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Evaluation of Cocoa Full-Sib Progenies in Challenging Conditions in Cameroon

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The improved vegetal material cultivated by cocoa farmers in Cameroon consists in full-sib progenies issued from pods harvested in bi-clonal seed gardens set up during the 1970s. Interviews of cocoa farmers revealed their general satisfaction with the yield level obtained from these progenies but also their disappointment with the high level of susceptibility to black pod disease, a disease caused by *Phytophthora megakarya,* which is a serious challenge for cocoa production in this country. In order to select new future varieties that would combine high yield and resistance to black pod disease, new progeny trial plots were set up from 2005, in research stations and on farm.
23 cocoa full-sib progenies were assessed and compared to 3 control progenies. in a trial plot set up in 2005 in a research station located in the south western region of Cameroon. The cocoa trees were assessed during eight consecutive years of cocoa production. A large level of variation was observed among the progenies for mortality rate (ranging between 6 and 52%), annual potential

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yield (ranging between 151 and 1,808 kg/ha), annual actual yield (ranging between 114 and 1,159 kg/ha) and black pod disease incidence (ranging between 19 and 39,8%) caused by *Phytophthora megakarya*. Nine of the assessed full-sib progenies were identified as promising and the authors suggest how to confirm their performances before their release to farmers.

Keywords: Breeding; Theobroma cacao L.; Phytophthora megakarya; disease incidence; potential yield; actual yield.

1. INTRODUCTION

Cacao (Theobroma cacao L.) is a Malvacea [1] originating in South America (Motamayor et al 2002), cultivated for its beans. used for the confection of chocolate. The first indices of use of cocoa beans were discovered in Ecuador, dating back to 3.300 years A.C. [2].

The species was separated in three morpho-geographical groups: Criollo, Forastero and Trinitario, the last one being described as a hybrid group between Forastero and Criollo [3]. The Forastero group is separated in Upper amazon Forastero and Lower amazon Forastero, this last sub-group including the amelonado variety, largely used for cocoa cultivation in Africa. This classification of Criollo and Forastero groups was revised and refined by Motamayor et al [4], who proposed a structure consisting in ten genetic groups, from their molecular diversity results.

Today, Cameroon produces 290,000 tons of cocoa beans (exported after fermentation and drying processes), and is now the fourth highest producing country of the world), contributing to 6% of the worldwide production [5].

After a first program of variety creation based on the distribution of rooted cuttings from locally selected trees, which resulted in disappointing results, a new cocoa breeding program was initiated in Cameroon in 1959, based on the creation and selection of full-sib progenies, issued from 350 crosses between local cocoa trees and imported clones, issued from selection performed in Trinidad and from collecting expedition in Peru [6].

The parents of the 22 highest-yielding full-sib progenies were planted in bi-clonal seed-gardens between 1971 and 2002 in the southern, central and south western parts of the country [7].

A round of farmers' interviews performed in the late 1990s revealed that a major part of them were satisfied with the level of yield shown by the commercial varieties but, on the other hand. they tended to find them more susceptible to black pod disease, caused by *Phytophthora megakarya,* than the traditional amelonado variety, locally called "German cocoa" [8]. This finding showed the need for the future release of new cocoa varieties combining high yield and resistance to black pod disease.

In 2004, the second phase of an international project was initiated [9], aiming at creating new cocoa varieties adapted to farmers'needs in the African, American and Asian participating countries. In Cameroon, the main constraint is the high parasitic pressure caused by *Phytophthora megakarya*. In order to select progenies combining high level of yield and resistance to black pod disease, a progeny trial plot was set up in 2005 in the research station of Barombi-kang, in the south west region of Cameroon, a region with climatic conditions favoring the incidence of this disease. This trial plot was set up as part of a regional trial, aiming at comparing full-sib progenies from Cameroon, Ghana, Côte d'Ivoire and Nigeria and at selecting new cocoa progenies tolerant to black pod disease. This article presents the data obtained on survival, vigor, yield and yield components and incidence of *Phytophthora megakarya* on the 26 progenies under assessment, and proposes ways to valorize the most promising genotypes.

2. MATERIALS AND METHODS

2.1 Vegetal Material

The 26 assessed progenies, indicated in Table 1, were obtained as follows:

- 23 full-sib progenies were issued from hand-pollination performed:
    - in the IRAD research station of Nkolbisson, near Yaoundé, in the central part of the country, in the case of the local full-sib-progenies
    - in the research station of Divo of the CNRA (Centre National de Recherche Agronomique), in Côte d'Ivoire, in the

research station of Tafo of the CRIG (Cocoa Research Institute of Ghana) and in the research station of Ibadan of the CRIN (Cocoa Research Institute of Nigeria) in the case of the full-sib progenies introduced from other countries.

- The seeds from other countries were brought to Nkolbisson, by researchers from the previously mentioned research institutes.
- All the seedlings were raised in the nursery of the Nkolbisson research station, before their shipment to Barombi-kang, where they were planted upon arrival.
- 3 half-sib progenies were used as controls and consisted in:

Progeny 26: Mixture of four full-sib progenies, issued from pods harvested in four local bi-clonal seed-gardens. Thus, this control represents a subset of commercial varieties.
Progeny 9: Mixture of seedlings issued from pods harvested on a commercial plot set using commercial varieties. This type of vegetal material is often used by farmers who have no access to commercial varieties and will be referred in the paper as farmers' hybrid.
Progeny 10: Mixture of seedlings issued from pods harvested on farmers' plot planted with the traditional variety (German cocoa). This type of vegetal material is often used by farmers who have no access to commercial varieties.

The control half-sib progenies were raised in greenhouse in Barombi-kang.

In order to introduce resistance to black pod disease in the assessed progenies, the local SNK parents were selected because of their resistance to black pod disease, evidenced by results from leaf and pod inoculation tests [10].

2.2 Design of the Trial Plot

For each of the 26 progenies, five rows of ten seedlings were established in the plot, resulting in 50 trees per progeny.

2.3 Agronomical Management of the Trial Plot

A total number of 1,500 cocoa seedlings (1,300 under assessment and 200 edge cocoa trees) were established in absence of permanent shade in a 1.25 ha plot, set up in 2005 at a planting space of 3 x 3 meters. Corresponding to a 1,111 trees/ha planting density. The cocoa seedlings were intercropped with maize during the first two years after establishment of the cocoa seedlings.

The plot was regularly submitted to weeding (manual or chemical).

No fungicide was applied during the assessment period. During the first years, no insecticide was applied, but, due to the increasing severity of the damages caused by insects, insecticide treatments were applied from 2013.

2.4 Assessment Methodology

Every two weeks, healthy ripe pods as well as rotten pods (ripe and unripe) were harvested on each cocoa tree and counted, during eight consecutive years, during the period from 2008 to 2016. These harvested and counting rounds were used to estimate the yield of each cocoa tree and the incidence of pod rot, caused by *Phytophthora megakarya*. The traits assessed are described below:

2.4.1 Cumulated number of total pods

sum of all the pods (healthy, unripe rotten and ripe rotten) harvested during the period from 2008 to 2016 were summed up. This number was calculated for all the trees, including the ones which died before the end of the assessment period.

2.4.2 Cumulated number of healthy pods

sum of all the healthy pods harvested during the period from 2008 to 2016 were summed up. This number was calculated for all the trees, including the ones which died before the end of the assessment period.

2.4.3 Mean weight of cocoa per pod (g)

In 2012 and 2015, the weight of cocoa was estimated on 871 of the 1,300 trees. For this purpose, the beans extracted from the pods harvested on each one of the trees were placed in separated fermentation nets and submitted to a six days fermentation in a box. The samples of fermented cocoa beans were then dried and then weighted separately.

Table 1. Description of the 26 progenies assessed in trial plot

		Female parent				Male parent	
Progeny Id	**geographic origin**	**Name**	**Geographic origin**	**Morpho-geographic group**	**Name**	**Geographic origin**	**Morpho-geographic group**
1	Cameroon	T 60/887	Trinidad	UAF	SNK 413	Cameroon	TR
2	Cameroon	UPA 134	Cameroon	UAF	SNK 64	Cameroon	TR
3	Cameroon	PA 107	Peru	UAF	SNK 614	Cameroon	*UAF x TR*
4	Cameroon	PA 107	Peru	UAF	ICS 40	Trinidad	TR
5	Cameroon	*SNK 625*	*Cameroon*	*UAF x TR*	*SNK 620*	*Cameroon*	*TR x UAF*
6	Cameroon	SNK 614	*Cameroon*	*UAF x TR*	SCA 24	Peru	UAF
7	Cameroon	SNK 614	*Cameroon*	*UAF x TR*	PA 7	Peru	UAF
8	Cameroon	SNK 614	*Cameroon*	*UAF x TR*	SNK 608	Cameroon	TR
9	*Cameroon*	*farmers' trees*	*Cameroon*	*UAF x TR UAFx AMEL*	*open pollination*		
10	*Cameroon*	*farmers' trees*	*Cameroon*	*AMEL*	*open pollination*		
11	Cameroon	SNK 625	Cameroon	*UAF x TR*	NA 33	Peru	UAF
12	Côte d'Ivoire	*IFC 303*	Côte d'Ivoire		*PA 121*	Peru	UAF
13	Côte d'Ivoire	*PA 4*	Peru	UAF	**P 7**	Peru	UAF
14	Côte d'Ivoire	T 60/887	Trinidad	UAF	ICS 89	Côte d'Ivoire	TR
15	Côte d'Ivoire	SNK 12	Cameroon	TR	PA 150	Peru	UAF
16	Côte d'Ivoire	*PA 13*	Peru	UAF	*P 19*	Peru	UAF
17	Ghana	*T 60/78*	Trinidad	UAF	*T 85/87*	Trinidad	UAF
18	Ghana	T 63/967	Trinidad	UAF	*T 17/524*	Trinidad	UAF
19	Ghana	MAN 15/2	Brazil	AMEL	*T 85/799*	Trinidad	UAF
20	Ghana	GU 144/C	French Guiana	GU	NA 33	Peru	UAF
21	Ghana	*AI/154*	Ghana	UAF	*T 60/78*	Trinidad	UAF
22	Ghana	GU 144/C	French Guiana	GU	EQX 3338	Ecuador	
23	Nigeria	*T 85/799*	Trinidad	UAF	*PA 120*	Peru	UAF
24	Nigeria	*P 7 x PA 150*	Nigeria	UAF	IMC 47	Peru	UAF
25	Cameroon	*SNK 620*	*Cameroon*	*TR x UAF*	*PA 150*	*Peru*	*UAF*
26	*Cameroon*	*mixture*	*Peru and Cameroon*	*UAF, TR, AMEL*	*mixture*	*Peru and Cameroon*	*UAF, TR, AMEL*

UAF = upper amazon Forastero; TR = Trinitario; AMEL = Amelonado; GU = Guyanese.
The parents indicated in italics are not present in Cameroon

2.4.4 Potential yield per tree (g)

Cumulated number of total pods multiplied by the weight of cocoa per pod estimated on the tree (or by the mean value of the progeny when the data for the individual tree were not available)

2.4.5 Actual yield per tree (g)

Cumulated number of total pods multiplied by the weight of cocoa per pod estimated on the tree (or by the mean value of the progeny when the data for the individual tree were not available).

2.4.6 Estimated potential annual yield (kg/ha)

"Potential yield per tree" x 1,111/(8x1,000). 1,111 is the usually recommended planting density, 8 is the number of years of the assessment and 1,000 the conversion rate from gram to kilo.

2.4.7 Estimated actual annual yield (kg/ha)

"Actual yield per tree" x 1,111/(8x1,000). 1,111 is the usually recommended planting density, 8 is the number of years of the assessment and 1,000 the conversion rate from g to kg.

2.4.8 Mean weight of one fermented and dried bean (g)

From each sample of fermented and dried cocoa beans, a sub-sample of 100 beans was weighted, in order to estimate the mean weight of one bean (wb). This trait is important. Because some chocolate manufacturers are reluctant to process beans with a mean weight lower than one gram.

2.4.9 Mean number of beans per pod

For each tree, the number of beans per pod was estimated by the ratio between the weight of cocoa per pod and the mean weight of one bean.

Incidence of black pod disease, caused by *Phytophthora megakarya* is calculated by the ratio between rotten pods (ripe and unripe) and the total number of harvested pods.

2.4.9.1 Adult vigor

Trunk's girth of the adult cocoa trees measured at a 30 cm height in 2012.

2.4.9.2 % survival

Cumulated number of dead trees at the end of the 2008-16 period, divided by the number of initially planted trees

2.4.10 Statistical analyses

XLSTAT software was used for performing ANOVA and ranking of progenies using Tukey test for all the variables. Each row of 10 trees was used as a replication.

3. RESULTS AND DISCUSSION

The results from ANOVA show a highly significant effect of the progeny for all the traits under evaluation, as shown in Table 2, in which mean values and variation coefficient are presented for each trait.

The actual yield value (604 kg/ha) is rather low and similar to the one reported in traditional farmers plots in the central part of Cameroon by Jagoret et al. [11], but lower than the one observed on some of on farm progeny trial plots by Feumba de Tchoua et al. [12], in an area of Central Cameroon region with climatic conditions resulting in a low incidence of *Phytophthora megakarya*.

The low mean level of yield in the plot can be explained by the rather high % of mortality (27%) and of rotten pods (31,4%). A similar % of mortality was observed on some of the on-farm trial plots assessed by Feumba de Tchoua et al. [12] in the central region of Cameroon, and a slightly lower one was observed in commercial cocoa plots by Wibeaux et al. [13], in Côte d'Ivoire. Ofori et al. [14] observed % of mortality ranging between 6.7 and 50% in a clone trial set up in marginal conditions, in Ghana.

The high % of mortality observed in our case can be explained by the setting up of the plot in full sun conditions, in absence of insecticide treatments until 2013.

The large level of variation observed among the assessed progenies for their level of mortality shows that this trait is worthy to be taken into consideration, even if, in our case, the causes of mortality have not been investigated.

The evolution of mortality with time is shown for the 26 progenies in Fig. 1. Progenies 5,25 and 26 show a high mortality rate during the first years after planting and this rate only slightly increases during the following years. On the other hand, progenies 4, 14 and 22 show a low commercial progenies, similar to the one observed on the traditional variety, is surprising

Table 2. Data from the ANOVA performed on several traits (The values in italics are yield expressed in kilos of cocoa per hectare)

Variable	F	Significance	Mean value	CV (%)
Total number of harvested pods 2008-16	7.5	**	179	47
Number of healthy harvested pods 2008-16	6.7	**	124	51
% of rotten pods 2008-16	3.4	**	31,4	29
Potential yield (cocoa from total pods) 2008-16 (g/tree)	8.8	**	6,34 *(880 kg/ha)*	47
Actual yield (cocoa from healthy pods) 2008-16 (g/tree)	7.1	**	4,35 *(604 kg/ha)*	50
Trunk girth 2012 (cm)	15.5	**	38.8	17
% survival	4,1	**	73	28
Weight of cocoa per pod (g)	13.3	**	36.2	14
Weight of one dried bean (g)	3.4	**	1.18	11
Estimated number of beans per pod	9.5	**	30.7	9

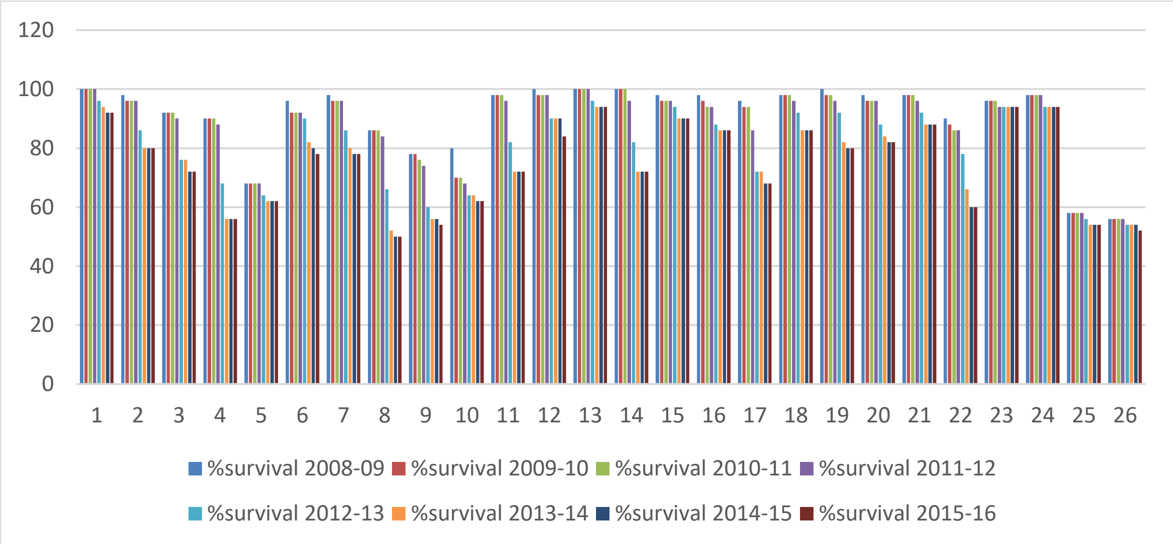

Fig. 1. evolution of survival rate of the 26 progenies

mortality rate during the first years but this rate increases later. The causes of the death of the trees were not investigated but these results show that the mortality rate at early stage is not always a good predictor of this trait during the following years.

The results observed for the components of potential yield (cumulated total number of pods, weight of dried cocoa per pod) are indicated in Table 3. These data allow to estimate the level of yield that could be expected in absence of the black pod disease.

The lowest yielding progeny (progeny10) is the “german cocoa” control, a traditional variety cultivated in Cameroon since the introduction of cocoa in this country. Its very low level of yield in this plot can be explained by its poor level of adaptation to full-sun conditions, evidenced by its low level of survival (58%) in our plot and already reported by Sounigo et al. [15] in on farm trials.

The second lowest yielding progeny (progeny 26) is another control, consisting in a mixture of commercial hybrids released to the farmers since the late 1970s. The yield value of progeny 9, the third control (farmers’ hybrids, progenies issued from pods harvested in a plot planted with commercial varieties) is much higher, although lower than the mean yield value of the plot.

The low level of yield observed on progenies 9 and 26 are partially explained by their low level of survival (54 and 48%). The very low level of potential yield observed on the mixture of and coincides neither with the general satisfactory level of yield reported in cocoa farmers' interviews [8] nor with the two-fold higher level of yield observed by Sounigo et al. [15] for this type of material in comparison with the traditional variety, in on farm progeny trials. The higher yield value of the farmers' hybrids than for the mixture of commercial varieties does not coincide with the comparable level observed by Sounigo et al. [15] for these two types of progenies.

The progenies 11, 14, 15,13, 18, 12, 2 and 1 present a level of potential yield significantly higher than the control progeny 9 (farmers' hybrids), which is the highest yielding among the three control progenies. Their level of potential yield ranges between 1,101 (progeny 1) and 1,808 (progeny 11) kg/ha.

The two progenies 11 and 14 are the highest yielding, despite a relatively low level of survival (70 and 68%) which can be considered as the result from a poor level of adaptation to full sun conditions. Progeny 20 produced a high number of pods (271), but these contain a low weight of cocoa (25 grams of dried cocoa per pod). Progeny 22 produced a rather large number of pods (202), but suffered a high mortality rate (44%).

The variation in stem girth values of the 8 highest yielding progenies suggests a certain level of variation for their optimal planting density.

The ranking of the progenies based on actual yield, indicated in Table 4, shows some differences with the one based on potential yield, because of differences of black pod incidence between progenies.

A lower incidence of *Phytophthora* is observed on the traditional control variety progeny (progeny 10) than on control progenies issued from commercial varieties (progenies 9 and 26), coinciding with the information reported by interviewed cocoa farmers [8].

The progenies with a level of actual yield, based on healthy pods, significantly higher than the highest yielding control progeny (progeny 9) are progenies 11, 14, 12, 2 and 21, with a level of yield ranging between 777 and 1,159 kg/ha. These values are in the range of the ones reported by Aikpokpodion et al. [5] in Nigeria (700 kg/ha) and Ofori and Padi [17] (1,200 kg/ha) in Ghana. On the other hand, these values are much lower than the ones reported by Lachenaud et al. [18] in French Guiana, Paulin et al. (1993) and Clément et al. [19] in Côte d'Ivoire, Dias et al. [20] in Brazil, and Tan and Tan [21] in Papua New Guinea. Indeed, the values reported by these authors for their best performing progenies range between 1,700 and 2,600 kg/ha.

The progenies 1,13, 15 y 18, despite their high potential yield level, are not included in this list, because of their relatively high level of black pod disease incidence, ranging between 34.5 and 39.1%. On the contrary, the progeny 21, which shows a potential yield not significantly different from progeny 9, is part of this list, thank to its low level of black pod disease incidence (19%). Progeny 11 combines high levels of both potential and actual yield despite its high level of black pod disease incidence (35.6%), while progenies 14,12 and 2 combine high levels of potential and actual yield levels with relatively low levels of black pod disease incidence, ranging between 23.6 and 27.7%.

A preliminary selection of the cocoa progenies in the nursery, using leaf inoculation [22], might have allowed to avoid the planting of the most susceptible progenies in the field.

A large level of variability is observed between the assessment years for pod production and rotten pod incidence as shown in Figs. 2, 3 and 4, confirming the necessity of assessing the progenies during several consecutive years.

One noticeable period is the campaign 2013-14, associated to a particularly high % of rotten pods and low numbers of healthy and total pods. This difference was caused by the absence of pruning, due to a shortage of human resources, resulting in a high level of self-shading, favoring the development of *Phytophthora megakarya* and reducing the development of flowers and fruits. It should be noted that the lowest % of rotten pods during this particular year is 58 %, observed on progeny 23, which shows a relatively high % of rotten pods (30.5) when estimated during the whole 2008-16 period. This result shows that even the progenies with the lowest incidence in this trial would probably not present any advantage in the case of overshaded and/or poorly managed plots in regions with high *Phytophthora megakarya* incidence. Consequently, all the progenies showed a low number of healthy pods during this particular period, with a maximum number of 9 observed for the progeny 12, which is one of the highest yielding progenies.

Table 3. mean value and ranking of the progenies for traits associated to potential yield, estimated from the total number of pods (healthy ripe + unripe rotten + ripe rotten) harvested on all the planted cocoa trees and for vigor, measured by trunk girth

Progeny Id	Cumulated potential yield 2008-16 (g/tree)	N.K (5%)	Estimated annual potential yield (kg/ha)	Cumulated total number of pods 2008-16	N.K (5%)	Mean weight of dried cocoa per pod (g)	N.K (5%)	% Survival 2008-2016	N.K (5%)	Mean trunk girth 2012	N.K (5%)
11	13,019	a	1,808	307	a	44	a	70	abcd	46.4	ab
14	8,952	ab	1,243	255	abc	37	abcdefg	68	abcd	44.2	abcd
15	8,822	ab	1,225	239	abc	38	abcdef	90	ab	42.2	bcde
13	8,463	bc	1,175	226	abcd	38	abcdef	94	a	50.5	a
18	8,432	bc	1,171	209	abcde	40	abcd	82	abcd	39.9	bcde
12	8,426	bc	1,170	278	ab	31	gh	82	abcd	37.4	cde
2	8,260	bc	1,147	239	abc	35	cdefg	80	abcd	40.8	bcde
1	7,926	bcd	1,101	214	abcde	38	abcdef	90	ab	38,0	cde
7	7,240	bcde	1,006	203	abcde	36	cdefg	78	abcd	41.7	bcde
20	7,202	bcde	1,000	271	ab	25	h	78	abcd	39.3	bcde
22	7,002	bcde	972	202	abcde	35	cdefg	56	abcd	37	de
21	6,863	bcde	953	159	bcdefg	43	a	88	abc	35	ef
3	6,694	bcdef	930	187	abcdef	36	cdefg	72	abcd	45.2	abc
24	6,405	bcdef	889	197	abcdef	34	defg	92	ab	44.6	abcd
17	6,050	bcdef	840	155	bcdefg	40	abcde	66	abcd	36.8	de
19	5,820	bcdef	808	165	bcdef	35	cdefg	80	abcd	37.9	cde
16	5,808	bcdef	807	174	abcdef	33	fg	86	abcd	39.1	bcde
4	5,772	bcdef	802	173	bcdef	34	efg	54	bcd	44.5	abcd
25	4,668	bcdefg	648	127	cdefg	37	bcdefg	54	bcd	37.8	cde
6	4,601	bcdefg	639	175	abcdef	26	h	78	abcd	28.3	fg
23	4,210	cdefg	585	122	cdefg	35	cdefg	94	a	35.2	ef
5	3,979	cdefg	553	96	defg	43	ab	62	abcd	35.9	ef
8	3,429	defg	476	85	efg	41	abc	50	cd	38.1	cde
9	3,381	efg	470	101	defg	35	cdefg	54	bcd	34.5	ef
26	2,210	fg	307	64	fg	35	cdefg	48	d	35.7	ef
10	1,087	g	151	32	g	39	abcdef	58	abcd	21.7	g

Table 4. Mean value and ranking of the progenies for incidence of *Phytophthora* and other traits associated to actual yield, estimated from the number of healthy pods

Progeny Id	Cumulated actual yield 2008-16 (g/tree)	N.K (5%)	Estimated annual actual yield (kg/ha)	Cumulated number of healthy pods 2008-16	N.K (5%)	% of rotten pods 2008-16	N.K (5%)	Mean weight of dried cocoa per pod (g)	N.K (5%)
11	8343	a	1,159	198	ab	35.6	ab	44	a
14	6746	ab	937	190	ab	24.4	ab	37	abcdefg
12	6398	abc	889	213	a	23.6	ab	31	gh
2	5931	abcd	824	172	abc	27.7	ab	35	cdefg
21	5593	abcde	777	130	abcde	19,0	b	43	a
20	5538	abcdef	769	209	a	23.2	ab	25	h
13	5507	abcdef	765	146	abcd	35.7	ab	38	abcdef
18	5497	abcdef	763	136	abcde	34.5	ab	40	abcd
15	5484	abcdef	762	148	abcd	39.1	a	38	abcdef
1	5029	abcdef	698	137	abcde	36.9	a	38	abcdef
3	5005	abcdef	695	140	abcde	27.8	ab	36	cdefg
24	4817	bcdefg	669	148	abcd	24.6	ab	34	defg
22	4584	bcdefg	637	133	abcde	34.8	ab	35	cdefg
7	4492	bcdefg	624	126	abcdef	39,0	a	36	cdefg
16	4141	bcdefgh	575	125	abcdef	29.3	ab	33	fg
19	4134	bcdefgh	574	116	abcdef	29.1	ab	35	cdefg
17	4114	bcdefgh	571	106	bcdef	32.2	ab	40	abcde
4	3480	bcdefgh	483	104	bcdef	39.3	a	34	efg
6	3340	bcdefgh	464	127	abcdef	27.3	ab	26	h
23	3006	cdefgh	418	86	cdef	30.5	ab	35	cdefg
25	2941	cdefgh	408	81	cdef	37.1	a	37	bcdefg
5	2470	defgh	343	59	def	38.4	a	43	ab
8	2311	efgh	321	58	def	32.8	ab	41	abc
9	2045	fgh	284	62	def	39.8	a	35	cdefg
26	1447	gh	201	43	ef	32.3	ab	35	cdefg
10	819	h	114	24	f	22.6	ab	39	abcdef

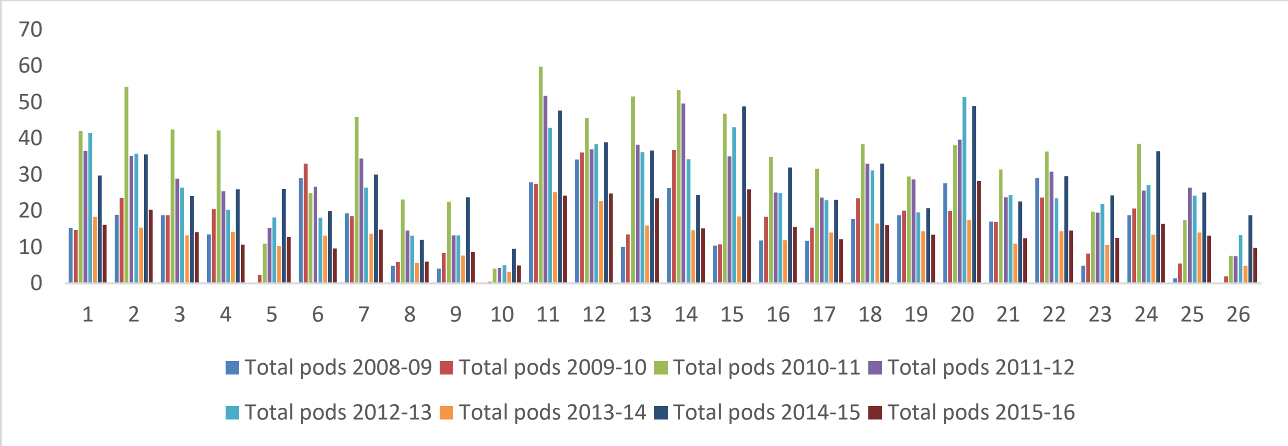

Fig. 2. Evolution of the total number of produced pods with time

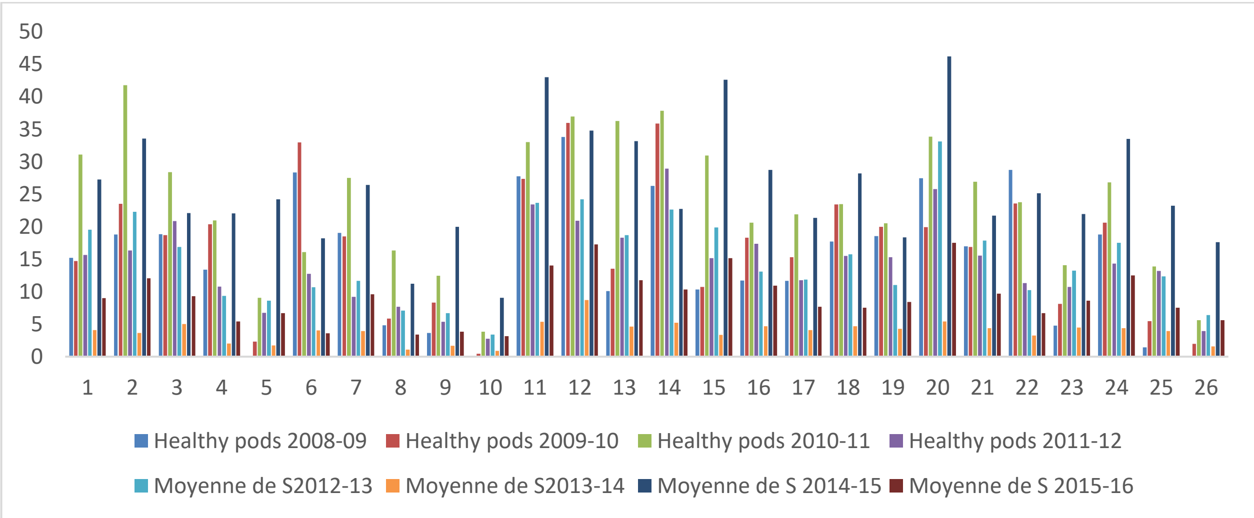

Fig. 3. Evolution of the number of produced healthy pods with time

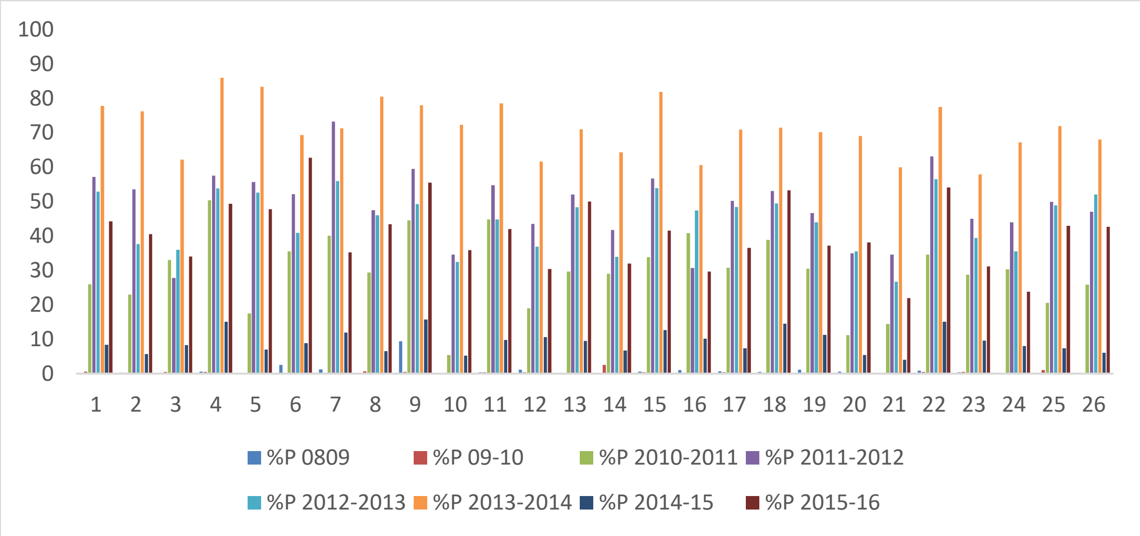

Fig. 4. Evolution of the incidence of rotten pods with time

Table 5. Cocoa bean and pod attributes (the values in bold are the ones observed for the highest yielding progenies)

Progeny Id	mean weight of dried cocoa per pod (g)	N.K (5%)	mean weight of 1 dried bean (g)	N.K (5%)	mean number of beans per pod	N.K (5%)
11	44	a	1.37	ab	31.9	abcde
21	43	a	1.32	abc	32.9	ab
5	43	ab	1.43	a	30	bcdef
8	41	abc	1.28	bcde	32.3	abcd
18	40	abcd	1.23	cdefg	32.6	abc
17	40	abcde	1.15	fghij	34.4	a
10	39	abcdef	1.16	fghij	33.3	ab
13	38	abcdef	1.20	defghi	31.7	abcde
15	38	abcdef	1.2	defghi	31	abcde
1	38	abcdef	1.22	cdefgh	31.3	abcde
14	37	abcdefg	1.3	bcd	28.6	cdef
25	37	bcdefg	1.17	efghij	31.1	abcde
3	36	cdefg	1.13	ghijk	31.7	abcde
7	36	cdefg	1.24	cdefg	28.5	defg
2	35	cdefg	1.20	cdefghi	29.4	bcdef
22	35	cdefg	1.11	hijkl	31.4	abcde
19	35	cdefg	1.06	jkl	33.4	ab
23	35	cdefg	1.14	ghijk	30.5	abcdef
9	35	cdefg	1.23	cdefg	28.6	cdef
26	35	cdefg	1.26	bcdef	27.9	efg
24	34	defg	1.02	kl	33	ab
4	34	efg	1.27	bcdef	26.6	fg
16	33	fg	1	l	33	ab
12	31	gh	1.09	ijkl	28.3	defg
6	26	h	0.83	m	31.5	abcde
20	25	h	1.01	kl	24.4	g

The weight of cocoa per pod is a combination of two traits: the mean weight of one bean and the number of beans per pod, and Table 5 shows the data for these attributes. The mean values of dried cocoa per pod range between 25 and 44, the first value being much lower than currently observed values which are usually around 40 g per pod. In addition to its contribution to yield, this trait is also an indicator of the amount of work dedicated to pod harvest and breakage for the obtaining of one kilo of commercial cocoa, and farmers obviously prefer cocoa trees producing pods with higher cocoa weight. The highest progenies (in bold in the table) show mean weight of cocoa per pod values between 31 (progeny 12) and 44 (progeny 11) grams, this last value being lower than the highest value observed by Feumba de Tchoua et al. [12] on commercial progenies in Cameroon (57,8 g), by Dias et al. [20], on progenies in Brazil (52g) and by Maharaj e al. [23] in Trinidad (80g).

The mean weight of one bean of dried cocoa observed for the highest-yielding progenies ranges between 1,1 (progeny 12) and 1,37 (progeny 11) grams, corresponding to suitable values for the trade of this product without any risk of rejection from the buyers. The latest value is still lower than the highest value observed by Maharaj et al. [23] in Trinidad (1,58g).

The mean numbers of beans per pod are rather low, ranging between 24.4 and 34.5 and are the main reason for the low mean cocoa weight per pod. 34.5 is much lower than the highest values observed by Ofori and Padi [17] in Ghana (42 beans) and by Maharaj et al. [23] in Trinidad (52.2 beans).

Our results allow us to select a list of 9 progenies to be confirmed in new trials before their possible release to cocoa farmers in Cameroon, Ghana and Côte d'Ivoire, according to the countries where the parents are present. These progenies are indicated in Table 6 and were selected in priority on the basis of their level of actual yield, when only the healthy pods are counted. On this basis, the following progenies were selected: 2,11,12,14 and 21. In addition, the progenies with high potential yield, counting both healthy and rotten pods, were also selected: 1,13,15 and 18.

Table 6 indicates as well the adequate environmental and cultivation conditions that should be applied to the confirmation trial plots and to the farms where they could be released. The progenies with a high level of mortality (>15%) are considered as poorly adapted to low shade conditions. Only the progenies with a low incidence of rotten pods (<30%) are considered as adapted to environments with high parasitic pressure caused by *Phytophthora megakarya.* The progenies with a low trunk girth (< 39 cm) could be assessed at high planting density while the ones with a high trunk girth (> 44 cm) could be assessed at a low planting density, in addition to their assessment under the average planting density recommended in the area where they will be assessed.

Table 6. promising progenies, that can be considered for future release to farmers after their assessment in confirmation trials

N°	cross	country for confirmation trials	adapted to low shade management	adapted to high incidence of black pod disease	expected optimal planting density
1	T 60/887 x SNK 413	Cameroon	Yes	no	average/high
2	UPA 134 x SNK 64	Cameroon	No	yes	average
11	SNK 625 x NA 33	Cameroon	No	no	average/low
12	IFC 303 x PA 121	Côte d'Ivoire	No	yes	average/high
13	PA 4 x P 7	Côte d'Ivoire	Yes	no	average/low
14	T 60/887 x ICS 89	Cameroon and Côte d'Ivoire	No	yes	average/low
15	SNK 12 x PA 150	Cameroon and Côte d'Ivoire	Yes	no	average
18	T 63/967 x T 17/524	Ghana	No	no	average
21	AI/154 x T 60/78	Ghana	Yes	yes	average/high

The assessment of the progenies introduced from other countries in our trial allows their evaluation under high black pod incidence conditions. It must be noted that some of our full-sib progenies created in Cameroon have also been introduced to Ghana, Ivory Coast and Ghana, where they can be assessed for their resistance to cocoa swollen shoot virus.

If the promising progenies can only be confirmed in the countries where the parents are present, on the other hand, the favorable alleles brought by the introduced progenies can be introduced to the local breeding program through to the selection of individual trees from these progenies and their use as parents in a next cycle of crosses.

4. CONCLUSION

The results from the progeny trial allowed us to identify nine promising full-sib progenies, among which five should be confirmed in Cameroon, four in Côte d'Ivoire and two in Ghana. Five of these progenies show a promising level of yield but a rather high incidence of black pod disease, in such a way they should be confirmed in areas with climatic conditions that hinder a high parasitic pressure from *Phytophthora megakarya.* The four other ones can be confirmed in areas with high parasitic pressure from *Phytophthora megakarya*, keeping in mind that their partial resistance risks to be overcome under unproper cultivation conditions such as excessive shading and/or absence of pruning of the cocoa trees.

In addition, the comparison between the results obtained from this trial plot with the ones from other progeny trials set up in other countries indicates that it should be possible to create and select higher yielding progenies than the nine ones we selected. The creation and selection of such progenies is underway in Cameroon and the other countries which took part to this trial, in the frame of their long term cocoa breeding programs.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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