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Bean quality traits and sensory evaluation of wild Guianan cocoa populations (*Theobroma cacao* L.)

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Abstract

Naturalized cocoa populations originating from the Oyapok and Tanpok basins in French Guiana were studied for their technological characters (bean count, fat content, purine content) and sensory characters (overall aroma intensity, cocoa flavour, acidity, bitterness, astringency, fruity or floral tastes, aftertaste, etc.), along with three controls (Amelonado and Ecuadorian varieties). The bean count in Guianan cocoa was higher than that of the controls, but it generally remained acceptable (below 100). Caffeine content was much higher than that of the Amelonado control. The overall aroma intensity and cocoa flavour of the chocolates made with the dry cocoa beans from Guianan trees were statistically superior to those of the industrial reference, the West African Amelonado. The other criteria studied, particularly the fat content, did not reveal any significant differences from the controls.

Abbreviations: AFCC – Association Française du Commerce des Cacaos, Paris (France); BCCCA – The Biscuit, Cake, Chocolate and Confectionery Alliance, London (UK); CIRAD – Centre de Coopération Internationale en Recherche Agronomique pour le Développement (Montpellier, France); IOCCC – International Office of Cocoa, Chocolate and Sugar Confectionery

Introduction

The naturalized cocoa trees of southeastern French Guiana, which have been known since 1729 (Leconte and Challot 1897), were collected during three major survey and collection expeditions between 1987 and 1995 (Lachenaud and Sallée 1993; Lachenaud et al. 1997). Studies undertaken on this new germplasm (Lanaud 1987; Lachenaud and Sallée 1993; Lachenaud et al. 1999, 2000; Lachenaud and Oliver 2001; Sounigo et al. 1998, 2001) revealed its originality and its substantial potential merits for cocoa breeding, particularly for yield, cropping efficiency and resistance to diseases.

Work was launched in 1988 on the agronomic, morphological and biochemical characterization of wild Guianan cocoa trees in French Guiana. The purpose of that research was to provide breeders with indications for rational use of this material, which is already widely distributed in numerous producing countries, regarding the degree of variability found and its genetic structuring, and the origins that should be preferred. One of the important aspects to know for any new planting material is end-product quality, i.e. in this case, fermented and dried cocoa beans and the chocolate obtained from these beans. It is known that the "flavour" characteristics of a cocoa partly depend on the genotype and can be selection criteria (Clapperton et al. 1994).

Table 1. Genetic populations and country of origin of the samples studied.

Genetic populations	Code	Country of origin of samples
Wild Guianan populations		
Population Camopi 1	Cam 1	FG
Population Camopi 7	Cam 7	FG
Population Camopi 9	Cam 9	FG
Mixture of Camopi populations	GU	FG and IC
Controls		
West African Amelonado	IFC 1	IC
Amelonado from F. Guiana	AMG	FG
Ecuadorian population	EC	FG

(FG, French Guiana; IC, Ivory Coast).

Consequently, it is important to be able to compare a new germplasm with known references. We therefore present here the technological characteristics (bean count, fat content, purine content) and sensory characteristics (aroma, acidity, bitterness, astringency, aftertaste, etc.) for some of the wild Guianan populations, compared with controls of various varieties (particularly Amelonado).

Materials and methods

Planting material

The wild Guianan populations studied here for their technological and organoleptic qualities came originally from pods collected in the wild in 1987 in the basins of the Camopi and Tanpok rivers, in the far southeast of French Guiana (Lachenaud and Sallée 1993). These populations were planted in a collection near Sinnamary (North of F. Guiana) in 1988 and harvested several years later to study yield and pod traits. The dry cocoa beans analysed came either from clearly identified populations harvested separately in collection plots (Cams 1, 7 and 9) or from a mixture of pods harvested from all the identified populations (indicated as "GU", Table 1). The plots involved contained Guianan material only.

The controls (planted in neighbouring plots) were (Table 1):

– Amelonado trees formerly cultivated in French Guiana (Lachenaud et al. 1998), called "AMG",
– a typical West African Amelonado, clone IFC 1 (Soria and Enriquez 1981),
– material from Ecuador, consisting of hybrid cocoa trees derived from "Nacional" types (with a few "Venezolano"), called "EC".

In all cases, pods were harvested at optimum ripeness and opened in accordance with the recommended technique, using a wooden club (Barel 1998). The dry cocoa samples analysed came from French Guiana, apart from five that came from Ivory Coast (Divo Station, belonging to the Centre National de Recherche Agronomique, where Guianan material was introduced by one of us as early as 1988).

Methods

Post-harvest processing

As it is well known that processing is an important factor affecting cocoa flavour (Clapperton et al. 1994), it was necessary to test the new Guianan germplasm under varying conditions. Thus, three comparative experiments (A, B, C), comprising one or two successive series during the main harvesting period, were conducted using processes that differed in the time lapse before pod opening, the types of fermenting boxes and fermentation times, turning and the duration and type of drying (Table 2). Fresh bean samples (2–5 kg) were placed in fine-meshed bags inside a fermentation box filled with beans of different origin, following BCCCA recommendations (Anonymous 1996). When turning, the bags were opened and the beans shaken and stirred. In some cases, unfermented bean samples (simply washed clean of their mucilage and dried in the sun) were taken for specific analyses (purine quantification). In principle, sun drying was carried out (with overnight protection), and in some cases additional drying was performed (Table 2). Sensory parameters were compared on samples from the same season and from the same geographical origin.

Analytical methods

Bean count. Three hundred grams of beans were weighed, and the impurities, debris and broken beans removed. The waste weight was replaced (w/w) with whole beans taken at random from the rest of the sample, and then the number of beans per 100 g was determined.

Table 2. Experimental conditions during post-harvest operations.

Experiment	Series	Pl. mat.	Pod opening (d)	Fermentation (d)	Turning (h)	Sun drying (d)	Additional drying (d)
A	1	GU (*)	6	7	24–72–120	9	6 (oven 55 °C, 18 h/d)
		AMG	1	7	24–72–120	9	6 (oven 55 °C, 18 h/d)
B	1	Cam 1	1	6	24–96	5	3 (oven 45 °C, 12 h/d)
		Cam 7	1	6	24–96	5	3 (oven 45 °C, 12 h/d)
		Cam 9	1	6	24–96	5	3 (oven 45 °C, 12 h/d)
		AMG	1	6	24–96	5	3 (oven 45 °C, 12 h/d)
		EC	1	6	24–96	5	3 (oven 45 °C, 12 h/d)
	2	ditto B_1	1	6	24–72	1	7 (oven 45 °C)
C	1	GU (*)	2	6	24–72–120	7–9	
		IFC 1	2	6	24–72–120		
	2	ditto C1	0	6	24–72	7–9	

Pl. mat., planting material, see text and Table 1 for meaning; *, two replications, d, days; h, hours. The fermenting boxes were made of wood with a slatted bottom (120 l for A and B, 2000 for C). Additional drying was carried out in the laboratory (19–20 °C) and in the oven for the indicated durations. Origin of samples: A and B, French Guiana; C, Ivory Coast.

Cut test. Three hundred beans were cut in two using a laboratory guillotine knife ("cocoa bean guillotine knife": MAGRA Surtherland Herrliberg. The halves were then classed according to AFCC criteria (Anonymous 1990; Pontillon and Cros 1998). A cut test, which depends primarily on post-harvest processes, was performed to ensure that the samples were suitable for sensory evaluation.

Sample preparation. The basic samples for chemical analysis were obtained from 100 g of manually shelled beans, frozen in liquid nitrogen and ground in a mill to obtain a particle size of 0.5 mm.

Water content. Two grams of powder (< 0.5 mm) were placed in an oven at 103°C for 16 h. Two determinations were performed per sample.

Fat content. The method used was derived from that described by Pontillon and Cros (1998), i.e. IOCCC No. 115. The only alteration was that the ground cocoa powder (20 g, < 0.5 mm) was refined to 23 μm. Two determinations were performed per sample. The result was expressed as a percentage of dry matter.

Chemical acidities. The methods used to quantify, free, total and volatile acidity, and ammonium nitrogen, and to determine pH were described by Pontillon and Cros (1998). As for the cut test, acidities were measured to check the good fermentation and conservation of the samples.

Purine determination (theobromine and caffeine). The method used was derived from that described by Pontillon and Cros (1998). Alkaloids (in 0.3 g of cocoa powder) were extracted in water (100 mL) for 30 min. After filtering on celite, the extract was analysed by high pressure liquid chromatography by the external calibration method (chromatography conditions: C18 column with pre-column, eluent, 30/70 methanol/water (v/v); flow, 1 mL min^{-1}; quantity injected, 20 μL; detection, 278 nm). The results were expressed as the mean of two replications.

Sensory analyses. Chocolates were prepared by the official method for small samples (IOCCC No. 15, *in* Pontillon and Cros 1998). The panel of tasters was a jury of 15 qualified members (AFNOR No. V 09-002-12-75, *in* Moreau and Pontillon 1998). Tasting was carried out in series, with two replications per sample. Each sample was scored (from 0 to 5) for some or all of the following descriptors: overall aroma intensity, cocoa flavour, acidity, astringency, sweet taste, fruity taste (fresh or dried fruit), floral taste, aftertaste and overall quality.

Statistical methods. Analyses of variance were carried out using the SAS software GLM procedure

Table 3. Bean count and fat content means (fat as a percentage of dry matter).

Experiment	Material	Bean count	Fat
A	GU	91	51.3
	AMG	86	54.9
B	Cam 1	97 ab	49.1
	Cam 7	100 ab	52.0
	Cam 9	110 b	53.6
	AMG	96 ab	52.3
	EC	84 a	53.3
C	GU	88	54.4
	IFC 1	83	53.9

Only means followed by a different letter are significantly different ($P < 0.05$).

(SAS Institute 1989). The means were classed by the Newman–Keuls test (5% limit).

Results

Bean count

The results are shown in Table 3. In experiment B, populations Cam 1 and 7 were not significantly different from the two controls, but population Cam 9 reached high values of 110–111, for a generally accepted rejection limit of 120 (Anonymous 1996).

In experiments A and C, the Guianan bean count was slightly higher than that for the Amelonado controls AMG and IFC 1, but it remained below 100.

In experiment A, the shell rates were determined: they were 0.134 for the Amelonados and 0.153 and 0.157 for the two Guianan batches.

Fat content

The fat contents are shown in Table 3. No significant differences were found. For the various genetic origins studied, the general mean contents were 52.1 for the wild Guianan trees, 53.2 for the Guianan Amelonados, 53.9 for the West African Amelonado and 53.3 for the Ecuadorian mix. For the samples from Ivory Coast, the result was 54.4 for the wild Guianan cocoas and 53.9 for the West African Amelonado. The wild Guianan cocoa trees revealed basic contents varying from 47.4% to 56.0% of dry matter.

Table 4. Purine quantification in experiment C, as a percentage of dry matter, and theobromine : caffeine ratios (in brackets: on unfermented samples).

Planting material	Theobromine	Caffeine	T : C
GU	1.26 a (1.59 A)	0.083 b (0.092 B)	15.1 a (17.4 A)
IFC 1	1.24 a (1.58 A)	0.049 a (0.058 A)	25.4 b (27.1 A)

For each purine, means followed by a different letter are significantly different ($P < 0.05$).

Cut test

The cut test was only carried out in experiments B and C. The results (not shown) revealed no mouldy, insect-damaged or germinated beans, virtually no slaty beans (only present in tiny quantities in a single sample), a flat bean rate of less than 1% and purple bean percentages always below 20%. Consequently, the samples were suitable for sensory evaluation.

Chemical acidity and ammonium nitrogen content

For the set of experiments, A, B and C, some heterogeneous results were noted for acidity and ammonium nitrogen: this was probably due to the diversity of post-harvest operations (time lapse before pod opening, turning rate, fermentation time, drying method and time).

In experiment A, the Guianan material (GU) had ammonium nitrogen content over 400 ppm, which could indicate a risk of over-fermentation, likely to reduce cocoa flavour and lead to off-tastes.

In experiment B, the samples in series 1 showed high acidity and low ammonium nitrogen content: these results were typical of lactic fermentation and the degree of fermentation was lower than for series 2.

In experiment C, the ammonium nitrogen content was higher for the GU trees than for the IFC 1 trees, but the samples were properly fermented.

Purine determination

Purine determination was only carried out on the samples in experiment C (Table 4). It can be seen

Table 5. Overview of sensory analysis results for experiments A and B.

Experiment	Pl. mat.	Cf	Ac	Bi	As	Fr	Af	Qua
A	GU	2.6	2.7	2.9	3.0	1.6	–	2.6
	AMG	3.4	2.7	2.7	2.4	2.3	–	3.1
B	Cam 1	3.3	2.1	3.0	3.0	2.1	3.3	2.6 b
	Cam 7	3.4	2.1	3.0	2.3	2.0	3.2	2.9 ab
	Cam 9	3.7	1.7	3.0	2.4	1.9	3.3	3.1*
	AMG	3.7	2.1	2.9	2.5	2.6	3.4	3.6 a
	EC	3.8	1.6	2.9	2.2	1.9	3.3	3.4 a

Cf, cocoa flavour; Ac, acidity; Bi, bitterness; As, astringency; Fr, fruity flavour; Af, aftertaste; Qu, overall quality. (Means of scores out of 5.) (In Experiment B only, for Qua, when Cam 9 was removed (*) due to interaction, see text, significant differences were noted; means with different letter are significantly different.)

that the theobromine contents were similar in the Guianan and Amelonado IFC1 materials, whilst the caffeine content was clearly higher in the Guianan materials, at around 0.08% as opposed to 0.05%. After fermentation, the theobromine : caffeine ratio was over 25 in IFC 1 and around 15 in the Guianan materials.

Sensory analyses

Table 5 gives the results of the sensory analyses carried out on chocolates made from the samples in experiments A and B. For experiment B, an analysis of variance carried out on the basic results (panel scores), with genetic type (planting material) as the factor studied and the series as the controlled factor (block effect) only revealed a significant genetic type effect for the "overall quality" criterion (with $Pr > F = 0.017$), though with a highly significant genetic type x series interaction, which prevented any conclusion from being reached. In view of the basic data, this interaction may have come from the Cam 9 and EC cocoas: by withdrawing Cam 9 from the analysis, the interaction effectively disappeared (which was not the case when EC was withdrawn). The analysis then brought out significant genetic type and series effects, and the Newman–Keuls test showed two groups of means (Table 5). The series effect was only significant for the "acidity" criterion.

Table 6 gives a rundown of the results for the sensory analyses carried out on chocolates made from the samples in experiment C. Using the basic data (scores of the remaining judges), an analysis of variance only revealed significant "genetic type" effects for two criteria, overall aroma intensity and cocoa flavour. For aroma intensity, the Guianan materials were significantly better than the West African Amelonado ($Pr > F = 0.02$). For cocoa flavour, the Guianan materials were better than the Amelonado ($Pr > F = 0.008$). Only one "series" effect was found, for bitterness. No genetic type x series interaction was found.

Table 6. Overview of sensory analyses for experiment C.

Pl. mat.	Oai	Cf	Ac	Bi	As	Sw	Ff	Df	Fl	Af	Qua
GU	3.4 a	2.9 a	2.3	2.3	1.3	2.9	1.5	0.7	0.2	2.9	2.8
IFC 1	3.0 b	2.4 b	2.1	2.2	1.1	3.1	1.2	0.8	0.2	2.8	2.8

Oai, overall aroma intensity; Cf, cocoa flavour; Ac, acidity; Bi, bitterness; As, astringency; Sw, sweet taste; Ff, fresh fruit taste; Df, dried fruit taste; Fl, floral taste; Af, aftertaste; Qua, overall quality. (Means of scores out of 5.) Only means with a different letter are significantly different ($P < 0.05$).

Discussion

The samples analysed did not reveal any primary defects: the absence of mouldy, insect-damaged or germinated beans, virtually no flat beans, and purple bean rates always below 20% were characteristic of good quality (Pontillon and Cros 1998), placing them in category 1 of the ISO quality classification (Anonymous 1973). Only one sample had slaty beans, but at a tiny rate (0.3%). The samples were therefore perfectly suitable for sensory analyses. In some cases, with ammonium nitrogen content over 400 ppm, off-tastes or a reduction in cocoa flavour might have been feared, but such fears did not appear to be warranted in view of the sensory analysis results. However, a significant genetic type x series interaction was noted in one experiment (B), indicating that the post-harvest processes required might be different for the genetic types studied here.

Of the various criteria analysed, a genetic influence was found for the following: bean count, purine content, aroma intensity, cocoa flavour and overall quality. According to Clapperton et al. (1994), differences in genetic origin can be found for cocoa flavour intensity, acidity, bitterness and astringency, in addition to the fat content and bean

count. Our work therefore partly confirmed their results.

Among the controls adopted in our study, the West African Amelonado is the germplasm (when it comes from Ghana) on which the "bulk" industrial cocoa standard is based, whilst "Nacional" is the origin of an acknowledged fine cocoa ("Arriba" cocoa) with quite large beans (Wood and Lass 1985; Enriquez 1993). For the Amelonados once cultivated in French Guiana, which are different from the West African ones (Lanaud 1987), it may be that they were intrinsically better than the West African Amelonado. The quality of the cocoa once produced in French Guiana was indeed disputed: it was of "superior quality" with more fat than Caraque (Criollo cocoa from Caracas) according to Guisan (1825), but that appeared to be contradicted by Gallais (1827).

The main characteristics of the cocoa produced by wild Guianan cocoa populations revealed in our study seem to be the following: a high bean count (at least in some populations, or clones), a much higher caffeine content and a stronger cocoa aroma than the reference control, the West African Amelonado. The other parameters, notably fat content, were similar to those of the controls.

The bean count was rather high, always above that of the controls, and sometimes over 100; the beans are therefore globally small, which is a defect. However, the samples from Ivory Coast, which were not statistically different from the West African Amelonado, always gave a bean count below 100, even in the dry season (in Ivory Coast, the bean count for the main crop varies from 92 to 105; Wood and Lass 1985). It seems that when Guianan populations are mixed the bean count might be as good as it is for the Amelonado controls and that additional work is needed to identify populations with really small beans that are not fit for use in cocoa breeding. The caffeine contents were well above those of the control (+50% to 79%) but did not result in more bitter chocolates. The cocoa aroma, which covered two criteria, "overall aroma intensity" and "cocoa flavour", proved to be better than the reference, the West African Amelonado. Clapperton et al. (1994) showed that the cocoa flavour of the West African Amelonado reference was considerably superior to that of some Upper Amazon Forastero (Na 33, IMC 67, Pa 7, Sca 12) and Trinitario (UIT 1) clones or the West African Amelonado variety (i.e. seedlings) grown in Sabah, Malaysia. They also found that differences in flavour were independent of the difference in bean size.

Conclusion

The wild cocoa trees of French Guiana, which form a particular group (Lanaud et al. 1999), are still barely used for cocoa breeding, though clones have already been distributed since 1988, sometimes widely in numerous producing countries. It is therefore important to facilitate their use with characterizations and evaluations accessible to researchers. This has already been partly done for agronomic aspects (Lachenaud et al. 2000; Lachenaud and Oliver 2001). Another fundamental aspect is the quality of the end product, dry cocoa beans, which governs the quality of the chocolate. The results presented here show that the aroma intensity and cocoa flavour obtained from cocoa beans produced by wild Guianan cocoa populations were statistically superior to those of the industrial reference, the West African Amelonado. The bean count was high, particularly in population Cam 9, and slightly higher than that of the various controls, whilst generally remaining acceptable. The caffeine content was well over that of the West African Amelonado. The other criteria studied did not reveal any significant differences, particularly fat content, and no special taste was noted.

Naturalised Guianan cacao clones can now be used for genetic improvement in full knowledge of the facts: among them, as in Upper Amazon Forastero germplasm, breeders will have to choose clones with large beans or cross them with clones known for their high mean bean weight, such as Trinitarios.

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References

Anonymous 1973. Norme internationale ISO 2451–1973 (F). Fèves de cacao, Spécifications. Première édition 1973-12-15.

Anonymous 1990. Règles du marché. Association Française du Commerce des Cacaos (2 rue de Viarmes, 75001 Paris (updated 1/7/1990).

Anonymous 1996. Cocoa beans. Chocolates Manufacturers? Quality Requirements. BCCCA, London.

Barel M. 1998. Première transformation du cacao. In: Cacao et chocolat J. Pontillon, coordinateur, collection "Sciences et Techniques agroalimentaires", Lavoisier, Paris, 638 pp.

Clapperton J., Yow S., Chan J., Lim D., Lockwood R., Romanczyk L. and Hammerstone J. 1994. The contribution of genotype to cocoa (*Theobroma cacao* L.) flavour. Trop. Agri. (Trinidad) 71(4): 303–308.

Enriquez G.A. 1993. Characteristics of cacao "nacional" of Ecuador. In: Proceedings, International Workshop on Conservation, Characterization and Utilization of Cocoa Genetic Resources in the 21st century. Port-of-Spain, Trinidad, 13–17/9/1992, 269–278.

Gallais A. 1827. Monographie du cacao, ou manuel de l'amateur de chocolat. Debauve et Gallais, Paris, Réédition: Phénix Editions, 2000.

Guisan 1825. Traité sur les terres noyées de Guyane. Imprimerie du Roy (1788, France), Seconde édition, 1825.

Lachenaud Ph., Bonnot F. and Oliver G. 1999. Use of floral descriptors to study variability in wild cocoa trees (*Theobroma cacao* L.) in French Guiana. Genet. Resour. Crop Evol. 46: 491–500.

Lachenaud Ph., Clément D. and Oliver G. 1998. Premiers clones sélectionnés dans les descendants des cacaoyers (*Theobroma cacao*) autrefois cultivés en Guyane. Plant Genet. Res. Newslett. 113: 31–34.

Lachenaud Ph., Oliver G. and Letourmy Ph. 2000. Agronomic assessment of wild cocoa trees (*Theobroma cacao* L.) from the Camopi and Tanpok basins (French Guiana). Plant Genet. Res. Newslett. 124: 1–6.

Lachenaud Ph. and Oliver G. 2001. Variability in various agronomic traits of wild cocoa trees (*Theobroma cacao* L.) from the Camopi and Tanpok basins (French Guiana). Plant Genet. Res. Newslett. 128: 35–40.

Lachenaud Ph., Mooleedhar V. and Couturier C. 1997. Wild cocoa trees in French Guiana. New surveys. Plantations, recherche, développement 4(1): 25–32.

Lachenaud Ph. and Sallée B. 1993. Les cacaoyers spontanés de Guyane. Localisation, écologie, morphologie. Café Cacao Thé (Paris), 37(2): 101–114.

Lanaud C. 1987. Nouvelles données sur la biologie du cacaoyer (*Theobroma cacao* L.) PhD thesis, Université de Paris XI, Orsay (France), 262 p.

Lanaud C., Motamayor J.-C. and Sounigo O. 1999. Le cacaoyer. In: Diversité génétique des plantes tropicales cultivées. Hamon P., Hamsu P., Seguin M., Perrier X., Slaszmam J.-C (eds), Collection Repères, CIRAD, 387 p.

Leconte H. and Challot C. 1897. Le cacaoyer et sa culture. In: Carré et G. and Naud C. (eds) (Paris), 121 pp.

Moreau E. and Pontillon J. 1998. Aspects organoleptiques. Flaveur, couleur. In: Cacao et chocolat, J. Pontillon, coordinateur, collection Sciences et Techniques agroalimentaires, Lavoisier, Paris, 638 pp.

Pontillon J. and Cros E. 1998. Méthodes analytiques pour le cacao et produits dérivés. In: Cacao et chocolat, J. Pontillon, coordinateur, collection Sciences et Techniques agroalimentaires, Lavoisier, Paris, 638 pp.

SAS Institute Inc., 1989. SAS/STAT User's Guide, Version 6, 4th edn. 1 and 2, Cary, NC.

Soria V.J. and Enriquez G. 1981. Cacao international catalog. Technical bulletin No. 6, Tropical Agricultural Research and Training Center, CATIE, Turrialba, Costa Rica.

Sounigo O., Ramdahin S., Umaharan R. and Christopher Y. 1998. Assessing cacao genetic diversity using IE and RAPD techniques. Annual Report 1998, 25–28, Cocoa Research Unit. The University of the West Indies St. Augustine, Trinidad and Tobago, 1999.

Sounigo O., Ramdahin S. and Christopher Y. 2001. Etude de la diversité génétique du cacaoyer à l'aide des RAPD. 13th International Conference on Cocoa Research, Kota Kinabalu (9–14/10/2000), Sabah, Malaysia, pp. 119–126.

Wood G.A.R. and Lass R.A. 1985. Cacao 4th edn. Longman, London, 620 pp.