde. 2010. Design of a cocoa pod splitting machine. *Research Journal of Applied Sciences, Engineering and Technology*, 2(7): 622-634.

Aliu, S.A., and P. Ebunilo. 2011. Development and performance evaluation of a cocoa pod breaking machine. *Advanced Materials Research*, 367: 725-730.

ASAE Standards,45th Ed.,1998. S410.1 DEC97 Moisture measurement of peanut. St. Joseph, Mich.: ASAE.

Aviara, N.A., S.K. Shittu, and M.A. Haque. 2007. Physical properties of guna fruits relevant in bulk handling and mechanical processing. *International Agrophysics*, 21(1): 7-16.

Bahnasawy, A.H., Z.A. El-Haddad, M.Y. El-Ansary, and H.M. Sorour. 2004. Physical and mechanical properties of some Egyptian onion cultivars. *Journal of Food Engineering,* 62(3):255-261.

Balakrishnan, M., R. Visvanathan, B. Soundararajan and V. V. Sreenarayanan. 2010. A hand-operated rotary type cleaner-cum-grader for black pepper and cardamom. *AMA-Agricultural Mechanization in Asia, Africa and Latin America*, 41(3): 36-40.

Balasubramanian, S., and R.Viswanathan. 2010. Influence of moisture content on physical properties of minor millets. *Journal of Food Science and Technology*, 47(3):275-280.

Bamgboye, A.I., and S. Odima-Ojoh. 2004. Design parameters for cocoa pod breaker. *AMA-Agricultural Mechanization in Asia Africa and Latin America*,35(2): 26-30.

Bart-Plange, A., and E. A. Baryeh. 2003. The physical properties of Category B cocoa beans. *Journal of Food Engineering*, 60(3): 219-227.

Burubai, W., A.J. Akor, A.H. Igoni, and Y.T. Puyate. 2007. Some physical properties of African nutmeg (*Monodora myristica*). *International Agrophysics*, 21(1): 123-126.

Dhas, P. H.A., S.Subramaninan, M.Balakrishnan, R.Viswanathan, and V.V.Sreenarayanan. 2004. Performance evaluation of a cleaner-cum-grader for black pepper. *Journal of Plantation Crops*, 32(1):32-36.

Ebaid, M. T., M.M. Atallah, and K.S. Khalil. 2012. Development of a grading machine for apricot fruits. *Misr Journal of Agricultural Engineering,* 29(2): 511-530.

Gayathri, G., K.V.Harshanjali, K. Rupavathi, D. V. Kumar, G. S. Kumaran, A. C. R. Kumari, and M.V. Ramana. 2016. Design, development and evaluation of a manually operated onion grader for Rose onion. *CIGR Journal*, 9(2): 121-129.

Ghanbarian, D., A. Ghorbani-Marghmaleki, M.A.Ghazavi, and Sh. Besharati. 2015. Design, development and evaluation of a divergent roller sizer for almond kernels. *Journal of Agricultural Machinery*, 5(2): 228-241.

Ghuman, B. S., and A. Kumar. 2005. Development of low cost rotary disc size grader for fruits and vegetables. *Journal of Research*, 42(4): 497-503.

Jayashree,E., and R. Visvanathan. 2011. Physical and biochemical parameters of fresh and dry ginger (*Zingiber officinale* Roscoe). *Journal of Spices and Aromatic Crops*, 20(1):14-21.

Josué, D.F., F.M.Guy-De-Patience, K.Bienvenu and D.Bonaventure.2019. Design and development of cocoa pod breaking and beans extraction machine. *International Journal of Engineering and Technology,* 8 (3): 357-366.

Karthik, S.K., V.Palanimuthu, and Satishkumar. 2018. Design and development of on-farm onion grader. *International Journal of Current Microbiology and Applied Sciences,* Special issue 6: 2907-2914.

Londhe, D. H., S. M. Nalawade, G. S. Pawar, V. T. Atkari, and S. V. Wandkar. 2013. Grader: A review of different methods of grading for fruits and vegetables. *CIGR Journal*,15(3): 217-230.

Mangaraj, S., A. C. Varshney,B. S. Reddy, and K. K. Singh. 2005. Development of a stepwise expanding pitch fruit grader. *Journal of Agricultural Engineering*, 42(3):74-79.

Mizera, C., D. Herak, P. Hrabe, and A. Kabutey. 2017. Effect of temperature and moisture content on tensile behaviour of false banana fibre (*Ensete ventricosum*). *International Agrophysics*,31(3): 377-382.

Muzamil, M., J. Wani, A. Mustafa, M. Mohiuddin, A. Mir, S. Faisal, and S. Nirbhavane. 2018. A lowcost divergent type apple grader for Kashmiri apples. *International Journal of Current Microbiology and Applied Sciences*, 7(4): 3561-3569.

Omre, P. K., and R. P. Saxena. 2003. Design and development of multi-fruit grader. *Agricultural Mechanization in Asia, Africa, and Latin America* (*AMA*), 34(3): 39-42.

Owolarafe, O.K., M.T. Olabige, and M.O. Faborode. 2007. Physical and mechanical properties of two varieties of fresh oil palm fruit. *Journal of Food Engineering*,78(4): 1228-1232.

Preetha, P., R.Pandiselvam. J.Deepa, and N.Varadharaju. 2016. Development and performance evaluation of rotary drum grader for tomato. *International Journal of Agriculture, Environment and Biotechnology*,9(1): 137-144.

Shahbandeh, M. 2020. Cocoa production by country 2018/19 & 2019/2020. Available at: https://www.statista.com/statistics/263855/cocoa-bean-production-worldwide-by-region/. Accessed 10 December 2020.

Shahir, S., and V.Thirupathi. 2009. Performance evaluation of a divergent roller grader for selected vegetables. *Agricultural Mechanization in Asia, Africa, and Latin America* (*AMA*), 40(4): 60-62.

Ukey, P. D., and P. A. Unde. 2010. Design, development and performance evaluation of sapota fruit grader. *International Journal of Agricultural Engineering*, 3(1): 62-64.

Wargula, Ł., B.Wieczorek, and M. Kukla. 2019. The determination of the rolling resistance coefficient of objects equipped with the wheels and suspension system–results of preliminary tests. *MATEC Web of Conferences 254*:No. 01005.

Zhang, H. 2016. Surface characterization techniques for polyurethane biomaterials. In *Advances in Polyurethane Biomaterials*, ed. S. L. Cooper, and J. Guan, ch. 2, 23-73. Cambridge: Woodhead Publishing (Elsevier).