The shape and size of cocoa beans*1/

B N GHOSH**

COMPENDIO

Se presenta una definición cuantitativa de la forma y tamaño de almendras de cacao, al estado húmedo, basada en su longitud, ancho, profundidad y las superficies planas y transversales, la última obtenida mediante un corte transversal de la almendra. Se proponen ecuaciones empíricas para estimar el área a partir de la medición de cualquiera de las tres principales dimensiones. — El autor

Introduction

THE importance of a thorough understanding of the various physical properties of an agricultural material (e g cocoa beans) in developing both primary (farm) and secondary (industrial) processing equipment is being recognized at an increasing rate during the past few years by researchers and processors alike This is evidenced by the number of research and review papers on this subject that are being published or presented at technical seminars and meetings (e g. the recent National Science Foundation/Pennsylvania State University Workshop on "Design Applications of Mechanical Properties of Food Material"), along with the active participation of industry in such Proceedings (7)

In the case of cocoa beans, a comprehensive study in this respect was initiated by the author in early 1971 at the start of his former assignment with the Agricultural Engineering Division of the Cocoa Research Center at Itabuna, Brazil (3), although cocoa beans have been grown and processed for the chocolate or other secondary industries for over a 100 years In this respect, cocoa serves as a typical example of an agricultural product where machinery and equipment has been developed in the past without due consideration of the important bio-engineering interface. The earliest recorded investigation on the physical properties of this material was made by Zehntner (9); a detailed review of later investigations in this field, along with the general scope of the present series of studies, has also been recently published (4) In the same paper, results obtained for angle of repose and bulk density of cocoa beans, as affected by bean moisture content during drying, has been discussed

Another important aspect that has also been considered in the above paper in detail is the wide range within which the bean moisture content may vary (55-39 per cent, wet basis) at the end of the fermentation and at the start of the drying processes. Some physical properties of agricultural material are dependent on its

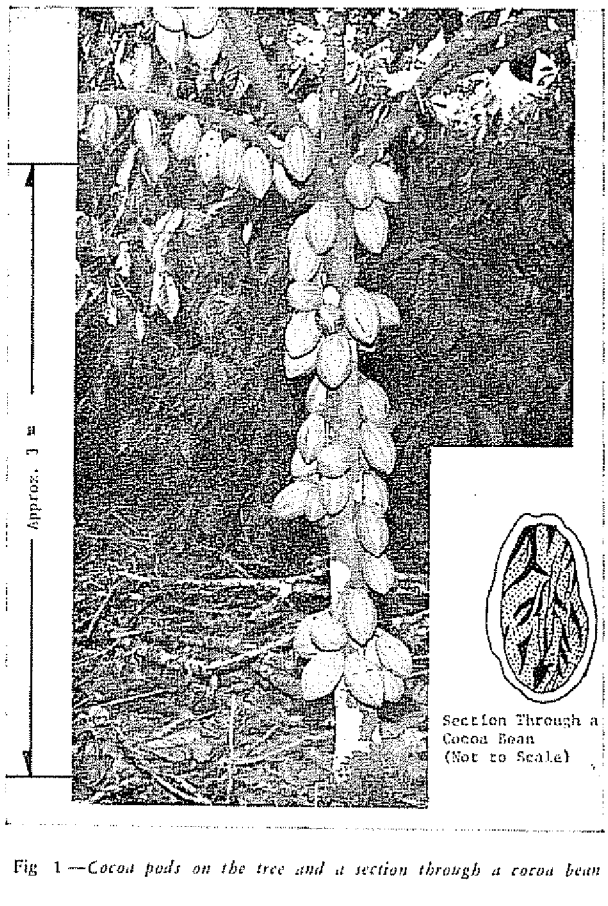

Fig 1 —*Cocoa pods on the tree and a section through a cocoa bean*

* Received for publication January 21 1976

1/ Presented as paper Nº 75-3536 at the winter meeting of the American Society of Agricultural Engineers Palmer House Chicago Illinois December 15-18 1975

** Present address: Advanced Development and Engineering Center, Gulf + Western Industries Inc 101 Chester Road Swarthmore Pennsylvania 19081 U S A

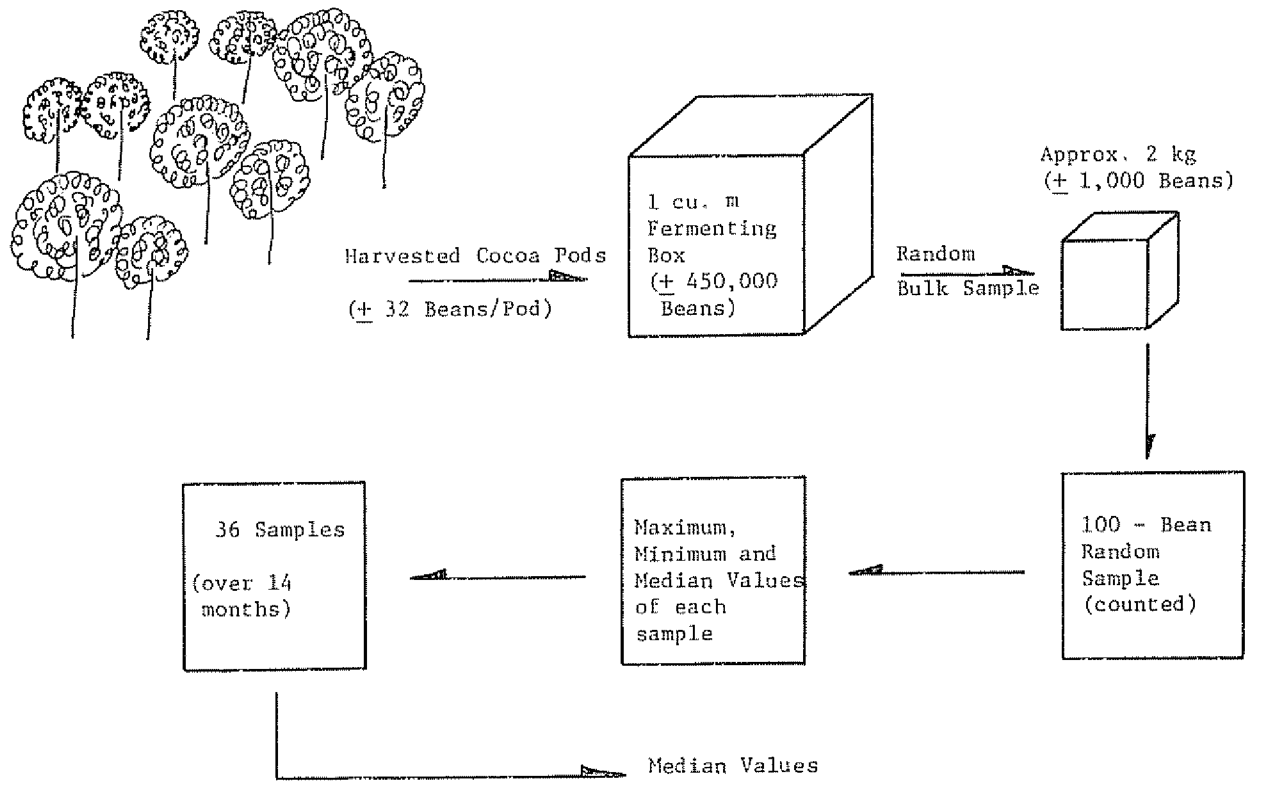

Fig. 2.—*Sampling technique*

moisture content, and it is interesting to note the wide range within which a cocoa bean can be found at the wet stage.

In the present paper, the results of a study with the shape and size of cocoa beans at the wet stage, along with the correlation between length, breadth, depth and areas of the flat and transverse surfaces have been discussed.

Cocoa pods and beans

The development of a cocoa pod and the beans that are contained in it (Fig. 1) is considered to be a highly complex physiological process that continues from the inflorescence to the ripe pod stage on the tree (1). A cocoa pod, containing an average of 32 beans, is considered to be ready for harvest between 150 to 190 days after pollination, depending mainly on the average daily temperature and other factors during the growing season. Harvesting may continue throughout the year, except during the cold season, when the pods do not mature. After harvest, the hard pod is split open by a cutlass and the beans, encased in a thick layer of mucilage, are extracted by the farm operator's fingers for the follow-up fermentation process which releases the bean from the mucilage. The beans are generally considered to be elliptical in shape.

Materials and methods

Fresh cocoa beans obtained from the pods are fermented in wooden boxes of approximately 1 cubic meter each for an average period of 6-7 days, after which they are dried; the output of each box may vary between 850 and 950 kg, with an average of approximately 450,000 beans (Fig. 2). The shape and size of cocoa beans at the wet or fermented stage were studied in terms of length, width, depth, and areas of the "flat" side and the "transverse surface" of the bean. A random bulk sample of approximately 2 kg or 1000 beans was drawn from the output of the fermenting box; at the laboratory, this was reduced to a randomly picked 100-bean sample for the experimental work. A total of 36 such samples, each containing 100 beans, were studied over a period of 14 months. The samples were obtained from the 760 hectare farm of the Cocoa Research Center, using the output of only those fermentation boxes where the processing is carried out in the traditional way and excluding hybrid and other experimental material, which are processed separately from the normal production.

The length, width, and depth of each bean was measured with a micrometer screw gauge. To calculate the two areas, the bean was dipped in methylene blue dye and the flat surface pressed against a graph paper resting on a thin soft surface; it was then cross-sectioned at the center (determined by eye through practice) and repressed against the graph paper to obtain an impression of the transverse surface. By counting the number of complete squares inside the outline so traced and adding to them a half of the incomplete squares, the areas for both the surfaces were determined. The method used is similar to that developed by the author in an earlier investigation with coffee beans (2).

It is considered to be an effective and economic method, albeit more time consuming, particularly for developing areas of the world where expensive and sophisticated equipment is neither easily available nor economically justifiable. Mohsenin (6), on the other hand, has described another technique of using a photographic enlarger for small objects like seeds, from which tracings of maximum and minimum projected areas are obtained and which are also used for measuring the values of x, y, and z axes.

Results and discussion

Correlation between length, width, and depth

Typical mean values obtained from the 3600 individual observations, using 36 samples of 100 beans each, are shown in Table 1, along with the maximum and minimum values and the arithmetic means of all the samples.

Using the mean values in Table 1, the following general equations can be written to express the relationship between length (L), width (W), depth (D), and the areas of flat (Fa) and transverse (Ta) surfaces:

$$L = 1.865\ W = 2.768\ D \quad [1]$$

$$W = 0.536\ L = 1.484\ D \quad [2]$$

$$D = 0.361\ L = 0.674\ W \quad [3]$$

$$Fa = 2.994\ Ta \quad [4]$$

$$Ta = 0.334\ Fa \quad [5]$$

The coefficient of correlation for the ratios of mean length/width, length/depth and width/depth is shown in Table 2, indicating that they are significant at the 1 per cent level.

Frequency distribution

The frequency distribution curves for the mean values of all the dimensions studied, shown in Fig. 3, indicates a trend towards normal distribution. The distribution of W is over a very narrow base compared to the other values, while that for Fa is over a very wide base, indicating that the area of the flat surface is much more variable than the other values. Also, the curves for both Fa and D have a tendency to be rather skewed, while the other three are normal in shape.

Table 1.—Length, width, depth, and areas of flat and transverse surfaces of cocoa beans: 36 samples of 100 beans each.

Sample	Length, cm	Width, cm	Depth, cm	Area of Flat Surface sq. cm	Area of Transverse Surface, sq. cm
Typical means	2.583	1.377	1.033	3.089	1.103
	2.361	1.278	0.825	2.786	0.934
	2.279	1.200	0.769	2.772	0.834
Maximum	3.450	1.820	1.950	5.470	1.830
Minimum	1.290	0.800	0.400	1.400	0.200
Arithmetic mean	2.439	1.308	0.881	2.928	0.978

The standard deviation and variance ratios (Table 3) of all the dimensions studied indicate that the difference within the samples is significant at the 1 per cent level. Also, as illustrated by Fig. 3, the standard

Table 2.—Correlation for length/width, length/depth and width/depth ratios.

Ratio	Correlation, r	t - test
Length/width	0.5709	16.4376*
Length/depth	0.5250	12.9353*
Width/depth	0.7606	46.6834*

* Significant at 1 per cent level

Table 3.—Standard deviation and variance ratios for length, width, depth and areas of flat and transverse surfaces.

Measurement	Standard Deviation	Variance Ratio
Length	0.2287	6.6889*
Width	0.0861	1.6644*
Depth	0.1197	3.2690*
Area of Flat Surface	0.2733	2.6001*
Area of Transverse Surface	0.1112	2.6645*

* Significant at 1 per cent level.

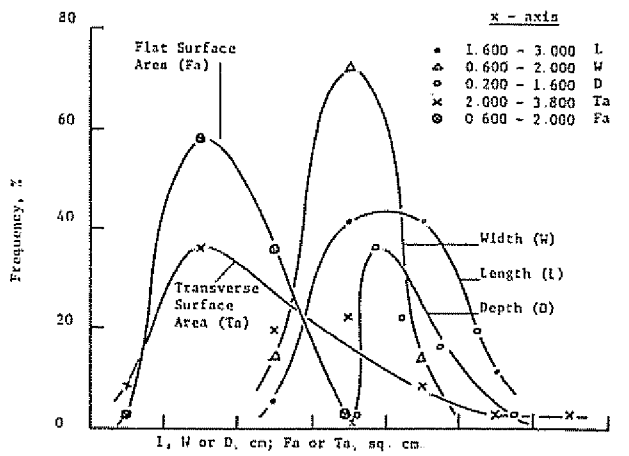

Fig. 3.—*Frequency distribution curves for mean values of cocoa beans*

deviation values obtained for W and Fa are the lowest and highest, respectively, in Table 3.

Area as a function of length, width, and depth

The areas of the flat surface and the cross-sectional or the transverse surface of a cocoa bean are useful values for designing processing equipment, e.g. for pneumatic conveyance of the beans. While determination by a direct measurement is difficult, the most commonly used indirect method is the prediction of area from the measurement of either length, width, or the depth of the product. In the present application, the measured values of Fa and Ta have been plotted as a function of the product of L and W and of W and D, respectively (Fig. 4), from which the relationship is found to be linear and positive.

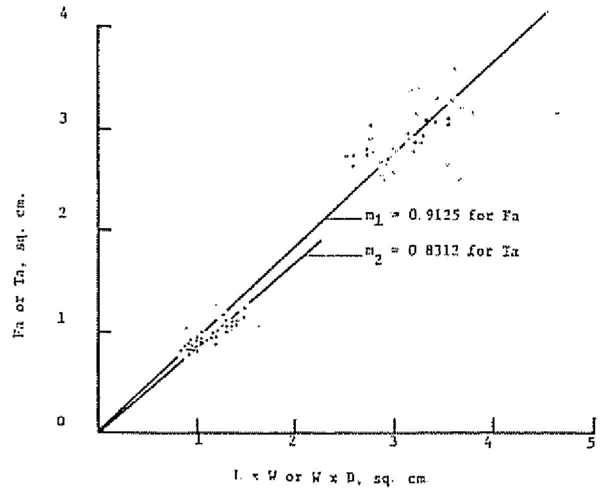

Fig. 4.—*Calculated vs measured values of Fa and Ta.*

As both the lines in Fig. 4 pass through the origin, the equation for a straight line ($y = mx + c$) can be rewritten as:

$$Fa = m_1 . L . W \quad [6]$$

and

$$Ta = m_2 . W . D \quad [7]$$

where m_1 and m_2 are the slopes.

By substituting the calculated values of m_1 and m_2 from Fig. 4 in Equations [4] and [5], we have:

$$Fa = 0.9125\ L.W \quad [8]$$

and

$$Ta = 0.8312\ W.D \quad [9]$$

The terms L, W, and D can, however, be also expressed as a function of the other two terms from equations [1] to [3], and equations [8] and [9] can therefore be rewritten as:

$$Fa = 0.4891\ L^2 = 1.7018\ W^2 = 3.7483\ D^2 \quad [10]$$

and

$$Fa = 0.4891\ L^2 = 1.7018\ W^2 = 3.7483\ D^2 \quad [10]$$

The main advantage of these two equations is that the flat or transverse area of a cocoa bean can be predicted with a reasonable accuracy from the measurement of any one of the three principal dimensions of length, width or depth.

By considering the cocoa bean as truly elliptical in shape, the calculated areas Af (flat surface) and At (transverse surface) can be obtained from the formula for ellipse:

$$A = \frac{\pi}{4} D.d \quad [12]$$

where D and d are major and minor diameters.

A comparison of the calculated values with the measured values (Table 4) indicate that the cocoa bean is more truly ellipsoid along its flat surface than along its transverse surface

Table 4.—Calculated and measured values of cocoa bean area.

Measurement	Area, sq. cm		Ratio C/M
	Calculated (C)	Measured (M)	
Flat	3.190 (Af)	2.928 (Fa)	1.089
Transverse	1.152 (At)	0.978 (Ta)	1.177

Effect of variety and season

It is recognized that variety and growing season are probably the two most important factors which are likely to affect the various numerical values obtained in this study to define the shape and size of cocoa beans. While the effect of the various recognized varieties of cocoa beans should be studied in detail, the present values would serve to quantify the dimensions of a cocoa bean; a similar study by Ghosh and Gacanja (2) with the two major varieties of coffee beans indicated that there is a distinct difference between them. The effect of the growing season on the numerical values for cocoa bean would be the subject of a separate report by the author, while an investigation by Wessel and Toxopeus (8) indicates that the environmental factors and seasonal effects affect the bean value of the West African Amelonado cocoa beans. Another report by Ghosh and Cunha (5) also indicates that the growing season has a significant effect on the sun drying rate of cocoa beans in Bahia, Brazil.

Summary

A quantitative definition to the shape and size of cocoa beans at the wet stage has been provided in terms of their length, width, depth and the areas of flat and transverse surfaces, the latter being obtained by a cross-sectioning of the bean. Empirical equations for estimating area from a measurement of any of the three principal dimensions have been proposed.

Acknowledgements

The study reported in this paper was carried out during the author's former association with the Division of Agricultural Engineering, Centro de Pesquisas de Cacau (Cocoa Research Center), Itabuna, Brazil, under the directorship of Dr Paulo de T. Alvim. A number of colleagues cooperated in the collection of the experimental data

Literature cited

1 ALVIM, P. T., and ROSARIO, M. L. Cacau ontem e hoje. Commemorative publication. Itabuna, Brazil, Centro de Pesquisas do Cacau, 1972. 83 p.

2 GHOSH, B. N. and GACANJA, W. A study of the shape and size of wet parchment coffee beans. Journal of Agricultural Engineering Research 15(2):91-99. 1970.

3 ——— Engineering aspects of cocoa drying in Brazil. Revista Theobroma 2(4):23-37. 1972

4 ——— Physical properties of cocoa beans. Turrialba 23(4):438-443. 1973.

5 ——— and CUNHA, J. Effect of season on sun drying of cocoa beans. Turrialba 25(4):396-403. 1975

6 MOHSENIN, N. N. Physical properties of plant and animal materials: Vol. 1, Structure, physical characteristics and mechanical properties. New York, Gordon and Breach, 1970

7 PROCEEDINGS OF the design application of mechanical properties of food materials. NSF/PSU workshop. The University Park, Pennsylvania State University. 1975

8 WESSEL, M. and TOXOPEUS, H. Seasonal influences on pod and bean values of West African Amelonado cacao. *In* Conferencia Internacional de Pesquisas em Cacau, 2a., Salvador e Itabuna, Bahia, Brazil, Novembro 19-26. Memorias. CEPLAC: 351-355. 1967

9 ZEHNTNER, L. Le cacaoyer dans l'Etat de Bahia. Berlin, Friedlander und Sohn, 1914. 50 p.