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ROOTSTOCK EFFECTS ON COCOA IN SABAH, MALAYSIA

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SUMMARY

Twelve seedling cocoa families were evaluated as rootstocks in Sabah, Malaysia using three commercial cocoa clones as scions. The average yield was about 3 t dry cocoa beans ha^{-1}. Yields on pure Scavina rootstock were about 10 % above average and those on pure West African Amelonado about 10 % below average. However, the effects of rootstock on yield were correlated with those on vigour and there was no effect on the ratio of yield to continuing vegetative growth. Rootstock did not influence bean weight or number of beans per pod or the uniformity of the trees. There was no indication of an interaction between rootstock and scion for any of the traits that were studied. The rootstock effect is considered large enough to warrant its control in critical work, especially field experiments with budded cocoa, but development of high performance scions is a higher priority in cocoa than intensive work with rootstocks.

INTRODUCTION

In a wide range of vegetatively propagated horticultural crops, rootstock choice influences traits such as vigour of scion, precocity, yield, the ratio of yield to vegetative growth (‘yield efficiency’, Daymond *et al*., 2002) and quality of economic product. The rootstock may also confer resistance to pests or diseases to the scion: for example the Malling Merton range of apple rootstocks incorporating resistance to woolly aphids (*Eriosoma lanigerum*) derived from the cultivar ‘Northern Spy’, or citrus rootstocks conferring tolerance of infection with tristeza virus. In apple, the rootstocks themselves are propagated vegetatively, while in citrus, the seed are produced by nucellar embryony and so are true to type, but in crops like rubber open-pollinated seedlings of selected clones are used.

In cocoa, seeds from clones resistant to root infection with *Ceratocystis fimbriata* are used as rootstocks for susceptible clones in Central America and the Caribbean. Seedling rootstocks are also in common use for the budded cocoa that is the preferred planting material in the plantation and smallholder cocoa sectors in Southeast Asia. The standard rootstock used in nurseries at Golden Hope Research Centre, Sabah (formerly Scientific Department, BAL Plantations Sdn Bhd), Malaysia was seed of the cross UIT1 × NA33, whereas most cocoa small holders and commercial cocoa nursery operators normally grow rootstocks from the larger seeds obtained from commercial cocoa fields. Large beans were adopted following reports that they produced vigorous seedlings that could be budded earlier (Shepherd *et al*., 1981).

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Cocoa rootstocks have received rather little research attention around the world. As West African cocoa, which represents 70 % of world production, is almost exclusively seedling cocoa, there was no interest among growers. Where clonal cocoa was developed in the early days of cocoa research, especially in the Caribbean, there was a preference for rooted cuttings, so the question of rootstocks did not arise in the era before composite plants.

Van der Knaap (1953), working in Indonesia, concluded that the effect of rootstock is small. Interest was further discouraged when Murray and Cope (1959), working in Trinidad with four clones grafted onto each other as rootstocks stated that 'the practical conclusion can be drawn that the yield of a high yielding clone cannot be increased by growing it on a stock which is itself no higher yielding than the first clone'. They added that the possibility of a dwarfing stock was precluded because ICS45, the clone with the most dwarfing effect, gave poor yields even with a potentially high yielding scion. Yields on a mutant dwarf were said to be extremely poor. High yields were associated with vigorous plants.

Interest in rootstocks was reawakened in Malaysia when experienced rubber researchers began to develop budded cocoa, especially at Golden Hope Plantations Bhd. A nursery experiment was laid down in Peninsular Malaysia, followed by a field experiment with four PBC clones (Chong and Shepherd, 1986) budded onto open-pollinated seedlings of PBC122, PBC130, ICS60 and UIT1 (for details of the clones see Turnbull *et al.*, 2002). The yields showed no evidence of a major effect of rootstock or interaction with scion in this trial. A second field trial was planted in Sabah, with three clones that were popular in Sabah budded onto UIT1 × NA33 from a seed garden, UIT1 × NA33 manually pollinated, polycross seeds from a planting of PBC clones and large beans taken from commercial cocoa. Again there was no evidence of a major effect of rootstock or of interaction with the scion on yield.

The possibility of rootstock effects of cocoa was investigated further for four reasons:

1) the need to identify the best choice of rootstock for clone trials and commercial plantings;
2) the opportunity to sell seeds of any superior rootstock;
3) earlier trials were limited to a genetically narrow range of rootstocks. It was thought possible that investigation of a wider genetic base might lead to different conclusions;
4) to provide a platform for further research if economically useful effects were revealed.

In cocoa, precocity, flavour and bean weight are under strong genetic control, and clones are not adopted commercially unless they are satisfactory. There is no known economically important root disease of cocoa in Sabah, so attention focused on yield. Given the well-established relationship between vigour and yield in cocoa, the desired rootstock influence is a positive change in 'yield efficiency'. A gain in tree-to-tree uniformity would be helpful.

This paper discusses the yields, vegetative growth and yield components of a large scale field trial of three commercial cocoa clones grown on twelve rootstocks of diverse genetic origin.

MATERIALS AND METHODS

There was little prior experience to guide choice of seedling rootstocks for evaluation. A limitation was that any successful progeny would need to be reproducible in bulk, so emphasis was placed on parents that were already available in seed production plots. Intra-population crosses were included so that if any promising populations could be identified, they could be investigated in greater detail in later stages of the programme. Eleven crosses and a control were evaluated:

Amelonado selfed	Pure West African Amelonado
IMC67 × IMC105	Pure IMC
P4 × NA33	Pure Nanay
PA76 × PA300	Pure Parinari
SCA12 × SCA9	Pure Scavina
ICS95 selfed	Pure Trinitario
'PA'35 selfed	Pure Trinitario
IMC67 × PA76	Inter-population cross
NA33 × Amelonado	Inter-population cross
P4 × 'PA'35	Inter-population cross
UIT1 × NA33	Inter-population cross
'Mixed F_2 big seeds'	From commercial fields

All the parents were thought to be correctly identified except that 'PA'35 is a self-compatible Trinitario. UIT1 is an introduced clone with strong affinities to the self-incompatible 'Nicaraguan Criollo' clones ICS39, ICS40 and ICS60.

Seeds for rootstocks were produced by manual pollination with flower buds capped before anthesis and after manual pollination to prevent accidental cross-pollination. Exceptionally, 'mixed F_2 big seeds' were 'large beans' selected from fresh wet beans received at the cocoa fermentary from commercial fields.

Three scions were selected as proven self-compatible clones. The genetic base was constrained by lack of strong candidates:

PBC123	A popular commercial clone in Sabah in the mid-nineties, of 'hybrid' origin. Medium vigour. Tolerant to 'Vascular Streak Dieback' disease, caused by infection with *Oncobasidium theobromae.*
BAL209	Parentage ('PA'35 × NA32). Selected at Golden Hope Research Centre, Sabah. Vigorous and highly tolerant to 'Vascular Streak Dieback' disease.
BR25	Selected by J. A. Anselmi on Balong River Estate, Sabah from commercial cocoa. Assumed to be a pure Trinitario. Vigorous. More precocious than BAL209 and PBC123. Moderately susceptible to 'Vascular Streak Dieback' disease.

Propagation was by patch budding onto three-month-old rootstocks. There were insufficient plants of PBC123 on P4 × NA33 rootstock, and those of PBC123 on IMC67 × IMC105 and on NA33 × Amelonado for four complete replications.

A split plot design was used with four replications in a randomized complete block. Scions were used as main plots and rootstocks as sub-plots, to give an efficient comparison between rootstocks at the expense of comparisons between scions. The trial had 18 bush sub-plots (3 × 6), grown at conventional spacing of 3.8 m × 2.4 m (1096 trees ha^{-1}). The trial was surrounded by perimeter guard rows of similar vigour. All four plots of PBC123 on P4 × NA33 and three each of PBC123 on IMC67 × IMC105 and on NA33 × Amelonado were missing. They were filled with spare plants of PBC123 on the other rootstocks used in the trial. The trial was field planted in Table Series basaltic soil in June 1991. The previous crop was oil palm.

Management practices corresponded to those of the commercial cocoa on Table Estate, which was broadly representative of commercial cocoa in Sabah as a whole. Thus, the cocoa was grown under a thin cover of gliricidia shade, which was thinned and pruned frequently. Weeds were controlled as required. Cocoa trees were pruned for access and height control only. Fertilizer and lime were applied according to annual soil analysis. Cocoa pod borer (*Conopomorpha cramerella*) was controlled by frequent tight harvesting of ripe pods and application of synthetic pyrethroid insecticides when monitoring threshold values were exceeded.

Yield in the form of weight of wet cocoa per plot was recorded from December 1992 to April 1996. Conversion ratios of weight of wet beans to yields of merchantable beans were obtained from four rounds of sample fermentations undertaken from May 1993 to November 1994 using Lockwood and Edwards' (1980) method. Girths at 0.15 m above ground level were measured with tapes in October 1995. Data were analysed using GENSTAT 5 version 3.2.

RESULTS

The average yield in the trial was 10.16 t ha^{-1} over the 41 month recording period, or just under 3 t ha^{-1} $year^{-1}$. BR25 was the highest yielding clone (Table 1), significantly ($p < 0.01$) outperforming PBC123 by 12 % and BAL209 by 17 %. These results were consistent with those from other clone trials at the Golden Hope Research Centre, Sabah (Joe Pang Thau Yin, unpublished data). There were significant effects of stocks ($p < 0.001$) and no indication of interaction between rootstock and scion ($p < 0.2$). SCA12 × SCA9 was the best performing rootstock, giving about twice the yield increment of the next best performer, IMC76 × PA76. Amelonado and ICS95 selfed were the two poorest rootstocks for yield. The best rootstock yielded 22.6 % more than the poorest.

In the analysis of trunk circumference there were significant effects of scions ($p < 0.05$) and of rootstocks ($p < 0.01$). As in the analysis of the yields, there was no evidence of an interaction ($p < 0.2$). As expected, BR25 was the most vigorous scion and PBC123 the least vigorous (Table 1). Among the rootstocks, the pure Scavina was the

Table 1. Yields and trunk circumference in cocoa rootstock trial.

	Yield (kg dry cocoa ha^{-1}) December 1992–April 1996	Trunk circumference (cm) October 1995	Within-plot Coefficient of Variation trunk circumference October 1995
Mean	10 167	34.6	13.6
Effects of scions			
BAL209	− 856	0.25	0.30
PBC123	− 284	− 0.80	− 1.46
BR25	1140	0.55	1.16
s.e.	257.8	0.30	0.654
Effects of rootstocks			
Amelonado selfed	− 1,064	− 0.43	− 0.57
IMC67 × IMC105	− 494	− 0.54	− 2.21
P4 × NA33	292	− 1.28	− 0.16
PA76 × PA300	292	0.62	− 1.07
SCA12 × SCA9	997	2.25	− 0.34
ICS95 selfed	− 728	− 0.29	1.50
'PA'35 selfed	217	0.40	1.51
IMC76 × PA76	481	0.33	− 0.41
NA33 × Amelonado	270	0.40	0.15
P4 × 'PA'35	− 658	− 1.19	1.48
UIT1 × NA33	265	− 0.73	− 0.44
Mixed F_2	130	0.44	0.54
s.e.	251.1	0.43	1.01

most vigorous and pure Nanay the weakest. The most vigorous rootstock had a trunk circumference 14 % greater than the weakest.

The effects of rootstocks on yield were correlated with those on girth ($r = 0.63$, $p < 0.02$) (Figure 1). The more vigorous rootstocks were the higher yielding, the regression of yield on circumference accounting for 33.4 % of the variance, with the regression equation significant at $p = 0.05$.

The coefficients of variation of single tree trunk circumference measure variability within the plot. The statistical analysis showed that there was no effect of scions ($p < 0.05$), rootstocks or interaction ($p < 0.2$). The yield component analyses (wet to dry conversion ratio, bean weight, number of beans per pod and pod value, the number of pods required to produce a kg of dry beans) are summarized in Table 2. There were significant effects of scions ($p < 0.001$) in all four analyses. PBC123 had the highest wet to dry weight conversion ratio, the largest number of beans per pod and the largest beans, so it also had the lowest pod value (i.e. the smallest number of pods required to produce a kg of fermented and dried cocoa beans). Rootstock effects were minor and inconsistent. There was a significant ($p < 0.05$) effect of rootstock on conversion ratio, but there was also a significant ($p < 0.01$) interaction between rootstock and scion. When the main effect of rootstock was tested against the interaction (random effects test), the variance ratio was less than unity, showing that there was no effect of rootstock over and above that for interaction. The analysis of bean weight gave similar results. There was no evidence of variation in number of beans per pod. In

Table 2. Yield component analysis in cocoa rootstock trial.

	Wet to dry weight conversion (%)	Bean weight (g)	Number of beans pod^{-1}	Pod value
Mean	38.51	1.19	34.88	24.84
Effects of Scions				
BAL209	1.47	− 0.096	0.06	1.61
PBC123	2.24	0.109	4.08	− 4.76
BR25	− 3.71	− 0.013	− 4.15	3.16
s.e.	0.31	0.009	0.63	0.54
Effects of rootstocks				
Amelonado selfed	− 0.01	− 0.002	− 0.03	0.07
IMC67 × IMC105	− 0.91	− 0.024	0.07	0.76
P4 × NA33	− 0.05	− 0.021	− 0.86	1.45
PA76 × PA300	0.09	0.010	− 1.15	0.48
SCA12 × SCA9	0.33	0.028	0.87	− 1.20
ICS95 selfed	− 0.22	− 0.019	− 0.97	1.04
'PA'35 selfed	0.09	0.004	− 0.02	− 0.18
IMC76 × PA76	0.35	0.005	− 0.05	0.10
NA33 × Amelonado	0.00	− 0.011	− 0.16	− 0.03
P4 × 'PA'35	0.28	− 0.003	1.70	− 1.20
UIT1 × NA33	0.10	0.016	0.45	− 0.87
Mixed F_2	− 0.06	0.017	0.14	− 0.41
s.e.	0.23	0.009	0.78	0.60

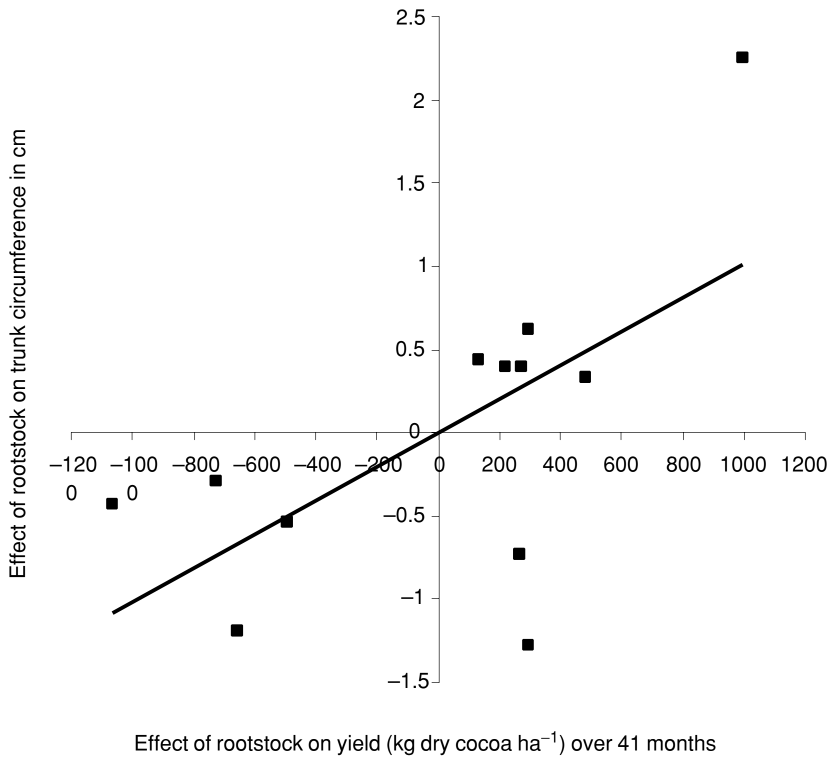

Figure 1. Girth–yield effects in cocoa rootstock trial.

the analysis of pod value, the effect of rootstocks was just significant at $p < 0.05$. As pod value is derived from bean weight and number of beans per pod, one of which showed anomalous interactions, no importance is attached to the apparent effect of rootstock.

DISCUSSION

This study gives the first clear indications that in cocoa the rootstock influences the vigour of the scion and through this its yield at least in the early years. However, the linear response of yield on trunk circumference suggests that there was no gain in yield efficiency, so the same yield response could have been obtained by changing the planting density. Given an efficient nursery, changes of planting density of 20–30 % would make little difference to the costs of establishing a cocoa field and bringing it into bearing. Cocoa clones are known to differ at least three-fold in optimal planting density (Lockwood and Pang, 1996), a range of variation that appears to be much larger than the rootstock effect. Clones are expected to be planted in mixtures because at least a proportion of them are expected to be self-incompatible. Using the observed effects of rootstock on vigour to obtain uniform growth in plantings of several clones requires a depth of knowledge of scions and rootstocks that is not yet available in cocoa.

This experiment was done under exceptionally favourable conditions for cocoa, with very high yields and little pressure from disease, as the scions all showed tolerance of vascular streak dieback disease. All three clones were freely self-compatible, so pollen movement within the large main plots did not limit yields. The experiment was a thorough test of the effect of rootstock on the yield of young budded cocoa in the absence of diseases affecting the root system.

There was no perceptible pattern to the rootstock effects on vigour. The Scavina cross, that gave the greatest vigour and the highest yields, had by far the smallest beans. Scavina 12 was typically about 0.66 g dry weight at Golden Hope Research Centre, Sabah, whereas UIT1, which gave much less vigorous seedlings, was about 1.58 g. The results of this trial provide no evidence that large beans confer any ultimate advantage in the field. The need for great vigour in the nursery has reduced with the introduction of green patch budding of very young seedlings (Yow and Lim, 1994), although the technique is technically demanding.

The genetic heterogeneity of the 12 rootstocks is apparent from their parentage. The data of Lanaud *et al*. (2001) data suggest that the two Scavina parents are more homozygous than ICS95, assuming that the identifications correspond, so clones grown on the Scavina progeny might be expected to be more uniform. This was not observed. The estimates of tree to tree variation within clones were slightly smaller than those obtained by Lockwood (1976) for West African Amelonado seedlings that were older when measured. If it is assumed that variability increases with age as differential competition exerts itself, and that West African Amelonado is genetically uniform, the absence of a rootstock effect on variability is further evidence that any rootstock effect is relatively small. The limited variation among the three scions is interpreted as confirmation that the three were equally well adapted to environment at Tawau.

The rootstock effects observed in this trial are large enough to warrant control of the rootstock in critical work. This applies to trials of budded clones, where every effort should be made to achieve the most uniform trees possible, and more arguably to commercial plantings, especially under favourable conditions. Once clones are evaluated on a standard rootstock, it would be wise to use this rootstock for commercial plantings. Given good nursery skills, the pure Scavina cross would be the safest choice, as it imparts vigour. However, different conclusions might be reached if for example the root pathogen *Phytophthora palmivora* were a serious problem and Scavina material did not show tolerance, or in the presence of *Ceratocystis*.

The results of this trial indicate that rootstock research remains a low priority in cocoa. It is far more important to select good clones as the basis of commercial plantings and to use as parents in a breeding programme. An exploratory trial of rootstocks, such as that described here, should be done once a suite of good clones has been proven.

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