Potential of recurrent selection for developing improved cocoa varieties in Ghana

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Abstract

In the major cacao producing countries, recurrent selection using clones available through the International Cocoa Quarantine Centre, Reading, UK, remains an important approach to identifying new clones with good combining abilities for desired traits. In 2010, 56 clones derived from within-family selections for productive trees in eleven progeny trials evaluated over different time periods were used to design a trial at Tafo, Ghana. The clones T60/887, T85/799, PA 7 and PA 150 were included as standards. A single-tree randomisation approach was used with 15 trees per clone in each of four replicates. Excluding pods damaged by *Phythophthora spp*., average bean yields of the four standard clones over a period of three years (34 to 69 months after transplanting) ranged from 0.34 to 0.54 t/ha/year whereas those of the six most productive new clones ranged from 0.7 to 1.0 t/ha/year. The pod index for the new clones ranged from 18 to 24, compared with 19 to 30 in the standard clones. Individual bean sizes were in the range of 1.23 to 1.39 g for the six new clones compared with a range of 1.21 to 1.32 for the standard clones. Expression of symptoms of CSSV disease among the selected clones following inoculation with severe CSSV strain 1A was comparable with those of the standard clones. Among seven of the clones tested for combining abilities with existing seed garden female clones, CRG 6035/103 and CRG 9006/106 showed good general combining abilities for juvenile tree vigour, precocity and bean yields, whereas CRG 3019/308 showed specific combining abilities with PA 121 and PA 150. Across farmers' plots in the Western Region of Ghana, seedling varieties developed using these new clones as males recorded higher seedling survival and better seedling vigour over those supplied from existing seed gardens. These results are evidence that further yield increments are attainable by selecting and crossing among cacao germplasm freely available in the international genebanks.

Introduction

In Ghana the development of high yielding cocoa varieties has relied on the exploitation of general combining ability (GCA) for yield and disease resistance (Adomako et al., 1999; Padi et al., 2012) in the limited number of clones made available from the international collections through the international cocoa quarantine centre, Reading UK. Recent parentage analyses of farmers trees has revealed that in addition to West African Amelonado, few clones in the Marañón, Nanay and Iquitos genetic groups are responsible for the increase in production (Padi et al., 2015) due to the better adaptation of their 'hybrids' to degrading soil and environmental conditions and better tolerance to the cocoa swollen shoot virus disease than the Amelonado seedlings that formed the basis of production. Expanding the genetic base for production beyond these group have been slow partly because the first selection of parental clones made for vigour and yield (Posnette, 1951) have been established in large hecterage in Seed Gardens that facilitate the supply of seed pods to farmers. Moreover, to take advantage of the existence of these Seed Gardens, the breeding approach have focused to a large extent on search of male clones with good specific combining ability (SCA) with these Seed Garden clones previously selected for good GCA.

The initial agronomic success from planting of the hybrids obtained from clones of this limited genetic base was such that further genetic improvement of the parental clones was not emphasized. In addition, because the use of clones for plantation establishment was considered incompatible with the pervasive peasant production practices at the start of formal research, clones were evaluated mainly for their per se value as a step to testing their combining abilities (Toxopeus, 1968; Bartley, 1970). The clones in use in the Seed Gardens are therefore

only a few generations of genetic recombination from the original trees in the Amazon forest. Recurrent selection was therefore advocated as an appropriate strategy to increase the frequency of desirable genes (for traits governed by GCA) in the clones used in production to ensure genetic progress (Clement et al., 1994). It has been noted that in recurrent selection schemes, the trade-off between genetic gain and genetic diversity usually favors narrowing diversity to make genetic progress (Rasmusson and Phillips, 1997). To achieve an appropriate balance between diversity and genetic gain, pedigree information and fingerprinting with molecular markers are adopted to broaden the genetic base of selected clones and to reduce the chances of mating closely related individuals (Pires et al., 1996; Lopes et al., 2011).

Current cocoa breeding strategies adopted in Ghana therefore has genetically enhanced clones as a key output through recurrent selection (Lockwood et al., 2007; Padi et al., 2013a). Thus, though the use of clones in commercial plantings have not been recommended, clone development in cocoa is important for two reasons. First, as stated earlier, clone selection is an essential step in genetic improvement of traits controlled by GCA through recurrent selection schemes. Second, a key constraint in cocoa cultivation in West Africa is aging plantations that have been long past the economic lifespan of 25-30 years (Asare, 2005). Rejuvenation of the aged farms using improved clones through canopy substitution has gained impetus in many cocoa producing communities in Ghana particularly in the last few years following demonstrations of the technique in farmers' aged cocoa plantations (F. Padi, unpublished). As selection theory emphasizes that the best clones are more frequently obtained in the best families (Simmonds 1996), success in large-scale clone development will therefore depend on effective identification and multiplication of individual trees within families exhibiting superior agronomic performance. Padi et al., 2013a argued that ortet selection for yield is more likely to lead to expected genetic gains if two conditions are met. First, the progenitor clones used to generate the families should have good phenotypic value for vigor and yield. Second, families selected should have high juvenile-stage vigor and high bean yields. The current analyses focuses on the performance of clones obtained from best yielding trees in superior families obtained from several trials, and provides their value as parents for seedling variety development.

Materials and Methods

Ortet selection and clone evaluation procedures

Ortets were selected from high yielding families in a total of 11 progeny trials established by the Cocoa Research Institute of Ghana. Five progeny trials established between 1982 to 1991 and reported in Adomako and Adu-Ampomah, 2005 and six progeny trials established between 1999 and 2002 under the Common Fund for Commodities project (Eskes, 2011) were analyzed in 2009 based on historical records. The number of families selected per trial varied from 2 to 4 based on those with yields above those of two standard varieties, T85/799 x P30 and T85/799 x T79/501, that were common to the trials. For each selected family, two trees were selected as ortets on the basis of visual inspection for number of pod-harvest scars, and absence of disease symptoms, including stem canker (caused by species of *Phytophthora*) and cocoa swollen shoot virus disease (CSSVD). Selected trees were budded onto five-month old seedlings of T85/799 x PA 7 in 2009. Clones were nursed for six to eight months before they were transplanted to the field in 2010.

A clone trial comprising 15 trees for each of 60 clones in each of 4 replications (60 trees per clone) was established in June 2010 at Tafo (latitude 6° 13' 55.2" N, longitude 0° 21' 36" W) in the Eastern Region of Ghana. Within each replicate, clones were planted in a single-tree randomization fashion. Trees were planted at a spacing of 2.5 m × 2.5 m (1,600 trees per hectare). To control boarder effects, the trial was surrounded by two rows of cocoa seedlings planted to the same density as used for the trial. Analyses of soil chemical properties indicated that the soil was adequately fertile to support growth of the crop before the bearing phase and fertilizers were not applied till 2012, when NPK (0:22:18) was applied at the rate of 350 kg/ha annually. Weeds were controlled manually using cutlass slashing. Black pod disease caused by *Phythophthora spp.* were controlled by recommended fungicides following a strict spraying regimen.

Recordings of stem diameter started in September 2010, at 15 cm above the graft union with the aid of electronic calipers. Subsequent recordings were made at six-monthly intervals. The stem diameter readings where converted into stem cross-sectional area. Pods produced were counted for each tree at harvest from 22 to 69 months after planting and bulked for each clone. Harvested pods were separated into healthy ripe pods, matured pods damaged by pod rot, immature-ripe pods, and pods damaged by rodents. The number of pods damaged by pod rot were grouped into useable blacks and discarded blacks. Dry bean yield from each clone was estimated from total useable pod production (the sum of healthy and useable black pods) divided by the pod value and expressed on per hectare basis. Yield efficiency was estimated as the cumulative yield (from 58 to 69 months after planting) divided by the increase in trunk cross-sectional area over the same period.

After analysing for the best clones for yield during 22 to 69 months after transplanting, 11 of the clones that combined high yields with good pod value and bean weight were selected for further tests on their reaction to the CSSVD. Five standard clones (T85/799, T60/887, T65/238, T65/326 and IMC 60) were included in these tests to obtain a total of 16 clones. Test clones were budded onto five month old seedlings of T85/799 x PA 7 to obtain 30 plants per clone. Each of the 30 plants per clone was tested for resistance to CSSVD as described in Padi et al., 2013b.

Test for combining abilities of selected clones, and yield assessment of hybrids

Seven of the 60 clones under evaluation were tested together with five international clones (as males) by crossing with five selected females to obtain 60 F_1 progenies. These were evaluated together with two standard varieties leading to 62 hybrids. Padi et al. 2016 reported detailed information on the mating design, trial establishment and data collection for this study. Essentially, data on survival, stem diameter increment, dry bean yield and black pod incidence was analyzed from the fourth to the seventh year after planting to obtain the combining abilities of the clones. The performance of specific crosses between selected new clones (as males) and seed garden females were further validated in four farmers' plots in the Western Region of Ghana.

Results

Yield records of only 55 of the 60 clones could be obtained because pods produced by four clones were too few to obtain pod values. Dry bean yields per year varied by several orders during the recording period (Table 1). Across the four yield-recording years, five clones including CRG 6035/103, CRG 9006/106, CRG 2029/508, CRG 8914/409 and CRG 6031/205 were among the those that ranked highly for yield. The production per unit of tree vigour (yield efficiency) in the fourth year of production ranged from 18.6 g/cm^2 in CRG 6035/103 to 1.9 g/cm^2 in IFC 5, moderately associated with the pattern for dry bean yields (coefficient of determination, R^2 = 0.48). Bean weight varied from 1.52 g in CRG 01/110 to 0.9 g in CRG 02/106 and CRG 4095/303. In comparison, the bean weights of the standard clones PA 7, T60/887, PA 150 and T85/799 were in the range of 1.06 to 1.27 g. The number of pods per kg of dry beans (pod value) ranged from 17 to 35, but with large standard errors between years reflected mainly in the effectiveness of control of mirids and stink bugs. The pedigree of the clones had significant influences on yield efficiency, as indicated in Figure 1a. When clone performances were compared based on six progenitors that contributed to the diversity within the base population for selection, P30 (West Africa Amelonado) had the lowest contribution to yield efficiency whereas clones with NA 79 in their pedigree had the highest yield efficiency. Regression of the yield efficiency of the selected clones over that of their progenitors indicated a good relationship with R^2 = 0.55, and the upper limit of heritability (2 × the slope) being 0.58 (Figure 1b).

The CSSVD symptom expression of 11 of the clones were compared to those of five standard clones known for their high levels of resistance to the disease under gauze-house conditions. All 16 clones showed susceptibility to mealybug feeding and subsequent development of symptoms typical of CSSV disease. Only six of the nine expected symptoms were observed among the test plants (Table 2). Five out of the 11 new clones, and two out of the five standard clones did not express tissue swellings. Based on the severity of symptom expression, CRG 2029/508, CRG 3019/308, CRG 6035/103, CRG 8214/109 and CRG 9006/106 were

considered as expressing high levels of resistance to the disease in relation to the standard clone. Interestingly, clone CRG 8914/409 that had the highest proportion of symptomless plants (47%) also had the highest proportion of plants with swellings (20%).

The combining ability of the clones were tested using a North Carolina II mating design in which the eight of the locally developed clones in addition to four international clones were used as males in generating F_1 progeny with five Seed Garden female clones. Desirable clone performance for combining ability was based on those that show positive GCA estimates for seedling survival, juvenile-stage increase in trunk cross-sectional area, dry bean yield and yield efficiency, and negative estimates for reproductive-stage increase in trunk cross-sectional area (from third year onwards). On the basis of this criteria, CRG 9006/106, CRG 6035/103, CRG 1018/102 and CRG 3019/308 were selected as clones with potential as parents for the Seed Gardens (Table 3). Only MAN 15-2 among the international clones had a performance comparable to these four locally selected clones. The average dry bean yield for all 62 tested progenies was 0.79 t/ha/year with narrow sense heritability estimate of $h^2 = 0.38$ whereas black pod incidence averaged 13.9% with heritability of 0.11 (Table 4). Compared with the three standard varieties (PA 7 x PA 150, PA 150 x Pound 7 and T85/799 x P 30), progenies involving the Seed Garden female clones with CRG 9006/106, CRG 6035/103 and CRG 3019/308 produced high bean yields.

In the on-farm tests on the performance of specific varieties developed using the locally developed clones, the specific varieties were generally of higher plant survival and were of higher vigour than the mixed hybrid variety from the Seed Gardens used as the standard variety (Table 5).

Discussion

The biclonal seedling varieties made available through the Seed Gardens in Ghana have been developed through the selection of parental clones for good GCA (Posnette, 1951). As the genetic gain realised by sexual progeny of selected parents results almost entirely from the additive component of genetic variation, recurrent selection based on these primary clones are expected to be high. In the current study, gains from selection of ortets from high yielding seedling families is shown by the higher dry bean yields (with better bean size and pod values) over those of the progenitor clones used in developing the seedlings families. Clones including CRG 6035/103, CRG 9006/106, CRG 2029/508 and CRG 8914/409 in addition to higher yields expressed similar (or better) levels of resistance to CSSV disease compared with clones previously considered to show the highest levels of resistance to the disease (Posnette and Todd, 1951; Bigger, 1975). Though for each clone only the average performance of one of the two progenitors were considered, disaggregating the performance of the clones by pedigree suggested an important influence of the progenitor clones on the performance of clones descended from them. Variation in the breeding value of progenitor clones obtained in earlier studies (Adomako et al. 1999) appears to be related to the average yield efficiency of their descendant clones in the current analyses. Padi et al., 2013a noted that the GCA of progenitors for both increase in TCSA and yield was more predictive of yield of clones derived from ortets than the yield of the families from which ortets were selected. The recorded pedigrees provide evidence that very few clones contributed largely to the genetic diversity in the seedling families of the base population. These were dominated by P30 (Amelonado), PA 7, PA 150, NA 79, T60/887 (NA 32 x PA 7) and T85/799 (IMC 60 x NA 34). As this approach of selecting from families arising from a few clones can lead to further narrowing of the genetic base in elite clones, the use of pedigree information is important to guide choice of parent pairs in crossings to generate subsequent seedlings families so as to broaden the genetic base. Though some 1000 clones from 8 genetic groups have been assembled in Ghana, the production base in the country has been based on clones from few clones in four genetic groups only (Padi et al., 2015). This suggests a scope for broadening the genetic base for production with the available diversity. This is particularly important as further genetic advance in subsequent cycles of selection is dependent on the available diversity.

As seedling, rather than clonal material, is mainly used for plantation establishment in Ghana, the value of the clones developed is judged primarily by its contribution to high yields in seedling families. In the current analyses, the dry bean yields obtained from progenies obtained from crossings between selected clones and existing Seed Garden female clones were higher than the standard variety (T85/799 x P30) and comparable to the two highest yielding progenies from the CFC-era implemented trials (Eskes, 2011; Padi et al., 2012). This attests to the value of the recently developed clones in improving yields when adopted in the Seed Gardens. Padi et al. 2016 established selection criteria for parental clones for the Seed Gardens as those exhibiting positive GCA estimates for survival after the first post-rainy season after planting, increase in trunk cross-sectional area (TCSA) during the first 24 months, and for precocity but negative GCA for TCSA during the bearing phase as this leads to both high yield and yield efficiency in the progenies. Two clones that showed these attributes of GCA (CRG 6035/103 and CRG 9006/106) generated progenies that were in particular better adapted (than the standard varieties) to farmers' growing conditions in the Western Region of Ghana where the bulk of Ghana's cocoa is obtained. That in all farmers' plots the standard variety was the least performing for plant survival to moisture stress and growth rate attests to the value of the new varieties.

The focus of the present analyses is to demonstrate that ortet selection from progenies of primary clones introduced at the start of formal research in West Africa by Posnette (1943) compiled in Lockwood and Gyamfi (1979) hold potential in developing seedling progenies with better adaptation and yield than existing varieties. The current results, though limited by the number of clones that constituted the base population, provides impetus for undertaking recurrent selection from a broader genetic base provided by clones currently available in the germplasm collection in Ghana.

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Table 1. Dry bean yield and yield components of sixty clones evaluated over a six year period in Ghana

Clone	Yield (kg/ha; 58 - 69 MAT)1	Yield (kg/ha; 46 - 57 MAT)	Yield (kg/ha/year; 22 - 45 MAT)	Yield efficiency (g/cm2)	Bean weight (g)	Pod value
CRG 6035/103	1089	989	614	18.6	1.11	25
CRG 2029/508	778	868	554	15.4	1.08	25
CRG 9006/106	717	1066	571	17.3	1.22	22
MO 20	713	368	178	6.2	1.19	26
CRG 8914/409	694	898	381	17.3	1.2	20
CRG 3015/210	674	671	320	10.6	1.28	23
CRG 6031/205	625	818	476	17.9	1.15	23
OPUAT 2	584	675	376	12.7	1.10	23
CRG 2021/202	556	575	380	11.4	0.94	33
CRG 9005/107	548	843	380	16.8	1.24	23
CRG 04/407	521	646	478	11.7	1.09	31
PA 7	495	334	238	6.0	1.06	33
CRG 9004/GH4	472	627	392	14.5	1.06	28
CRG 1019/109	467	527	226	9.2	1.22	21
CRG 4095/303	453	623	458	10.9	0.90	33
CRG 881	447	451	233	8.3	1.11	22
CRG 01/110	446	616	294	10.9	1.52	18
CRG 2018/103	442	467	247	8.7	1.16	23
CRG 9108/401	433	758	269	12.1	1.37	18
CRG 8220/319	430	530	400	11.4	0.98	32
CRG 2001/105	427	500	267	11.0	1.50	23
CRG 2022/104	421	486	272	7.5	1.12	26
CRG 3005/105	416	725	406	11.7	1.19	25
NA 79	405	392	237	8.3	1.20	25
T60/887	399	590	454	10.8	1.12	29
CRG 8214/319	389	450	200	8.2	1.27	20
CRG 9109/304	386	463	219	10.2	1.23	23
CRG 1401/107	375	457	250	7.6	1.26	24
MAN 15-2	351	318	174	4.5	1.15	22
CRG 2016/105	350	672	280	10.9	1.51	17
CRG 8510/303	326	630	275	11.6	1.26	20
PA 150	315	347	188	7.3	1.27	27
A1/154	298	304	125	5.6	1.13	21
CRG 6023/105	283	423	247	11.0	1.31	26
CRG 8305/425	273	702	400	13.4	1.1	23
T85/799	261	457	245	7.1	1.26	21
CRG 8508/204	259	403	193	10.3	1.07	23
CRG 1016/110	258	427	226	6.6	1.17	24

CRG 6020/109	255	481	581	8.5	0.93	28
CRG 8303/404	255	312	193	4.4	1.04	29
CRG 3019/308	245	618	398	14.2	1.14	27
OPUAT 1	242	314	160	4.6	1.05	25
CRG 02/106	241	307	218	4.9	0.90	33
CRG 8212/511	234	795	419	14.7	1.14	25
CRG 882/313	232	384	173	5.0	1.28	21
EET 59H	215	164	191	2.5	1.09	28
CRG 9001/107	207	445	301	9.1	1.21	25
CRG 1009/508	189	275	140	4.2	1.41	19
CRG 2024/101	180	301	148	5.3	1.31	20
CRG 8316/409	161	125	119	2.2	1.04	31
P 30	139	126	159	2.2	1.02	30
CRG 1017/209	124	402	233	5.2	1.06	31
CRG 1025/107	93	312	219	5.4	1.24	35
IFC 5	83	141	174	1.9	0.95	30
CRG 1018/102	53	397	217	6.9	1.13	24
SED $_{df = 162}$	147.4	134.7	83.3	1.76	0.07	1.3

[1]MAT is months after transplanting

Table 2. Percentage (± standard error of the mean) of plants in various severity ratings of CSVD for 16 clones after five months of inoculation with the CSSV 1A strain in a gauzehouse facility

	Cocoa Swollen Shoot Virus Disease severity rating [1]					
Clone	healthy	RVB	CVF	CVC	GVB	Swellings
CRG 01/110	13 ±2.3	13 ±1.7	53 ±2.9	0	7 ±1.2	13 ±3.9
CRG 2022/104	7 ±0.8	14 ±3.2	65 ±4.0	7 ±2.5	0	7 ±1.1
CRG 2029/58	13 ±0.9	7 ±0.5	80 ±1.1	0	0	0
CRG 3015/210	6 ±1.2	0	88 ±1.6	0	0	6 ±1.0
CRG 3019/308	13 ±3.8	0	87 ±4.0	0	0	0
CRG 6035/103	36 ±3.5	7 ±0.6	57 ±5.8	0	0	0
CRG 8214/319	20 ±1.5	27 ±2.9	53 ±1.7	0	0	0
CRG 8305/425	27 ±2.2	0	67 ±3.9	0	0	7 ±0.9
CRG 8914/409	47 ±4.0	0	33 ±3.5	0	0	20 ±1.7
CRG 9006/106	20 ±2.8	7 ±0.0	73 ±2.9	0	0	0
CRG 9109/304	27 ±3.5	0	67 ±2.3	0	0	7 ±1.2
IMC 60	7 ±0.0	0	79 ±1.6	0	7 ±0.4	7 ±0.5
T60/887	7 ±0.5	0	93 ±1.6	0	0	0
T65/238	0	0	90 ±5.7	0	0	10 ±2.2
T65/326	0	10 ±2.1	70 ±1.5	0	10 ±2.0	10 ±1.5
T85/799	13 ±2.4	0	87 ±4.5	0	0	0

Table 3. GCA and maternal and paternal per se performance for vegetative and reproductive traits for five female and 12 male cacao clones evaluated at two locations in Ghana

	Survival		TCSAj† (cm^2/year)		TCSAr§ (cm^2/year)		Average yield (t/ha/year)		Yield efficiency (g/cm^2/year)	
Parents	GCA	Per se	GCA	Per se	GCA	Per se	GCA	Per se	GCA	Per se
Maternal										
CRG 03	-16.61	43	-1.13	15.08	-1.79	44.68	-0.10	0.64	-3.19	19.06
PA 121	-15.50	57	-2.22	13.87	-7.48	38.47	-0.21	0.52	-3.71	18.49
PA 150	2.13	56	0.18	15.15	-0.18	42.57	0.11	0.79	4.35	25.02
PA 7	20.33	60	2.07	17.02	4.64	47.39	0.08	0.77	0.85	21.51
T60/887	9.64	54	1.10	16.01	4.81	47.56	0.13	0.82	1.71	22.38
SE¶	1.30	2.7	0.41	0.58	0.59	0.84	0.02	0.02	0.52	0.74
Paternal										
CRG 1018	13.92	54	0.18	15.20	0.50	43.25	0.12	0.80	3.71	24.38
CRG 1019	-2.08	58	0.01	14.92	6.82	49.57	0.04	0.72	-2.22	18.45
CRG 2024	-10.08	42	1.94	16.91	5.96	48.71	-0.01	0.67	-2.45	18.22
CRG 3019	3.92	53	-0.23	14.73	-0.01	42.74	0.10	0.79	3.76	24.43
CRG 6035	6.58	57	1.28	16.26	-3.07	39.67	0.11	0.80	6.21	26.88
CRG 8220	-7.42	53	-3.01	14.89	-7.22	44.41	-0.15	0.67	-4.83	19.80
CRG 9001	-7.42	55	-0.31	14.59	-1.15	41.60	-0.18	0.51	-4.62	16.05
CRG 9006	11.25	62	0.16	15.05	-3.11	39.64	0.03	0.71	3.35	24.01
EET 59H	1.58	53	0.09	15.07	3.12	45.87	0.02	0.70	-0.97	19.70
IFC 5	0.25	52	-0.11	14.87	4.34	47.09	-0.04	0.65	-2.74	17.93
MAN 15-2	0.25	61	3.04	18.04	-1.04	41.71	0.09	0.77	5.43	26.09
MO 20	-10.75	50	-3.03	14.87	-5.15	47.00	-0.10	0.73	-4.64	20.04
SE¶	2.01	2.8	0.29	0.89	0.91	1.30	0.03	0.04	0.81	1.15

† TCSAj is the increase in trunk cross-sectional area from date of planting to first pod production

§ TCSAr is the increase in trunk cross-sectional area during pod production years

¶Standard error for comparison of performance for GCA effects, standard error of difference for the variables

Table 4. Average dry bean yields and black pod incidence for cocoa progenies from the fouth to the 7th year after transplanting (62 varieties used)

Progeny	Yield (t/ha/year)	Black pod (%)
PA 150 × CRG 3019/308	1.35 ±0.23	9.4 ±1.5
T60/887 × CRG 6035/103	1.34 ±0.22	23.3 ±4.6
PA 7 × PA 150	1.27 ±0.22	17.3 ±3.4
PA 7 × CRG 6035/103	1.24 ±0.18	15.0 ±5.0
CRG 03 × CRG 9006/106	1.19 ±0.21	14.2 ±1.1
PA 150 × CRG 9006/106	1.16 ±0.18	12.9 ±4.2
PA 150 × POUND 7	1.07 ±0.24	16.9 ±6.2
T60/887 × CRG 9006/106	1.00 ±0.16	10.2 ±3.6
PA 150 × CRG 6035/103	0.99 ±0.14	10.7 ±2.4
CRG 03 × CRG 6035/103	0.99 ±0.16	18.1 ±3.2
PA 121 × CRG 9006/106	0.95 ±0.13	24.0 ±2.1
PA 7 × CRG 9006/106	0.85 ±0.16	11.8 ±5.1
PA 121 × CRG 6035/103	0.76 ±0.09	8.7 ±0.9
T85/799 × P30	0.74 ±0.14	9.7 ±3.8
SED $_{df = 721}$	0.12	5.4
Average of 62 tested progenies	0.79	13.9
h^2	0.38 ±0.01	0.11 ±0.27

Table 5. Increase in stem diameter and survival of 13 cocoa varieties evaluated across five farmers' plots in the Western region of Ghana over a period of two years

Clone	Osumanukrom		Punikrom		Homegyebre		Appeakrom	
	Survival (%)	**SD (mm)**	**Survival (%)**	**SD (mm)**	**Survival (%)**	**SD (mm)**	**Survival (%)**	**SD (mm)**
AMAZ 15-15 × CRG 9006	93 ±0.8	14.5 ±0.47	91 ±1.2	22.5 ±0.77	-	-		
PA 7 × CRG 6035	89 ±1.2	15.6 ±0.54	76 ±2.7	21.6±0.86	-	-		
Standard Variety	87 ±1.0	12.2 ±0.44	68 ±3.4	18.2 ±0.87	69 ±2.7	14.8 ±0.65	75 ±3.7	19.2 ±1.06
T63/971 × SCA 9	92 ±1.0	14.6 ±0.37	84 ±1.6	22.9 ±0.84	89 ± 3.8	20.7 ±0.61	90 ±1.7	26.2 ±0.88
T79/501 × CRG 6035	97 ±0.4	16.9 ±0.65			-	-		
T85/799 × PA 7	91 ±0.5	14.2 ±0.50			87 ± 4.8	20.5 ±0.55	94 ±1.0	27.3 ±0.92
PA 150 × CRG 3019	77 ±2.2	13.7 ±0.60			-	-		
T60/887 × MAN 15-2	-	-	93 ±1.5	24.0 ±0.77	90 ±2.9	18.4 ±0.60	91 ±2.4	22.4 ±0.95
PA 150 × CRG 9006	-	-			93 ±2.9	19.7 ±0.62	91 ±1.0	22.4 ±0.89
PA 7 × Man 15-2	-	-			74 ±3.1	16.0 ±0.62	91 ±1.8	23.4 ±0.87
T79/501 × CRG 9006	-	-			78 ±2.0	19.1 ±0.65	91 ±0.7	18.1 ±0.96
T60/887 × CRG 0314			85 ±1.8	21.7 ±0.79				
PA 7 × CRG 6020			79 ±2.6	21.9 ±0.85				

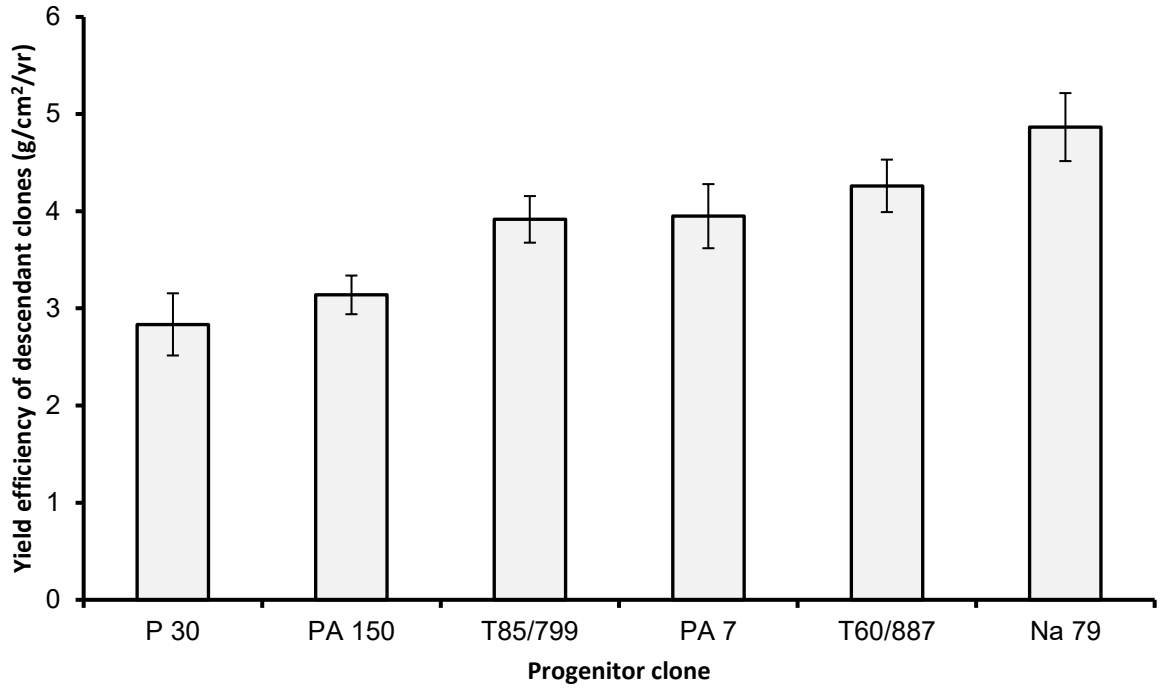

Figure 1a The contribution of six progenitor clones to yield efficiency in their descendant clones

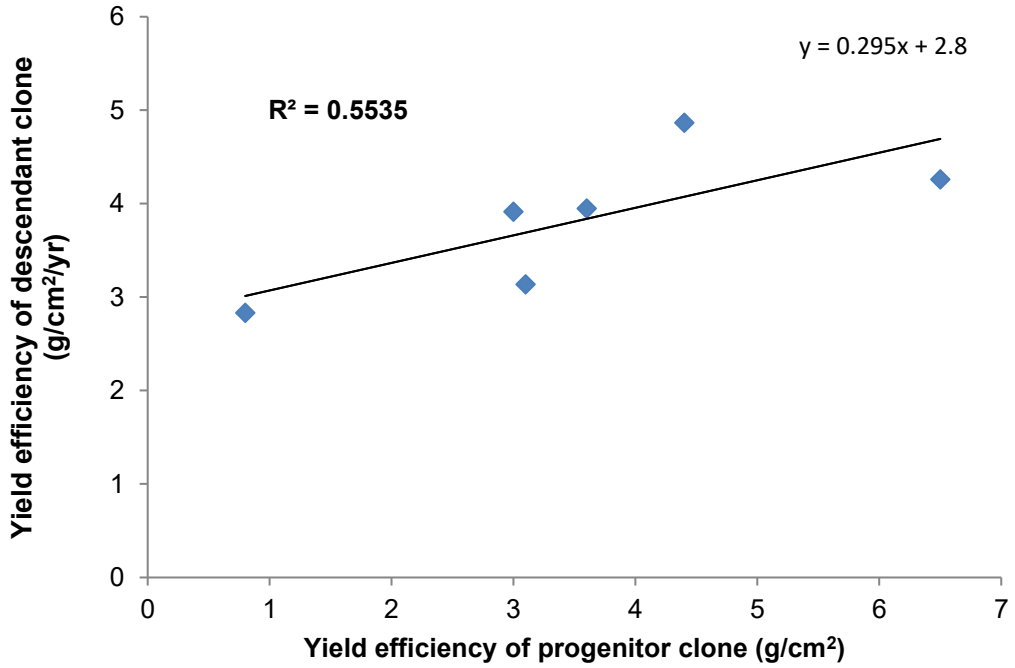

Figure 1b. Regression of the yield efficiency in descendant clones over that in their progenitor clones following field evaluations over a period of 69 months