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Effect of Pod Weight Variation on the Physical Properties of Cocoa Pods and Beans in Gazipur District of Bangladesh

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Abstract: Cocos is well-known as a cash crop across the world for its beans. Its fruit weight influences both the internal and external characteristics of the pod. The objective of this study was to evaluate the physical properties of pods and beans under Gazipur conditions of Bangladesh and observe the effect of fruit size on the physical attributes of cocoa pods and beans. Pods are developed and mature in a plant from July to December 2025. Pods were harvested on 15 December 2025 at the optimum maturity stage when the colour turned green to yellow. All the harvested pods were weighted by a digital balance and categorized as a treatment into six groups considering weight range. Groups were A (>375 to 400g), B (>350 to 375g), C (>325 to 350g), D (>300 to 325g), E (>275 to 300g) and F (>250 to 275g). The study revealed that pod categories based on weight significantly affected hush weight, mucilaginous pulp with seed weight, seed number per pod, seed dry weight per pod, individual seed dry weight, pod length, pod diameter and roasted bean weight per pod. All the studied values were found higher in the larger fruit weight category (>375 to 400g) and gradually decreased up to the smaller fruit weight category (>250 to 275g) that is produced in the local environment of Gazipur district of Bangladesh. Pod length and diameter ratios were found more or less similar except for the larger fruit weight category (>375 to 400g). Pod size has an influence on the number of beans in a pod as well as the weight of cocoa beans. The highest bean number per pod (46.00) and dry bean weight per pod (35.55g) were found in the highest fruit weight, category A (>375 to 400g), but the lowest number of beans per pod (36.75) and dry bean weight per pod (27.99g) were found in F category fruits weight (>250 to 275g). The number of beans and the total weight of the dry beans per pod was found to be higher in the larger fruit weight category (>350g). The highest individual sun-dry bean weight (0.77g) was found in the larger fruit size category A. Sun-dry and roasted bean recovery rate (%) was found higher in the small fruit compared to larger ones. The measured physical properties of grown pods and beans of an eight-year-old plant in the local environment are at a satisfactory minimum level considering major cocoa-growing countries. In conclusion, to obtain individual high bean weight and bean numbers as well as desired physical attributes, selection of large pods of cocoa should be highly recommendable. On the other hand, grading cocoa pods based on size after harvest is better to obtain similarity in bean's size.

Keywords: Cocoa cultivation; Fruit size; Quality bean; Bangladesh.

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is a tropical plant in the Malvaceae family. The economic value of cocoa is determined by the quality of the beans (Sitohang and Siahaan, 2018). Bean powder of cocoa is generally used for producing quality chocolate, butter, ice cream, bread, pudding, cosmetics, and drinks (Payne et al., 2010; Beg et al., 2017). The leading cocoa-producing nations are currently Ivory Coast, Ghana, Indonesia, Nigeria, Cameroon, Brazil, Ecuador, Peru, the Dominican Republic, and Colombia (Aremu-Dele, 2022). Peru currently holds the top rank in the world for yield per hectare (FAOSTAT, 2020). Cocoa is grown in over 10 million ha in more than 58 countries, producing 52,42,000 t dry beans (ICCO 2020). Cocoa is also grown in a few Asian countries such as Malaysia, Indonesia,

and India. Climate and soil conditions have a significant impact on cocoa growth and yield (Ramírez-Jaramillo et al., 2021). Criollo, Forastero and Trinitario were mainly classified based on their morphology, especially the pod and bean characters (Wood and Lass, 2001). At present, commercially Forastero is being cultivated predominantly in neighboring countries in India (Vithya et al., 2018). Evaluation of cocoa genotypes for pod and bean characters is the prerequisite to identify high yielding genotypes (Vithya et al., 2018). Cocoa is an important crop that provides a livelihood for most producing countries. The agroclimatic requirements of cocoa plants are more or less similar to the climatic conditions of Bangladesh. In Bangladesh, the cocoa plant grows well and there is a possibility to become a prospective crop (Hossain and Islam, 2024).

Cocoa seeds, commonly known as cocoa beans, are obtained from the pods. Diverse factors have a major impact on cocoa bean quality, encompassing genotypic variations, environmental conditions, bean maturity levels, and post-harvest procedures (Calvo et al. 2021). Cocoa plants produce the most fruit in the age range of 10-15 years and experience a decrease in production after the age of the plant exceeds 15 years. Changes in fruit weight of cocoa plants at plant age above 15 years have entered an unproductive age, so rejuvenation is needed in order to maintain cocoa productivity (Elisabeth et al., 2024). One tree can get up to several thousands of flowers each year. However, only 1–50% of them are pollinated. The cocoa production is highly dependent on pollination, and the tree is pollinated by midgets (*Forcipomyia* spp). One tree usually gets 20–50 pods, and it takes up to six months for the pods to ripen (Frimpong-Anin et al., 2015). Pods are produced throughout the year, but the main harvest usually begins at the end of the wet season and may extend for 3 months. A longer maturation period for the pods results in larger beans (Doaré et al., 2020). Cocoa fruit weight heavily influences both the internal and external characteristics of the pod, serving as a primary driver for bean yield and husk development. Although heavier fruits generally produce larger pods and higher commercial yields, how that weight is proportionally distributed varies greatly based on genetics, environmental factors, and pod development. Pod size and dry weight of beans decreased and bean count per 100 g increased with the increase in altitude (Sitohang and Siahaan, 2018). According to Sosu (2014), both seed number and size are essential factors in determining cocoa yield. The objective of this study was to observe the physical performance of cocoa pod and bean under Gazipur conditions and observe the effect of fruit size categories on the physical attributes of cocoa pods and beans.

MATERIALS AND METHODS

Experimental site and test crop

This research was carried out on a cocoa plant pod which was planted in 2018 at Bangladesh Open University (BOU) campus Gazipur. Morphological features of the studied cocoa plant match with Forastero (Asare, 2006). Gazipur district is located between 23°53'-24°2' north latitude and between 90°09'-92°39' east longitude (Rony et al., 2021). The experimental site is situated under the Agroecological Zone 28 (AEZ-28) (UNDP and FAO, 1988). Sits at an altitude of approximately 13 meters above sea level. The field soil is sandy loam with a pH of 6.5 and organic matter of 1.36 %. Other major soil elements were N 0.08%, P 70.55 mcg/gram soil, K 0.42 meq/100g soil, S 11.02 mcg/g soil, Zn 0.75mcg/g soil, B 0.49 mcg/gram soil (SRDI, 2026).

Figure 1. Eight-year-old cocoa plant at BOU Gazipur campus, Bangladesh

Collection and classification of cocoa pods

The pods grow both along the main stem of the tree and throughout the canopy. Forty-five mature pods were harvested on 15 December 2025 at the optimum maturity stage when the color turned green to yellow.

Figure 2. Six categories of harvested cocoa fruits (A, B, C, D, E and F)

All the harvested pods were weighted by a digital balance and categorized as a treatment into six groups considering weight range. Groups were A (>375 to 400g), B (>350 to 375g), C (>325 to 350g), D (>300 to 325g), E (>275 to 300g) and F (>250 to 275g). Randomly, four pods were selected from each group (based on weight range) and an individual pod was considered as a replication for each group.

Sample and data collection procedure

Data on ripened pod weight, pod length, pod diameter (cm), fresh husk weight, fresh pulp with seed weight and number of seeds per pod were measured and counted before fermentation. After fermentation, sun-dried seed weight per

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pod, individual dry seed weight and roasted powder weight per pod were measured and recorded. All weights were measured using a digital balance, but the length and diameter of the pod were measured by a scale and digital slide calipers, respectively. The selected pods were cut with a sharp knife and separated into husk and mucilaginous pulp. The fresh husk and mucilaginous pulp without the placenta The freshly extracted beans were collected from ripened pods and placed on banana leaves inside a plastic basket for fermentation. The beans were covered by banana leaves and left for 7 days. After fermentation, the rest of the pulp is removed by washing the beans with sand. Thereafter, the beans were spread out on mats placed in the sunlight for six hours a day, and they stirred frequently for 4 days to achieve 6-7% moisture content. A Digital Grain Moisture Meter was used to measure dry cocoa bean's moisture. The number of beans in each pod category was counted, weighted and recorded. Fermented sun-dried seeds of each group were roasted then powdered and weighed. To roast cocoa beans in an oven, maintain a temperature between 120°C for a total time of 30 minutes.

Experimental design

The experiment was conducted as a single-factor experiment following a completely randomized design (CRD). The fruit-size category based on pod weight was considered the sole experimental factor with six levels (A–F), with four individual pods serving as replications for each category. Thus, the experiment consisted of six fruit-size categories × four replications, giving a total of 24 experimental units. All experimental pods were collected from a single cocoa plant; the study represents variation among individual pods within the sampled plant. Therefore, the experiment does not provide an independent estimate of variation among plants, genotypes, or locations.

Statistical analysis

The data obtained for pod husk weight, fresh seed and pulp weight, number of seeds per pod, sun-dried seed weight, roasted seed weight, pod length, pod diameter, pod length-to-diameter ratio, and the calculated seed-related proportions were subjected to one-way analysis of variance (ANOVA) following a completely randomized design. The six fruit-size categories (A–F) were considered as treatments, with four individual pods serving as replications for each treatment. Treatment means were compared using the least significant difference (LSD) test at the 5% level of probability. Means followed by the same letter were considered statistically similar, whereas means followed by different letters were considered significantly different at $P<0.05$. The coefficient of variation (CV%) was calculated to indicate the relative variability of observations within the experiment. Pod weight was not subjected to mean comparison because pod weight was used to establish the six fruit-size categories.

RESULTS AND DISCUSSION

A. Physical properties of cocoa pod and beans under Gazipur conditions

Average mature individual pod weight (260.23-383.50g), husk weight (183.15–272.28g), pulp weight (76.40-114.45g), pod length (11.28-14.03cm), pod diameter (7.30-8.23cm), number of seed per pod (36.75-46.00), Dry seed weight per pod (27.99-35.55g), individual dry seed weight (0.74-0.77g) ranges were found in an eight years old cocoa plant grown under Gazipur condition of Bangladesh (Table 1). Schwan and Wheals (2014) stated that cocoa seeds, commonly known as cocoa beans, are obtained from oval pods that measure between 12 and 30 cm long. Each pod contains 30 to 40 beans embedded in a mucilaginous pulp, which comprises approximately 40% of the fresh bean weight. ICCO (2020) reported that the average fresh weight of a mature cocoa pod in Asia typically ranges from 300 to 700 grams, heavily influenced by local environmental conditions, altitude, and clonal variations. Globally and regionally, a baseline average of 350 to 400 grams is widely accepted for healthy parent trees. The physical properties of the cocoa pod and beans under the study are similar to those of other cocoa-producing countries. This observation will be encouraging for future research into improving cocoa production technology through breeding, selection and conservation of cocoa plants, considering the local environment of Bangladesh. The physical properties of cocoa pods and beans produced in the local environment are similar to other cocoa-producing countries.

Table 1. Physical properties of pod and beans of cocoa under different fruit size

Fruit size categories (6)	Physical properties of pod and beans of cocoa (mean values)									
	Average pod weight (g)	Pod length (cm)	Pod diameter (cm)	Pod length: diameter ratio	Fresh pod husk weight (g)	Fresh seed with pulp weight/pod (g)	Seed/pod (no.)	Sun-dry seed weight/pod (g)	Individual dry seed weight (g)	Roasted seed weight/pod (g)
A (>375 to 400g)	383.50a	14.03a	8.23a	1.708a	272.28a	114.45a	46.00a	35.55a	0.77a	30.20a
B (>350 to 375g)	362.43b	13.15b	8.13a	1.705b	258.28b	113.25a	45.00ab	34.26ab	0.76ab	28.02b
C (>325 to 350g)	335.40c	12.88b	7.60b	1.683b	237.10c	98.30b	43.25bc	31.92bc	0.76ab	26.41bc
D (>300 to 325g)	305.70d	12.25c	7.58b	1.615b	214.55d	91.15b	41.25cd	30.37cd	0.76ab	25.70c
E (>275 to 300g)	291.10e	12.03c	7.33b	1.613b	201.85d	89.25b	39.50d	28.25d	0.75ab	23.98d
F (>250 to 275g)	260.23f	11.28d	7.30b	1.505b	183.15e	76.40c	36.75e	27.99d	0.74b	23.15d
LSD (0.05)	**12.16**	**0.55**	**0.44**	**0.1022**	**13.73**	**9.88**	**2.65**	**2.64**	**0.0232**	**1.67**
CV (%)	**2.53**	**2.92**	**3.89**	**4.20**	**4.06**	**6.84**	**4.25**	**5.67**	**2.04**	**4.28**

Note: Means followed by the same lowercase letter are not significantly different from each other according to Fisher's Least Significant Difference (LSD) test at a 5% level of significance

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B. Influences of cocoa fruit size on pod and beans

Significant influences of fruit size categories (A-F) on different studied physical parameters of pod and beans of cocoa were found and presented in Table 1.

Average cocoa pod and husk weight

Figure 3. Harvested cocoa pods (Left) and husk (Right)

The average individual mature higher pod weight (383.50g) was found under category A (>375 to 400g) and the lowest average individual pod weight (260.23g) was found in category F pod size (>250 to 275). The highest average individual husk weight (272.28g) was found in the larger fruit weight category A and the lowest individual husk weight (183.15g) was found in the smaller F category of fruit size. The husk constitutes the largest percentage of total pod weight and it was approximately 71%. The results showed that total fruit weight increases and husk weight increases proportionally. This finding agreed with Mariatti et al. (2021). They stated that cocoa pod husks represent approximately 67 to 76% and beans represent 33% of the whole cocoa fruit weight. Cocoa pods are made up of an external part, the husk, and an internal mucilage, the pulp, which surrounds the seeds (Beckett, 2008). The weight of pods and beans of cocoa is mainly controlled by the genetic potentiality of the variety (Cilas et al., 2010; Enriquez and Soria, 1968). Single dry bean weight is a vital industry parameter, exhibiting a significant statistical association with husk and pod weights (Bhavishya et al., 2024). Some earlier findings indicate that dry bean weight shares a positive correlation with both larger pods and increased husk weight (Soria, 1978).

Average cocoa pod length and diameter

Maximum average individual pod length (14.03 cm) and diameter (8.23 cm) was found in the larger fruit size category A (>375 to 400g) under the study. Average individual pod length was gradually and significantly increasing from smaller to larger in every fruit size category (F to A). A higher pod diameter (8.23cm) was found in A category fruit size, which was statistically similar to B category fruit size. Whereas, the average pod diameter from C to F category did not show any significant difference (Table 1). The largest pods showed increased longitudinal length and equatorial diameter in this study. Pod length and diameter ratio was found higher (1.708) in the larger A fruit size category, but the lowest ratio (1.505) was found in the smaller F fruit size category, which was statistically similar to the B, C, D and E categories (Table 1). It indicates that cocoa fruit length and diameter ratio are more or less the same and do not vary significantly due to increasing fruit size. A previous study reported a positive correlation with the length of pods and number of seeds per pod (Sitohang and Siahaan, 2018). Tetteh and Obeng (2021) stated that the number of seeds per pod and pod diameter was significant and positively correlated.

Fresh pulp weight with seed per fruit

Figure 4. Opened ripened pod (Left) and pulp with seeds (Right)

The total fresh mass pulp weight of beans was found higher (114.45g) in the larger pod size group category (A), which was statistically similar to the B fruit size category (>350 to 375g). The lowest pulp weight with seed (76.40g) was found in the small F fruit size category (>250 to 275g). Category C, D and E do not show any significant differences. The white mucilage pulp accounts for roughly 30% of the fruit weight. The fresh pulp weight of beans values upward with the overall weight of the fruit. Within a single pod, internal parameters compete for the resources provided by the overall fruit weight. Larger pods offer greater physical space and maternal resources, allowing beans to develop higher density and superior quality (Vithya et al., 2018).

Seed number per pod

The average highest seed number per pod (46.00) was found in A category (>375 to 400g), which was statistically similar to the B fruit size category (>350 to 375g). The lowest number of seeds per pod (36.75) was found in the small fruit size category F (>250 to 275g). This finding agreed with Rahmi et al. (2025). They reported that six cocoa pod genotypes exhibited a range of bean counts, from 34 to 46 beans per fruit. The number of beans per pod gradually decreased from higher to lower in size. Bigger pods generally showed a significant, positive relationship with the number of seeds. This observation indicates that the number of seeds per pod varied significantly due to changes in fruit size. Pod size has an influence on the number of beans in a pod as well as the weight of cocoa beans (Alhassan et al., 2024). The number of beans per pod depends on the number of ovules per ovary and the level of pollination of the flowers (Falque, et al., 1995). The number of ovules per ovary is a very heritable trait (Cilas et al., 2010). Conversely, in bigger pods with low bean counts, biomass distribution shifts primarily toward pulp development rather than seed mass

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(Iwaro et al., 2003). Glendinning (1963) reported that seed number per pod is a genetically controlled trait but it is also influenced by environmental and physiological variables (De Reffye et al. 1978; Falque et al. 1995; Da Silva et al. 2016).

Individual dry seed weight (g)

Higher individual dry seed weight (0.77g) was found in A category larger fruit size (>375 to 400g) and the lowest individual seed weight (0.74g) was found in the smaller F category fruit size (>250 to 275). Bhavishya et al. (2024) stated that greater pod and husk weights correlated with an increase in dry bean weight. The average weight of the beans is not the same within a pod; the beans in the apical zone have significantly lighter beans than the beans in the other two zones, peduncular and median (Doaré et al., 2020).

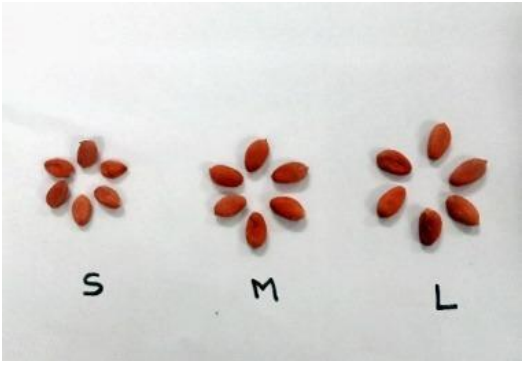

Figure 5. Sun-dry small (S), medium (M) and large (L) size beans of cocoa

Consequently, while the average weight of a bean is highly heritable, it is simultaneously influenced by fruiting cycle length, bean count per pod, and the bean's position within the pod (Doaré et al., 2020). Several studies indicate that the weight of the individual beans has a high heritability in cocoa. Cocoa beans represent the economically viable component of cocoa, with their size directly influencing overall yield (Soria, 1978). Pod weight had significant and positive correlation with single dry bean weight (Vithya et al., 2018).

Sun-dry seed weight and roasted beans weight per pod

The average maximum dry seed weight per pod (35.55g) was found in a category A fruit size (>375 to 400g) that was statistically similar (34.26g) to category B (>350 to 375). The lowest dry seed weight of a pod (27.99g) was found in the smaller F category pod size (>250 to 275).

Figure 6. Sun-dry and roasted cocoa beans

Single dry bean weight had significant and positive correlation with dry bean weight per pod (Vithya et al., 2018). The average maximum dry seed weight per pod (30.20g) was found in a category A fruit size (>375 to 400g) and the lowest dry seed weight per pod (23.15g) was found in the smaller F category pod size (>250 to 275). The result showed that dry bean weight per pod had a significant correlation with roasted bean weight per pod.

C. Recovery of pulp with seed, dry seed weight and roasted bean (%)

Recovery rate (%) of pulp with seed did not differ significantly due to fruit size variation. Sun-dry and roasted bean recovery rate (%) was found higher in the comparatively small category of fruit size. The highest dry bean weight recovery (10.76%) was found in the smaller F category fruit size category which was statistically similar to E and D. Bean recovery was found lowest (9.27%) in the larger A category fruit size, which was statistically similar to B and C category fruit size. Similar type recovery rate was found in the roasted bean weight per pod (Table 2).

Table 2. Recovery of pulp, dry seed weight and roasted bean under different fruit size (%)

Pod-size category	Pulp with seed recovery %	Sun-dry seed recovery %	Roasted bean recovery %
A (>375–400 g)	29.82	9.27b	7.88b
B (>350–375 g)	31.24	9.45b	7.73b
C (>325–350 g)	29.30	9.53b	7.88b
D (>300–325 g)	29.86	9.93ab	8.41ab
E (>275–300 g)	30.66	9.70ab	8.24ab
F (>250–275 g)	29.30	10.76a	8.89a
LSD (0.05)	**NS**	**0.82**	**0.44**
CV (%)	**5.65**	**5.67**	**3.60**

Note: Means followed by the same lowercase letter are not significantly different from each other according to Fisher's Least Significant Difference (LSD) test at a 5% level of significance.

CONCLUSION

Boosting cocoa production requires a closer look at the physical traits of both pods and beans. The measured physical properties of grown pods and beans of an eight-year-old plant in the local environment of Gazipur district of Bangladesh were observed up to the mark. To obtain individual high bean weight and bean numbers per pod, a selection of large pods of cocoa should be highly recommended. On the other hand, grading cocoa pods based on size after harvest is better to obtain similarity in bean's size. There is a scope to improve cocoa bean yield through practising modern production technology similar to other major cocoa-producing countries. As a new promising cash crop in Bangladesh, continuous research in different aspects is necessary.

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Conflict of Interest

The authors declare no conflicts of interest.

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