

Full Length Research Paper

Selection of cocoa clones (*Theobroma cacao* L.) for the morphological and sensory qualities of the beans in Côte d'Ivoire

Attiaipo Pépin Assi^{1,2*}, Honorine Brigitte Guiraud², Patricia N'goran², Klotioloma Coulibaly², Walet Pierre N'guessan², Firmin Goure Bi^{1,2}, Masse Diomande¹ and Gnion Mathias Tahi²

¹Agroforestry Training and Research Unit, Université Jean Lorougnon Guédé, Daloa, Côte d'Ivoire.

²National Agronomic Research Center, Divo Research Station, Divo, Côte d'Ivoire.

Received 16 September, 2025; Accepted 13 January, 2026

The current context of cocoa farming in Côte d'Ivoire is marked by a decline in the quality of commercial cocoa. This study aims to identify cocoa trees with good grain size and good plant morphological, aromatic, and sensory qualities. The methodology used consisted of analyzing 11 clones and 27 families of high-yielding hybrids for two morphological characteristics (grain size and homogeneity of the beans) and sensory quality (aroma, acidity, bitterness, astringency, etc). The plant material came from multi-site trials set up at the Divo and Soubré research stations and in the Toumodi farming community. The results revealed that the weight of a marketable cocoa bean was greater than 1 g for all the plant material studied. Clones IFC16 (1.81 g), C123 (1.65 g) and families F6 Séch/Divo (1.81 g); F25 Séch/Divo (1.45 g); F26 TO/Soubré (1.43 g) and F3 Séch/Divo (1.42 g) obtained very good bean size and good homogeneity with scores greater than or equal to 6. In addition, Fifteen of the twenty-seven hybrid families and six clones were characterized by specific flavors (floral, woody, and fresh fruit) sought after by chocolatiers. The value of researching the best-performing trees within hybrid families such as F2, F3, and F4 (from E6/5 Divo), or these two quality criteria, is considered and discussed.

Key words: Clone, hybrid, cocoa tree, qualities, morphological, sensory.

INTRODUCTION

Cacao trees are tropical perennial plants grown mainly for their beans, which are used to make chocolate, cosmetics, and pharmaceutical products. Côte d'Ivoire is the world's

leading producer of commercial cacao. Ahead of production with 2.225.000 tons (International Cocoa Organization [ICCO], 2020). Accounting for approximately

*Corresponding author. E-mail: attiaipopépin@gmail.com.

Table 1. List of 11 cocoa clones (from the E5/1 clonal plot in Divo) evaluated for morphological and sensory qualities.

Clones	Plant material type	Genealogy
C20	Cloned hybrid	PA13 × IMC 67
C70	Cloned hybrid	IFC 720 × ICS 46
C71	Cloned hybrid	UPA 409 × IFC 1
C123	Cloned hybrid	UPA 409 × POR
C131	Cloned hybrid	SCA6 × PA150
C140	Cloned hybrid	NA32 × SCA 6
IFC 16	Trinitario	Mass selection
IFC 1026	Cloned hybrid	IFC 6 × UPA 603
IFC 1027	Cloned hybrid	IFC 6 × UPA 603
IFC 1201	Cloned hybrid	PA 150 × IFC 5
IFC 1208	Cloned hybrid	H692 × IFC 5

40% of global supply. The cocoa sector thus contributes 15% of gross domestic product (GDP) and 44% of exports earnings (ICCO, 2014). It is an important source of foreign exchange and employment for more than 60% of the population (ICCO, 2012). In fact, around 6.000 farm managers in Côte d'Ivoire depend directly or indirectly on income from this plantation.

Despite this remarkable performance, the current context of Ivorian cocoa farming is marked by numerous production constraints, including aging plantations, high pest pressure (Kébé and N'guessan, 2003), and the average, even unsatisfactory quality of commercial cocoa. The latter is the result of producers' failure to comply with sequential harvest and post-harvest processing operations and practices as well as the low level of use of improved plant material, which negatively impacts cocoa quality (Chen-yen-su, 2014).

Today, the concept of the fine qualities of cocoa has evolved considerably. The old concept was based on the principle that the sensory qualities of fine chocolates are acquired during fermentation or are defined by the aromatic environment around the cocoa trees (Eskes, 2021). These ideas have been contradicted by important discoveries concerning the presence of 43 flavors and aromas in the pulp of fresh fruit varieties in Peru and Brazil. These flavors and aromas are genetic with qualitative heritability (Eskes et al., 2012, 2017, 2018; Eskes, 2021). These results have been confirmed by chemical studies on aromatic compounds present in the pulp of fresh cacao fruit (Hegmann, 2015; Kadow et al., 2013).

The sensory characteristics of fresh fruit include the different characteristics of the pulp, namely citric acidity, sweetness, fruity flavors, and floral/spicy aromas, as well as the bitterness and astringency of the beans (Eskes et al., 2018). Based on this information, the first objective is to identify the possible variations in sensory attributes that may exist in cocoa. The second objective is to demonstrate

that the sensory characteristics of cocoa pulp are highly dependent on genotype.

METHODOLOGY

Clonal and hybrid plant material was evaluated for its morphological and technological, and sensory qualities.

Study sites

The study was conducted at the Divo research station and at the Centre National de Recherche Agronomique (CNRA)'s morphological, chemical, and sensory analysis laboratory in Bingerville.

Plant material

The plant material studied comprises 27 hybrid families (Table 1) and 11 productive cocoa clones (Table 2). The hybrid families were obtained from various trials conducted at the CNRA sites in Divo and Soubré (two areas with normal rainfall) and in a farming environment in Dimbokro (an area with low rainfall). The clones were all obtained from a clonal trial conducted at the CNRA station in Divo. F9, F17, F22, and F25 families were planted in both Divo and Dimbokro.

The clonal material consists of cloned hybrids except for IFC16, which is a trinitario derived from mass selection. Except for families with codes 131, 127, 124, and 126, which are double hybrids. The others are single hybrids (the majority) and three-way hybrids (families with codes 123 and 133). The clones and hybrid families are planted in rows or in a completely randomized pattern, with 10 to 15 plants/clone and 15 to 30 plants/family. Each plot had two peripheral border rows outside the trial. The rows are 3 m apart, and the trees in the row are 2.5 m apart, giving a planting density of 1.320 trees/ha.

Evaluation of the physical qualities of the plant material

The physical qualities of the plant material were assessed based on three parameters of grain size, sample homogeneity, and the overall aroma of the beans.

Grain size

Grain size was measured by the average weight of a marketable cocoa bean. For each plant material, grain size was determined by randomly selecting a sample of 100 marketable cocoa beans and weighing them individually to determine the average weight of the marketable cocoa bean.

Homogeneity

This is assessed on a scale of 0 to 10 by visual observation of a given quantity of marketable beans (at least 100). For a given plant material, the standard deviation of the weight of 100 individually weighed beans also gives an indication of the homogeneity of the bean sample. The lower the standard deviation, the more homo-

Table 2. List of 27 hybrid families (from different trial plots) evaluated for morphological and sensory qualities.

Fam.	Plot	Lab code	Genealogy
F2	Séch/Divo	103	UPA409 × IFC1
F2	E6/5 Divo	119	P7 × GU284-A
F3	E6/5 Divo	122	IMC57 × GU123- B
F3	Séch/Divo	99	UPA608 × IFC412
F4	Séch/Dimbokro	65	UPA413 × IFC1
F4	E6/5 Divo	120	IMC57 × GU175-A
F6	Séch/Divo	91	UPA409 × POR
F6	TO Soubré	131	E6/1 L22 A11 × E6/4 L27A8
F9	Séch/Dimbokro	64	PA150 × IFC5
F9	Séch/Divo	78	PA150 × IFC5
F10	E6/5 Divo	113	IFC303 × GU175-A
F11	TO Soubré	127	E6/1 L23 A17 × E6/4 L27 A8
F12	Séch/Divo	92	IMC67 × IFC1
F13	E6/5 Divo	115	E 41-12 × E42-17
F15	Séch/Divo	97	PA150 × POR
F17	Séch/Dimbokro	72	SCA6 × LAF1
F17	Séch/Divo	85	SCA6 × LAF1
F22	Séch/Dimbokro	66	P7 × GU284A
F22	Séch/Divo	79	P7 × GU284A
F22	TO Soubré	124	E6/1 L22 A18 × E6/4 L27 A8
F23	Séch/Divo	83	IFC303 × GU175-A
F25	Séch/Divo	90	P7 × IMC67
F25	Séch/Dimbokro	75	P7 × IMC67
F26	TO Soubré	130	UPA 409 × POR
F27	TO Soubré	123	E5/1 L29 A2 à 6 × C2/1-1
F28	TO Soubré	126	E5/1 L71 A7 à 11 × E6/4 L27 A8
F41	TO Soubré	133	GU 139 A × E6/1 L11 A23

geneous the cocoa beans are.

Overall aroma of the beans

The overall aroma of the beans is determined by smelling a random quantity of marketable beans held between the hands and brought to the nose to determine the intensity of the aroma (cacao) they give off. The beans are smelled while looking for the cocoa flavor, and a score ranging from 0 to 4 is assigned: mild = 0; smell = 1; lowly strong = 2; strong = 3, and very strong = 4.

Evaluation of the sensory qualities of the plant material

This stage began with the preparation of cocoa bean liquors, which involves processing beans that have been previously characterized in terms of their physical and aromatic properties. This phase involved the following steps: manual sorting of whole beans, roasting (at 130°C for 25 min), cooling, crushing, winnowing (production of nibs), manual sorting of nibs and liquefaction by grinding.

A panel of at least eight trained individuals evaluated the cocoa masses produced according to Cocoa of Excellence (CoEX)

requirements. The cocoa mass (or liqueurs) was divided into pots and placed in an oven at 50°C for 15 min. The characteristics (Figure 1) were evaluated on a scale of 0 to 10.

RESULTS

Evaluation of the physical and technological qualities of 11 cocoa tree clones

Table 3 shows the morphological and technological characteristics of the cocoa clones studied. The moisture content of the commercial cocoa bean samples ranged from 6.8 to 7.8% for all clones. There was a highly significant clone effect on bean size, measured in this study by the average weight of a commercial cocoa bean. The average weights of commercial beans ranged from 1.14 to 1.81 g, with a coefficient variation (CV) of 15.7%. The clones IFC16, C123, C20, and IFC1027 ranked highest for this parameter, with respective averages of

Sensory Quality Evaluation		BLAISE KOBENAN	YAO MICHEL	ASSEMIEN FABRICE	PRUDENCE	SYLVIE	DK	LBK	MOUSSA OUATTARA
	Échelle 0-10								
Cocoa	5,9	6	6	5	6	6	6	5	7
Acidity	2,8	3	4	3	2	2	3	1	4
Bitterness	4,5	4	3	5	4	6	6	6	2
Bitterness	4,8	4	4	3	5	5	5	6	6
Astringency	1,9	2	4	2	2	1	1	1	2
Fresh fruit	1,4	1	4	0	1	1	2	1	1
Brown fruit	1,5	2	2	1	0	2	0	2	3
Floral	2,3	1	2	2	2	3	3	2	3
Woody	1,1	2	1	1	2	1	1	1	0
Spicy	0,9	0	1	0	1	1	1	1	2
Nutty	0,4	0	1	0	1	0	0	0	1
Sweet	5,4	5	5	5	6	5	7	5	5
Sensory Quality Evaluation – Defects									
	0,0	0	0	0	0	0	0	0	0
Salty, dusty	0,0	0	0	0	0	0	0	0	0
Ham / meat / Animal	0,1	0	0	0	1	0	0	0	0
Leather	0,1	1	0	0	0	0	0	0	0
Smoky	0,1	0	0	1	0	0	0	0	0
Moldy	0,4	0	0	0	0	3	0	0	0
Putrid / over-fermented	0,0	0	0	0	0	0	0	0	0
Other odor									
Overall Score	5,5	5	5	5	6	5	6	6	6

Figure 1. Sensory quality assessment by a panel of eight people.

1.81, 1.65, 1.41 and 1.40 g. The clones IFC1201, C140, and C131 ranked lowest for bean size. The homogeneity of the different dry bean samples varied depending on the evaluation method used. Based on a rating scale of 0 to 10, the bean sample from clone C70 was the most homogeneous. However, based on the standard deviation value, the sample from clone C131 with a deviation from the mean of 0.08 was the most uniform.

In terms of the overall aroma of the samples, six clones (C123, IFC1027, C70, IFC1201, IFC1208) out of the 11 evaluated had two types of aromas (cocoa and vinegar) with cocoa being the dominant aroma. Clone C131 (SCA6 x PA150) had the strongest cocoa intensity with a score of 6. Regarding the technological parameter measured by the number of normal fresh beans per pod significant differences were found between clones. The averages ranged from 34.7 to 51 beans per pod for a CV of 23.6%. The best-performing clones for this parameter were C20 (51 beans), IFC1208 (44 beans), C71 (42.3) and IFC1201 (40 beans) while the least performing were IFC16 (34.7 beans), IFC1027 (35.6 beans) and IFC1026 (36.1 beans).

Evaluation of the morphological and technological qualities of 27 hybrid families

Table 4 shows the results of the comparison of 27 families of cocoa tree hybrids in terms of the morphological and technological qualities of the plant material. For all hybrid families, the moisture content recorded ranged from 6.5 to 8.1%. In terms of seed size, a highly significant family effect was observed among the 27 families. The averages ranged from 1 to 1.81 g for a CV of 12.6%. The three families at the top of the ranking are F6/Séch Divo, F25/Séch and F26/TO Soubré with marketable bean weights of 1.81, 1.45 and 1.43 g, respectively. The homogeneity scores for these families range from 6 to 8. The dominant aromas are vinegar with scores ranging from 1 to 4 and cocoa with scores ranging from 1 to 2. The two dominant aromas were present in six families (F3 Séch/Divo, F12 Séch/Divo, F3 E6/5, F13 E6/5, F6 TO Soubré and F11 TO Soubré).

The results also showed significant differences between families. The averages ranged from 21.92 to 55.65 beans

Table 3. Morphological and technological characteristics of 11 cocoa tree clones.

Variable		Morphological characteristics		Technological characteristics	
Clones	Genealogy	Grain size (P1FS in g)	Homogeneity score (0-10)	Dominant aroma (0-5)	NFN
IFC 16	Mass selection	1.81 ± 0.24 ^a	-	-	34.7 ± 5.1 ^e
C123	UPA 409 × POR	1.65 ± 0.19 ^b	6	Cocoa (2)	37.9 ± 7.6 ^{cde}
C20	PA13 × IMC 67	1.41 ± 0.19 ^c	-	-	51.0 ± 6.8 ^a
IFC1027	IFC 6 × UPA 603	1.4 ± 0.22 ^c	6	Cocoa (2) vinegar (2)	35.6 ± 5.4 ^{de}
C70	IFC 720 × ICS 46	1.36 ± 0.12 ^{cd}	8	Cocoa (4)	36.2 ± 6.1 ^{de}
IFC1026	IFC 6 × UPA 603	1.31 ± 0.17 ^d	-	-	36.1 ± 4.7 ^{de}
C71	UPA 409 × IFC 1	1.24 ± 0.13 ^e	-	-	42.3 ± 8.7 ^{bc}
IFC1201	PA 150 × IFC 5	1.2 ± 0.11 ^{ef}	6.0	Cocoa (2)	40.0 ± 6.3 ^{cd}
IFC 1208	H692 × IFC 5	1.15 ± 0.10 ^f	4	Cocoa (1) vinegar (1)	44.0 ± 4.1 ^b
C140	NA32 × SCA 6	1.14 ± 0.15 ^f	-	-	37.8 ± 10.8 ^{cde}
C131	SCA6 × PA150	1.14 ± 0.08 ^f	7	Cocoa (6)	38.9 ± 7.3 ^{cde}
Means		1.36			38.7
CV (%)		15.7			23.6
<i>P</i>		< 0.0001			< 0.0001

Means followed by different letters are statistically different according to the student-Newman-Keuls test at the 5% threshold. P1FS (Weight of a dry bean); NFFN (Number of normal fresh beans).

per pod for a CV of 18.2%. The families were classified into three homogeneous groups: group 1 includes family F6 from the TO/Soubré trial at the top of the ranking, with 55.65 beans per pod. Group 3 is ranked at the bottom of the scale. also consists of one family (F9 from the Dimbokro Drought trial) with 21.92 beans per pod. Between these two groups is group 2, which includes all the other families with numbers of beans per pod intermediate between the two previous groups, ranging from 43.60 (F3 from E6/5) to 37.50 beans (F28 from TO/Soubré).

Evaluation of the sensory qualities of 11 cocoa tree clones

Based on the tasting of the liqueurs, seven out of

eleven clone samples exhibited the desired attributes (Table 5). These were C20, C70, C123, C131, IFC1027, IFC1201 and IFC1208. The different flavors detected in these clones were floral, woody, and then complex, fresh fruit/floral, and floral/woody. The sensory profile of one of the seven clones, referred to as C20, is highlighted in the study. When compared to the reference sensory profile of Côte d'Ivoire cocoa (Figure 2), as outlined by Cocoa of Excellence (CoEx), C20 exhibits a complex sensory profile (Figure 3). It showcases a strong intensity of cocoa flavor, along with fresh fruit and floral notes. Clone C20 like the reference according to Cocoa of Excellence. Still has a lot of bitterness and astringency. Clone C20, on the other hand, has other favorable characteristics.

Evaluation of the sensory qualities of 27 hybrid families

The results shown in Table 6 indicate that 15 samples of hybrid families have the desired flavors. These are the families with codes 119, 122, 99, 120, 91, 113, 127, 92, 115, 90, 75, 130, 123, and 126. Several flavors were detected, ranging from simple (woody floral) to complex (floral/woody, fresh fruit/floral, fresh fruit/floral/woody). The sensory profile of one of these 15 families of hybrids, characterized by specific flavors, namely that of the F22 family (code 124), is shown in the study. Compared to the reference sensory profile of Côte d'Ivoire cocoa, that of F22 (Figure 4) is characterized by fresh and floral fruit flavors with additional woody notes.

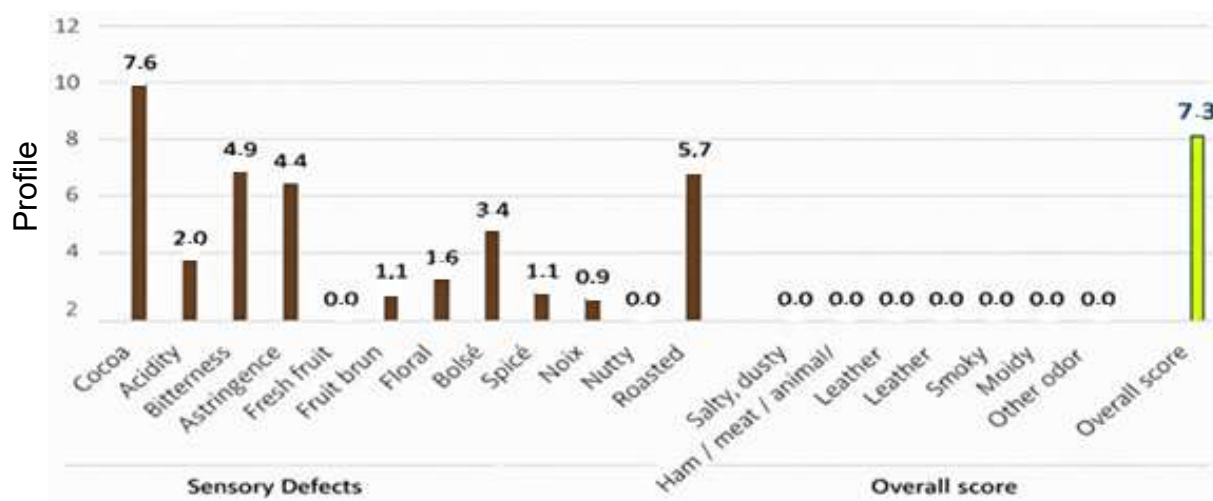
Table 4. Comparison of 27 families of cocoa tree hybrids for 3 morphological characteristics and 1 technological characteristic.

Variable				Morphological characteristics		Technological characteristic	
Fam.	Essay	Lab code	Genealogy	Grain size (P1FS)	Homogeneity score (0-10)	Dominant aroma (0-5)	NFN
F6	Séch/Divo	91	UPA409 × POR	1.81±0.44a	6	Vinegar (1)	42.30 ± 6.5 ^b
F25	Séch/Divo	90	P7 × IMC67	1.45 ± 0.28 ^b	8	Vinegar (1)	46.30 ± 9.8 ^b
F26	TO/Soubre	130	UPA 409 × POR	1.43 ± 0.09 ^b	7	Vinegar (4)	40.85± 8.8 ^b
F3	Séch/Divo	99	UPA608 × IFC412	1.42 ±0.27 ^b	6	Cocoa (1), vinegar (1)	39.30 ± 10.6 ^b
F4	Séch/Toumodi	65	UPA413 × IFC1	1.36 ± 0.26 ^c	7	Cocoa (2)	38.33 ± 10.2 ^b
F12	Séch/Divo	92	IMC67 × IFC1	1.35 ± 0.19 ^c	8	Cocoa (2), vinegar (2)	43.60 ± 9.2 ^b
F15	Séch/Divo	97	PA150 × POR	1.31 ± 0.19 ^c	7	Cocoa (2)	38.03 ± 10.1 ^b
F3	E6/5	122	IMC57 × GU123- B	1.30 ± 0.21 ^{cd}	6	Cocoa (1), vinegar (1)	43.60 ± 7.4 ^b
F17	Séch/Divo	85	SCA6 x LAF1	1.30 ±0.04 ^{cd}	-	-	37.90 ± 6.0 ^b
F23	Séch/Divo	83	IFC303 × GU175-A	1.30 ± 0.20 ^{de}	-	-	40.20 ± 6.8 ^b
F9	Séch/Divo	78	PA150 × IFC5	1.30 ± 0.17 ^{de}	-	-	41.00 ± 5.8 ^b
F17	Séch/Toumodi	72	SCA6 × LAF1	1.30 ± 0.23 ^{de}	-	-	38.69 ± 6.0 ^b
F25	Séch/Toumodi	75	P7 × IMC67	1.24 ± 0.16 ^{def}	8	Vinegar (4)	36.70 ± 12.7 ^b
F2	Séch/Divo	103	UPA409 × IFC1	1.24 ± 0.22 ^{def}	-	-	42.83 ± 8.6 ^b
F27	TO/Soubre	123	E5/1 L29 A2 at 6 × C2/1-1	1.24 ± 0.05 ^{def}	8	Cocoa (2)	38.30 ± 6.7 ^b
F4	E6/5 Divo	120	IMC57 × GU175-A	1.24 ± 0.05 ^{def}	7	Cocoa (2)	42.25 ± 6.7 ^b
F2	E6/5 Divo	119	P7 × GU284-A	1.22 ± 0.05 ^{ef}	8	Vinegar (3)	39.90 ± 9.8 ^b
F10	E6/5 Divo	113	IFC303 × GU175-A	1.20 ± 0.04 ^{gf}	7	Vinegar (3)	37.50 ± 37.5 ^b
F22	Séch/Toumodi	66	P7 x GU284A	1.20 ± 0.19 ^{fgh}	8	Vinegar (1)	39.53± 10.6 ^b
F28	TO/Soubre	126	E5/1 L71 A7 at 11 × E6/4 L27 A8	1.20 ± 0.06 ^{fgh}	7	Cocoa (2)	37.50 ± 11.02 ^b
F41	TO/Soubre	133	GU 139 A × E6/1 L11 A23	1.15 ± 0.05 ^{gh}	7	Vinegar (2)	41.85 ± 6.7 ^b
F13	E6/5 Divo	115	E 41-12 × E42-17	1.14 ± 0.03 ^{gh}	6	Cocoa (2), vinegar (2)	39.05 ± 7.5 ^b
F22	Séch/Divo	79	P7 x GU284A	1.14 ± 0.17 ^{gh}	8	Vinegar (1)	38.63 ± 10.3 ^b
F22	TO/Soubre	124	E6/1 L22 A18 × E6/4 L27 A8	1.14 ± 0.07 ^h	8	Vinegar (1)	38.63 ± 9.4 ^b
F9	Séch/Toumodi	64	PA150 × IFC5	1.10 ± 0.10 ^h	-	-	21.92 ± 11.8 ^c
F6	TO/Soubre	131	E6/1 L22 A11 × E6/4 L27A8	1.00 ± 0.01 ⁱ	8	Cocoa (2), vinegar (2)	55.65 ± 10.3 ^a
F11	TO/Soubre	127	E6/1 L23 A17 × E6/4 L27 A8	1.00 ± 0.09 ⁱ	7	Cocoa (2), vinegar (2)	38.95 ± 9.4 ^b
Means				1.3			40.36
CV (%)				12.6			18.2
P				< 0.0001			< 0.0001

Means followed by different letters are statistically different according to the Student-Newman-Keuls test at the 5% threshold. P1FS: Weight of a dry bean; NFFN: number of normal fresh beans.

Table 5. Distinctive flavors are detected in cocoa liqueurs made from 7 cocoa bean clones.

Clone	Genealogy	Lab Code	Distinctive flavors
C20	PA13 × IMC 67	-	Fresh fruits/Floral
C70	IFC 720 × ICS 46	135	Floral
C71	UPA 409 × IFC 1	137	Normal
C123	UPA 409 × POR	141	Floral
IFC 16	Mass selection	139	Normal
C131	SCA6 × PA150	142	Floral
C140	NA32 × SCA 6	143	Normal
IFC1026	IFC 6 × UPA 603	144	Normal
IFC1027	IFC 6 × UPA 603	140	Woody
IFC1201	PA 150 × IFC 5	145	Floral/Woody
IFC 1208	H692 × IFC 5	138	Floral/Woody

**Figure 2.** Reference sensory profile for cocoa from Côte d'Ivoire according to cocoa of excellence.

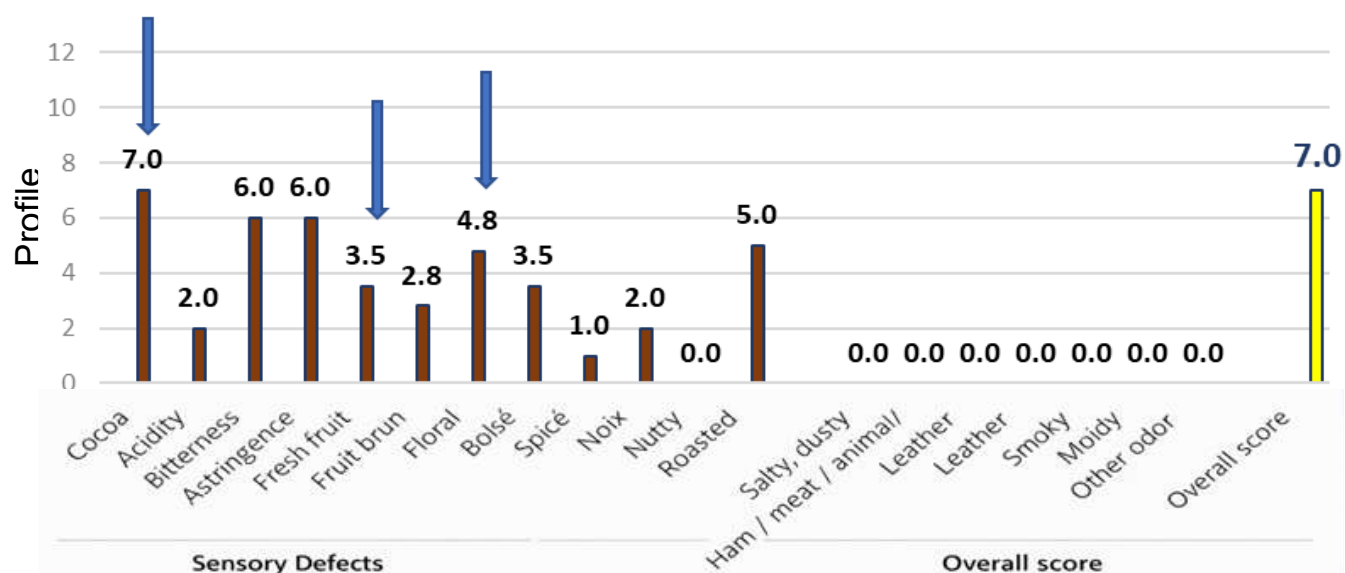
DISCUSSION

Eleven cocoa clones and twenty-seven CNRA hybrid families were selected from among the most productive varieties in various trials conducted in Côte d'Ivoire. Some at the CNRA sites in Divo and Soubré and others in low rainfall production areas (Dimbokro) were evaluated for both physical characteristics (moisture content, grain size, sample homogeneity, and dominant aroma) and a technological characteristic (number of normal fresh beans per pod). With regards to physical characteristics, analyses showed that the moisture content of samples of marketable cocoa beans from clones or hybrid families was all below 8.5%. The threshold recommended by international standards for proceeding to the sensory quality assessment stage.

In terms of bean size measured by the weight of a commercial cocoa bean both clones and hybrid families, although showing significant differences within each group had average values greater than or equal to the industry standard of 1 g per commercial cocoa bean. The three best performers were among the clones IFC16 (1.81 g), C123 (1.65 g) and C20 (1.41 g) and among the hybrid families. F6 Séch/Divo (1.81 g), F25 Sech/Divo (1.45 g) and F26 TO/Soubré (1.43 g). Indeed, it appears that the two clones IFC16 and C123 which rank highest in terms of marketable bean weight are of Trinitario origin, confirming the excellent performance of this genetic group in terms of bean technological quality. Since the weight of marketable cocoa beans is a heritable trait (Cilas et al., 1989). It would be advisable to search within these three families of hybrids for the best trees for this criterion and clone them

Table 6. Distinctive flavors detected in the liqueurs of 15 families of cocoa tree hybrids

Fam.	Essay	Lab code	Genealogy	Distinctive flavors
F2	Séch/Divo	103	UPA409 × IFC1	Normal
F2	E6/5 Divo	119	P7 × GU284-A	Floral/Woody
F3	E6/5 Divo	122	IMC57 × GU123- B	Fresh fruit/Florales
F3	Séch/Divo	99	UPA608 × IFC412	Woody
F4	Séch/Toumodi	65	UPA413 × IFC1	Normal
F4	E6/5 Divo	120	IMC57 × GU175-A	Fresh fruit floral
F6	Séch/Divo	91	UPA409 × POR	Woody
F6	TO Soubré	131	E6/1 L22 A11 × E6/4 L27A8	Normal
F9	Séch/Toumodi	64	PA150 × IFC5	Normal
F9	Séch/Divo	78	PA150 × IFC5	Normal
F10	E6/5 Divo	113	IFC303 × GU175-A	Floral/Woody
F11	TO Soubré	127	E6/1 L23 A17 × E6/4 L27 A8	Floral
F12	Séch/Divo	92	IMC67 × IFC1	Floral/Woody
F13	E6/5 Divo	115	E 41-12 × E42-17	Woody
F15	Séch/Divo	97	PA150 × POR	Normal
F17	Séch/Toumodi	72	SCA6 × LAF1	Normal
F17	Séch/Divo	85	SCA6 × LAF1	Normal
F22	Séch/Toumodi	66	P7 × GU284A	Normal
F22	Séch/Divo	79	P7 × GU284A	Normal
F22	TO Soubré	124	E6/1 L22 A18 × E6/4 L27 A8	Fresh fruits/Floral/Woody
F23	Séch/Divo	83	IFC303 × GU175-A	-
F25	Séch/Divo	90	P7 × IMC67	Woody
F25	Séch/Toumodi	75	P7 × IMC67	Floral
F26	TO Soubré	130	UPA 409 × POR	Floral
F27	TO Soubré	123	E5/1 L29 A2 at 6 × C2/1-1	Fresh fruits
F28	TO Soubré	126	E5/1 L71 A7 at 11 × E6/4 L27 A8	Floral/Woody
F41	TO Soubré	133	GU 139 A × E6/1 L11 A23	Normal

**Figure 3.** One of the sensory profiles of the clone C20.

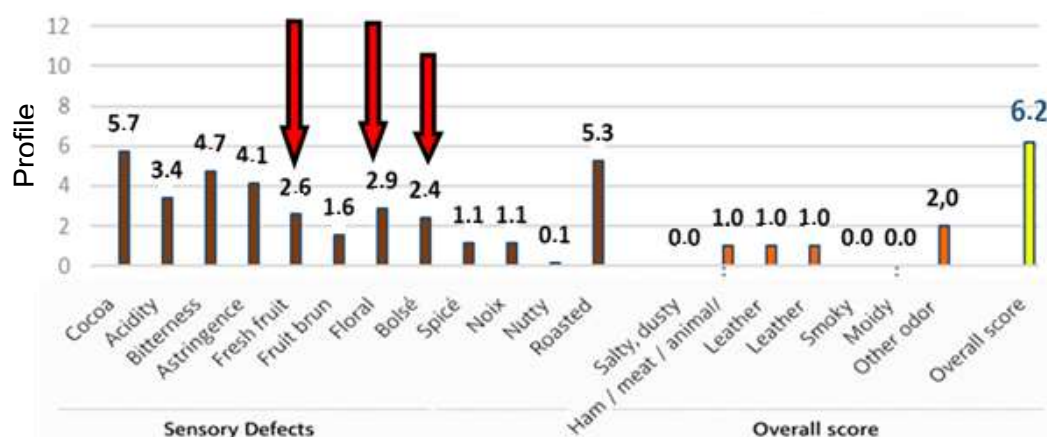


Figure 4. Sensory profile of hybrid F22.

for use as parents in the genetic improvement program. Furthermore, according to Turnbull and Eskes (2010), cocoa trees with an average marketable cocoa bean weight between 1.48 and 1.30 g can be considered to have good bean size. Based on this information, six clones (IFC16, C123, C20, IFC1027, C70 and IFC1026) out of the eleven and seven families (F6 Sech/Divo, F25 Sech/Divo, F26 TO/Soubré, F3 Sech/Divo, F4 Séch/Dimbokro, F12 Sech/Divo and F15 Sech/Divo) out of 27 are considered to have good grain size.

Homogeneity was not the same for all samples for both types of plant material tested as evidenced by scores ranging from 6 to 8 on a scale of 0 to 10. While some materials were characterized by a total absence of aroma others had at least one dominant aroma which was vinegar or cocoa. The clones IFC1027 and IFC1208 on the one hand and the hybrid families F3 Sech/Divo, F12 Sech/Divo, F3 E6/5, F13 E6/5, F6 TO/Soubré and F11 TO/Soubré on the other were characterized by the presence of both aromas.

In terms of technology, the most productive varieties in terms of the number of fresh beans per pod are at the clonal level, C20 (51 beans), IFC1208 (44 beans) and C71 (42.3 beans) and at the family level, F6 TO/Soubré (55.65 beans), F25 Sech/Divo (46.30 beans), F12 Sech/Divo (43.60 beans) and F3 E6/5 (43.60 beans). Referring to the technical manual on sustainable cocoa farming, recommending that the average number of beans per pod should be between 30 and 40, it is said that all 11 clones tested due to their number of fresh beans per pod ranging from 51 to 34.7 beans and therefore above 30 beans, can be considered well-filled.

As a result, clone C20, a cloned hybrid derived from the PA13 × IMC67 cross is characterized by excellent filling. In addition to having a grain size of 1.41 g well above the recommended standard of 1 g per marketable bean. The

same is true of the F26 TO/Soubré family, which also has a good bean weight (1.43 g) and a relatively low standard deviation of 0.09. According to Lanaud et al. (1987) the good filling of the pods of the C20 clone and those of F26 TO/Soubré is attributable to enough compatible pollen allowing for good pollination of their flowers.

At the family level, the study also showed that families F25 and F9 planted both in Divo, an area with normal rainfall and in Dimbokro, an area with below-average rainfall, did not perform equally well in terms of grain size and bean pod filling. The averages for both families for these two criteria were significantly higher in the area with normal rainfall in Divo than in the area with low rainfall in Dimbokro revealing the impact of climate on the two parameters measured. A similar result was highlighted by the study of Tahi et al. (2019) in Côte d'Ivoire.

Regarding the sensory quality of the plant material studied, the results of the analyses revealed samples with a high cocoa content for some and complementary attributes of floral and fresh fruit notes for others. The results highlighted specific flavors in seven of the eleven clones and in fifteen of the 27 hybrid families. Four flavors were detected in the clones and six in the hybrid families demonstrating the diversity of flavors among the clones and hybrid families studied.

A thorough examination of the genealogy of the plant material studied. Whether clonal or familial shows that certain clones or genetic groups, particularly the IMC clones (57.67) and most of the clones in the Trinitario group when used as parents in genetic combinations confer particular flavors on their offspring. At the clone level, it can be cited that; C70 a cloned hybrid resulting from the cross IFC720 × ICS46, involving two Trinitario parents, this clone is characterized by floral flavors; C173 a cloned hybrid resulting from the cross UP409 × POR with POR as the Trinitario, this clone is also characterized by

floral flavors.

The idea that the sensory characteristics of the pulp are highly dependent on the genotype (Eskes et al., 2018) was further supported by the results of sensory analysis at the hybrid family level. Indeed, it was observed that crosses involving one of the two clones IMC57 and IMC67 were characterized by specific flavors (families F3 E6/5, F4 E6/5, F25 Sech/Divo and F25 Sech/Dimbokro). These families were characterized by fresh fruit flavors/floral, woody or floral notes.

The majority of families where one of the progenitor parents involved an SCA6 or Trinitario offspring were also characterized by remarkable flavors: this is the case for families F6 Sech/Divo (woody notes) involving Trinitario POR as the progenitor; F10 E6/5 Divo (floral/woody notes) involving Trinitario IFC303 as the progenitor; F11 TO/Soubré (floral notes); F22 TO/Soubré (fresh fruit/floral/woody notes); and F28 TO/Soubré. All three having involved as the female progenitor an individual of the three-way hybrid (UF676 × IFC303) × IFC18, a combination of genotypes belonging to the Trinitario group. F27 TO/Soubré family (fresh fruits) involving as female parent, an individual from PA13 × IMC67 cross where the IMC67 clone appears.

The results presented reveal the existence within hybrid families with flavors of specific genotypes conferring to the entire offspring, its sensory quality. This therefore suggests searching within these families for genotypes carrying the desired sensory quality genes. To select such genotypes within families having presented the desired flavors the sensory quality evaluation will have to be done this time tree by tree. Once the trees with favorable characteristics for the pulp have been identified and they have interesting yield components. The next step is multiplication and/or improvement. First, the individually selected trees will be vegetatively multiplied to obtain clones for conservation purposes. Then, if the selected tree also has interesting yield components and is self-compatible. It could be used directly for commercial purposes. Selection should aim for high yield, resistance and flavor quality. An interesting option is the creation of hybrid varieties by crossing the best genotypes together in order to produce high-yielding disease-resistant varieties with particular flavors sought after by chocolatiers.

Conclusion

The results presented in this study have strengthened scientific knowledge on the plant material tested, information on the sensory qualities of the clones and hybrid families studied. The results obtained makes it possible to affirm that cocoa from Côte d'Ivoire. Once characterized by a high cocoa intensity, it is full of clones and hybrids with complex sensory characteristics. The

results of the study have proven that flavors are highly dependent on genotypes.

As part of its recurrent and reciprocal cocoa selection program started in 1990. The CNRA has developed numerous families of hybrids resulting from double crosses and three-way crosses involving numerous Trinitario parents IMC67 and IMC57 clones. The evaluation of sensory quality will now have to be focused on trees from these different families to select those with fine flavors.

Thus, clones that have presented flavors will have to be better valued by the creation of wood yards to reproduce them on a large scale to satisfy the needs of chocolate manufacturers for beans of high sensory quality.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Chen-Yen-Su A (2014). Analyse morphologique et profils aromatique sensoriel du cacao du Sambirano. Mémoire: Sciences et technologies. Université de la réunion. France 78p.
- Cilas C, Duchemin C, Lotodé R (1989). L'amélioration génétique de la qualité du cacao: Étude de la granulométrie. Café Cacao Thé (Paris) 33(1):3-8.
- Eskes AB (2021). Phenomenal cocoa and chocolate delicacies. The magic of reality. First Priority 186 p.
- Eskes A, Ahnert D, Garcia Carrion L, Seguire E, Assemat S, Guarda D, Garcia R (2012). Evidence on the effect of the cocoa pulp flavor environment during fermentation on the flavor profile of chocolates. 17th International Cocoa Research Conference (COPAL) Yaounde, Cameroon.
- Eskes AB, Rodriguez CA, Ahnert D, Condori D, Parizel A, De F, Durão P, Growers C, Peru I (2017). Advances on genetical and naturally induced variations for fine flavors and aromas in *Theobroma cacao*. International Symposium on Cocoa Research (ISCR) Lima, Peru pp. 13-17.
- Eskes A, Rodriguez CA, Cruz Condori D, Seguire E, Garcia Carrion L, Lachenaud P (2018). Large genetic diversity for fine-flavor traits unveiled in cacao (*Theobroma cacao* L.) with special attention to the native Chuncho Variety from Cusco, Peru. Agrotropica 30:157.
- Hegmann E. (2015). Qualitätsbedingende Eigenschaften neuer Kakao-Genotypen und deren Verhalten im Nachernteverfahren: eine Analyse neuer Kakao-Selektionen aus Costa Rica. Doctoral dissertation, Staats-und Universitätsbibliothek Hamburg Carl von Ossietzky.
- International Cocoa Organisation (ICCO) (2012). Table ronde sur une économie cacaoyère Accra 3-6 Octobre 2012. Le cacaoyer, édition Maisonneuve et Larose (Ed). 160p.
- International Cocoa Organization (ICCO) (2014). ICCO Quarterly Bulletin of Cocoa Statistics. Cocoa year 2015/16. XLII.
- International Cocoa Organization (ICCO) (2020). Quarterly bulletin of Cocoa statistics. Cocoa Year 2019/2020.
- Kadow D, Bohlmann J, Phillips W, Lieberei R (2013). Identification of main fine or flavor components in two genotypes of the cocoa tree (*Theobroma cacao* L.). Journal of Applied Botany and Food Quality 86:89-98.
- Kébé BI, N'guessan KF (2003). Rapport de la mission de prospection du swollen shoot. 11-13 septembre 2003. C.N.R.A – Divo pp. 7.

- Lanaud C, Sounigo O, Amefia YK, Paulin D, Lachenaud P, Clément D (1987). Nouvelles données sur le fonctionnement du système d'incompatibilité du cacaoyer et ses conséquences pour la sélection. *Café Cacao Thé* (Paris) 31(4)267-277.
- Tahi GM, Guiraud BS, Kassin, KE, Kouame B, Ehounou JN, Kouakou H (2019). Une approche intégrée pour améliorer l'efficacité et la résilience des cacaoyers au changement climatique pour une meilleure utilisation des ressources génétiques du cacao en Côte d'Ivoire: première phase. In *Rapport Technique de fin de projet Bioversity en Côte d'Ivoire* 34p.
- Turnbull CS, Eskes AB (2010). A Visual Aid to Identify Widely distributed Cocoa Accessions. Amsterdam, The Netherlands: CFC, UK: ICCO, Italy: Bioversity International P 43.