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Studies on pod and bean values of *Theobroma cacao* L. in Nigeria. I. Environmental effects on West African Amelonado with particular attention to annual rainfall distribution

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Summary

All pod and bean values except pod length/width ratio and weight of oven-dried shell and seed-coat per bean were affected by season. Pods developed in a period of considerable water stress had much lower values than pods developed during periods of adequate water supply. Under conditions of water stress the positive correlations between most pod characters disappeared. The mean weight, however, of oven-dry beans was independent of any other pod value irrespective of water supply to the trees. Percentage butterfat was positively, and shell content negatively related to bean size. Butterfat content of beans in the same weight class was higher in September than in June, and shell content of beans was lower. The mean weight of cured beans was highly correlated ($r = 0.82$) to the total rainfall of the first four months of pod development.

Introduction

Nigerian cocoa receives a lower price on the world market than Ghanaian because of alleged differences in quality, though not in flavour. Some chocolate manufacturers explain this in terms of lower fat content and higher percentages of shell in Nigerian cacao beans. Bean analyses of the main crops of various cocoa producing countries (Kleinert, 1966; Mohr, 1966; Riedl, 1963), however, reveal that the fat content and bean weight of Nigerian cocoa compare favourably with cacao from Ghana (Table 1). Both in Ghana and Nigeria, the bulk of the exported cocoa is produced from the West African Amelonado variety which is the same in both countries and well known for its lack of inherent variability. Differences in quality between the cocoa of the two countries are therefore likely to result from differences in the environment, especially climate.

Voelcker (1935), Doyne and Hartley (1938) and Russell (1952) have shown that in Nigeria bean weight and butterfat content are affected by seasonal variations (Table 2). During the main crop season (September to January) when most of the pods are

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Table 1 Annual quality assessment of the main cocoa crop of Ghana and Nigeria (simplified after Kleinert, 1966; Mohr, 1966; Riedl, 1963)

	1962–63		*1963–64*		*1964–65*		*1965–66*	
	Ghana	*Nigeria*	*Ghana*	*Nigeria*	*Ghana*	*Nigeria*	*Ghana*	*Nigeria*
Water content	5.1	4.4	4.3	4.1	4.4	4.8	4.4	4.8
Fat percentage in dry matter (nibs)	57,2	58.7	57.1	57.4	56.6	55.8	55.6	57.4
100 bean weight in grams	100	110	112	112	101	109	109	111
Percentage fully fermented beans	68	56	73	69	71	75	77	72
Percentage violet beans	22	32	20	24	22	19	20	21
Quality index	90	89	93	91	90	91	93	90

produced, bean weight and butterfat content are much higher than in the light crop (April–July).

In subsequent work, we confirmed the seasonal effect on bean weight (Toxopeus and Wessel, 1969). We found also that shell percentage is mainly a function of bean weight but is also affected by season. The shell percentage decreases with increasing bean weight and beans of the same weight have a higher shell percentage in the light crop than in the main crop We found furthermore that supplementary irrigation equivalent to 150 mm of rainfall per month lowered the mean bean weight significantly in October and not in other months, but low pod production of the experimental trees made it impossible to investigate this effect further. We could not find relations between bean weight and geographical location, total annual rainfall, different soil types and fertilizers although occasional differences were observed.

The work presented here was undertaken to provide a better understanding of the seasonal effects on all pod and bean characters that can be easily measured, and to provide the basis for a routine quality assessment of new varieties in terms of manufacturers' requirements.

Table 2 Seasonal differences in mean cured bean weight ($\bar{b}_f$) (Voelcker, 1935) and butterfat content (Doyne and Hartley, 1938) of West African Amelonado in Nigeria

Mean cured bean weight of pods harvested in 1933		*Butterfat content of peeled cured beans in pods harvested in 1936*	
month	$\bar{b}_f$	*month*	*% fat*
January	—	January	54.0
February	—	February	50.6
March	0.79	March	49.5
April	0.87	April	50.7
May	0.84	May	—
June	0.90	June	—
July	1.09	July	—
August	1.15	August	55.0
September	1.32	September	—
October	1.33	October	55.9
November	1.20	November	56.1
December	1.10	December	56.7

Materials and methods

The following definitions and symbols have been used:

Bean	= peeled bean consisting of cotyledons, plumule and radicle
Seed coat	= the seed coat rubbed clean of mucilage
Shell	= the fermented dried seed coat with adhering particles of fermented dried mucilage
Cured beans	= fermented, sun-dried beans (whole).

Pods were obtained from the CRIN Agodi Farm, a 30–40 year old seven acre cacao plot at Agodi, Ibadan, a typical Nigerian cacao farm (Russell, 1952). One hundred pods were harvested on 7 June 1967 and 5 September 1967 and from each batch 20 were chosen representing the whole range of pod lengths. These were used to measure the pod and bean values of each pod for the study of the effect of season and the correlations between these values.

Pod and bean characters recorded were:

Fresh:

L and W	= pod length and width
P	= pod weight
N	= number of beans per pod
BMS	= weight of beans, seed coats and mucilage per pod, excluding the central placenta
B	= weight of peeled beans per pod
MS	= weight of seed coat and mucilage per pod computed as BMS – B

Oven-dried:

B_d	= weight of oven-dried peeled beans per pod
S_d	= weight of oven-dried seed coats of the beans in a pod.

The same symbols have also been used in lower case to indicate weights per bean; means are indicated by placing the (—) sign above the symbols.

The beans from 60 remaining pods were fermented in trays and sun-dried, after which a random sample of 100 beans was taken, and oven-dried. The weight was taken of each (peeled) bean and its shell seperately.

Butterfat was determined on fermented and unfermented beans in different weight classes according to the analytical method of the Office International du Cacao et du Chocolat (Anon., 1963). Dry weights were recorded after drying for 24 hours at 105° C.

For cured beans the following symbols were used:

b_f = weight of a whole cured bean (not oven-dried)

b_{fd} = weight of a cured bean, oven-dried

b_n = weight of a peeled cured bean (or nib) oven-dried

sh = weight of the shell of a cured bean oven-dried.

In the periods 8 April 1946 to 23 January 1950 and 24 March 1953 to 15 February 1954 the weights had been recorded of samples of 300 cured beans from pods harvested at Agodi at three weekly intervals. The records were still available and were, computed into monthly mean bean weights, related to monthly rainfall records of Agodi over the same period. Monthly rainfall totals were added into two, three, four, five and six monthly totals (monthly moving totals) and correlation coefficients were calculated between these and bean weights.

Table 3 *Seasonal effects on pod and bean characters of 20 chosen pods harvested in June and Sept. 1967*

	Mean pod values										
					fresh weights				oven-dried weights		
	length	width	L/W	$\overline{N}$	$\overline{P}$	$\overline{BMS}$	$\overline{B}$	$\overline{MS}$	$\overline{B}_d$	$\overline{S}_d$	butter-fat
September 1967	14.9	8.4	1.78	38.6	365.1	106.1	60.4	45.7	39.1	2.92	21.9
June 1967	12.2	7.0	1.74	33.0	179.9	60.6	39.2	39.2	21.2	2.33	10.3
June as % of September	82	83	98	86	48	57	65	46	57	80	47

	Mean bean values										
	fresh weight			oven-dried weight			cured oven-dried weight				
	$\overline{bms}$	$\overline{ms}$	% ms	$\overline{b}_d$	$\overline{s}_d$	% S_d	$\overline{b}_n$	$\overline{sh}$	% sh	butter-fat	% butter-fat
September 1967	2.75	1.18	43.1	1.10	0.076	7.0	1.05	0.13	11.0	0.588	56
June 1967	1.84	0.64	37.7	0.68	0.071	9.5	0.68	0.13	16.3	0.313	46
June as % of September	67	54		66	93		69	100		53	

Measurements in grams or cm; symbols explained under 'Materials and methods'.

Table 4 *The effect of bean weight (in grams) and season on shell percentage and butterfat content*

Weight class of nib (b_n)	*Pods harvested September 1967*					*Pods harvested June 1967*				
	Number of beans	$\overline{b}_n$	$\overline{sh}$	% sh	% butter-fat	Number of beans	$\overline{b}_n$	$\overline{sh}$	% sh	% butter-fat
0.10—0.20	1	0.14	0.10	41.7						
0.20—0.30	2	0.26	0.11	29.7						
0.30—0.40	3	0.35	0.12	25.5						
0.40—0.50	17	0.45	0.11	19.6						
0.50—0.60	9	0.55	0.13	19.1		3	0.59	0.10	14.5	
0.60—0.70	15	0.65	0.13	16.7	46.0	2	0.65	0.12	15.7	
0.70—0.80	24	0.75	0.13	14.8	47.7	4	0.75	0.11	12.3	54.9
0.80—0.90	16	0.84	0.12	14.3	48.0	7	0.84	0.12	12.2	
0.90—1.00	11	0.92	0.16	14.8	49.1	14	0.95	0.13	11.8	
1.00—1.10	2	1.06	0.14	11.7	} 50.3	26	1.06	0.13	10.7	
1.10—1.20						24	1.15	0.13	10.5	56.9
1.20—1.30						19	1.24	0.14	10.3	
1.30—1.40						1	1.38	0.14	9.1	57.4
Averages		*0.68*	*0.13*	*16.3*			*1.05*	*0.13*	*11.0*	

Results

In September larger and heavier pods and beans are produced than in June, the effect on weights being more pronounced than the effect on pod size and number of beans

Table 5 Correlation coefficients of some pod and bean values obtained from 20 chosen pods harvested in September (upper figure) and in June (lower figure)

	Husk weight	*MS*	B_d	*N*	$\overline{ms}$	$\bar{b}_d$
Husk weight	—					
	—					
MS	+ 0.88	—				
	— 0.54	—				
B_d	+ 0.58	+ 0.57	—			
	— 0.49	+ 0.60	—			
N	+ 0.46	+ 0.62	+ 0.76	—		
	— 0.54	+ 0.71	+ 0.47	—		
$\overline{ms}$	+ 0.78	+ 0.96	+ 0.17	+ 0.11	—	
	— 0.20	+ 0.60	+ 0.01	+ 0.11	—	
$\bar{b}_d$	+ 0.41	+ 0.14	+ 0.43	+ 0.07	+ 0.14	—
	— 0.06	+ 0.03	+ 0.40	— 0.01	+ 0.18	—

LSD 5 % : 0.44
LSD 1 % : 0.56
LSD 0.1 % : 0.68

per pod. The only values which are not affected are pod L/W index and the weights of oven-dried seed coats and shell per bean (Table 3).

It was observed that shell and butterfat percentage of cured beans depend on bean weight and are also affected by season. With increasing bean weight shell percentage decreases and butterfat percentage increases. Beans of the same weight class have a higher shell percentage and a lower butterfat content in June than in September (Table 4).

The correlations between the measurements of various values of individual pods harvested in June and September are shown in Table 5. September pods show on the

Table 6 Correlation coefficients (r) between mean cured bean weight ($\bar{b}_f$) and monthly rainfall (M) or periods of rainfall with different time lags. M0* in rainfall in the month of harvesting, M5* is the month when the flower was presumably fertilized**

	r		*Various periods of rainfall* (*M7 M6 M5 M4 M3 M2 M1 M0*)	*r*
$\bar{b}_f$ × M0	— 0.07	$\bar{b}_f$ ×	M3 + M2	0.59
„ × M1	0.18	„ ×	M4 + M3 + M2	0.75
„ × M2	0.43	„ ×	*M5 + M4 + M3 + M2*	*0.82*
„ × M3	0.58	„ ×	M6 + M5 + M4 + M3 + M2	0.77
„ × M4	0.63	„ ×	M7 + M6 + M5 + M4 + M3 + M2	0.64
„ × M5	0.49	„ ×	M4 + M3 + M2 + M1	0.63
„ × M6	0.08	„ ×	M5 + M4 + M3	0.68

Significance levels (n–2 = 58): P 0.05 → r = 0.25; P 0.001 → r = 0.41.

* M7 M6 M5 M4 M3 M2 M1 M0

M5 ↑ flower fertilized; M0 ↑ ripe pod harvested; M5 to M0: pod development

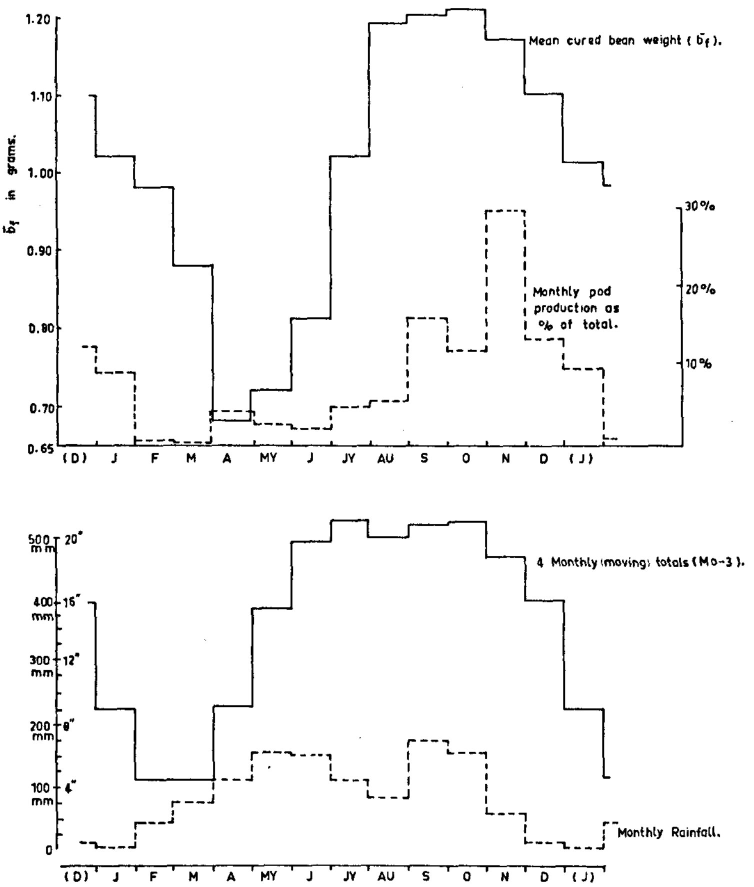

Fig. 1 Seasonal trends of mean cured bean weight, pod production, 4-monthly (moving) totals of monthly rainfall, and monthly rainfall. (All figures are monthly means for the periods January 1946 to December 1949 and January 1952 to December 1953.

whole significant *positive* correlations between pod husk weight and the other values, while June pods show significant *negative* correlations. Mean dry bean weight per pod is not significantly correlated with any of the other values.

Table 6 shows the relation of monthly mean cured bean weight ($\overline{b}_f$) with monthly rainfall and with the cumulative rainfall for various periods. The monthly rainfall 2, 3, 4 and 5 months prior to harvesting are each significantly correlated with mean bean weight ($\overline{b}_f$) and the cumulative rainfall over these four months (M_{2-5}) shows a high correlation ($r = 0.82$) with mean bean weight (see also Fig. 1).

Discussion and conclusion

The distribution of rainfall is thus mainly responsible for the seasonal variations in bean weight and probably in the other pod and bean values.

Pod development from fertilization to ripe fruit takes about 5½ months and must greatly depend on the water relations of the tree. These largely depend on rainfall because the cacao soils in Western Nigeria have no permanent watertable and a low available water storage capacity (Wessel, 1967). Under the conditions of low rainfall from mid-November to March the soil dries out to a considerable depth, and field capacity in the main rooting zone of the trees is usually not reached before June or July.

It seems therefore that a water stress period during development of pods harvested in June is the main factor responsbile for the differences recorded here.

Table 5 shows the correlations between some pod and bean values at different times of the year. In the large pods of September, those with a heavier husk contained more beans and had a greater weight of dried beans, mucilage and seed coat. The smaller and lighter June pods, however, showed a reverse pattern in that the pods with a heavier husk tend to have fewer beans and a lower weight of dried beans per pod and weight of mucilage and seed coat. This is also shown in the following series of correlation coefficients. Weight of the pod husk was highly correlated with pod length (June pods $r = 0.77$, September pods $r = 0.91$). The correlation coefficient between pod length and total pod weight was very high in September pods (0.91), but very low and not significant in June pods (0.25).

The absence of significant correlations of mean dry bean weight with the other characters gives an impression of independent growth of the bean. This is attributed to the fact that the zygote (embryo) differs genetically from the maternal tissue. It is an important observation that mean bean weight is independent from the number of beans in the pod.

Nichols (1964) observed in Trinidad that 'It must also be true that seeds influence the size of the pod, because fairly frequently pods containing one or a few seeds are found, these pods are invariably intermediate in size between seedless and fully seeded fruits.' In the present study which does not include seedless fruits or fruits with one or a few seeds the number of beans per pod was significantly correlated with pod length in September pods ($r = 0.68$) but in June pods no correlation existed ($r = -0.11$). It shows that Nichols' expected positive correlation does exist in the variety West African Amelonado but only in pods that have developed in the wet season in Nigeria.

Table 6 and Fig. 1 show the relation of the weight of cured beans with monthly rainfall totals. Rainfall in the six to eight weeks prior to harvesting has little or no effect on bean weight, indicating that either the tree can depend on its moisture reserves, or that in the final stage of bean development only little water is required. According to McKelvie (1956) the rate of pod and ovule growth slows down considerably at about 3 months after fertilization, while Nichols (1965) reports that at 100 days a gelatinous endosperm fills the whole seed. At this time, the embryo starts to absorb endosperm into its rapidly growing cotelydons.

According to the data presented in Table 6 rainfall ceases to affect bean size at about the time that the embryo has begun to absorb the endosperm into its cotelydons implying that this process is independent of rainfall. This is understandable on the presumption that only few additional metabolic products are required from the tree to sustain embryo growth in this stage.

Fig. 1 shows a graph of the monthly pod production of an Agodi subplot. The peak of pod production largely coincides with the period that pods have large beans but a sizeable part of the crop is produced during December and January when bean

Table 7 Calculated differences in butterfat content between early and late Nigerian main crop (weights in grams)

September	
Whole bean weight (see Fig. 1)	1.200
Shell weight (10.4 % ; see Table 4)	0.125
Weight of nib (calculated)	1.075
Butterfat weight (56 % ; see Table 2)	0.601
Butterfat over whole beans (%)	50.1
January	1.020
Whole bean weight (see Fig. 1)	0.112
Shell weight (11.0 % ; see Table 4)	0.908
Weight of nib (calculated)	0.490
Butterfat weight (54 % ; see Table 2)	
Butterfat over whole beans (%)	48.0

weights and butterfat content have started to decline. Table 7 shows that the fat content is on average 2 % lower in January than in September. It should be stressed that differences in 'butterfat yields' will be larger or smaller in individual years and in extreme years may be as high as 8 %. Beans of both months are sold as 'main crop' and it would appear that conflicting reports on the quality of Nigerian main crop cacao may have arisen because some manufacturers assess the quality of beans from the late main crop.

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