



Parental contribution analysis in hybrids bred for vascular streak dieback (VSD) disease resistance in cocoa

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Abstract

Vascular streak die back (VSD) disease caused by *Oncobasidium theobromae* (now renamed as *Ceratobasidium theobromae*), is one of the major threats in cocoa growing countries, mainly because it cannot be controlled by any chemical application. In India, since the disease outbreak in 1990, it has become an unmanageable problem of cocoa trees. Knowing the importance of resistant hybrids for controlling this disease, Kerala Agricultural University took up resistant breeding programme. It was a massive breeding programme which resulted in production of 5921 hybrid seedlings. After nursery screening of these hybrids by subjecting to heavy inoculation load for more than two years from March 1996 to June 1998, only 566 seedlings survived and they were field planted during June 1998. When relative efficiency of mother plants to transfer resistance to their progenies was estimated, it was seen that G VI 126 (Scavina 6) showed maximum recovery of 32.6 per cent after fifteen years of screening. Comparison of efficacy of male parents indicated that G VI 55 showed maximum recovery of resistant parents (168 nos.). During the entire period of investigation, 267 hybrids were found free from the disease. Out of this, only 51 recorded satisfactory yield levels. All these hybrids showed high value for selection differential (S) indicating maximum genetic gain. These hybrids can be used as mother plants for establishing polyclonal garden, as VSD disease resistance is highly heritable and polygenically controlled. The resistant hybrids identified (both high and low yield) can be utilized for further studies employing conventional and molecular breeding methods.

Keywords: Cocoa, disease resistance, pollination, selection differential, vascular streak dieback (VSD)

Introduction

The chocolate tree, *Theobroma cacao* L. is a very popular intercrop in tree based cropping systems of peninsular India. Being a new crop commercialized in India only by late 1970s, the threats from pests and diseases were low. However, 1990 witnessed a massive outbreak and spread of vascular streak dieback (VSD) disease in certain locations of Kerala causing concern among the growers. This situation prompted Kerala Agricultural University to develop viable strategies to manage the disease. VSD, reported from SE Asian countries, is caused by *Oncobasidium theobromae* (now renamed as *Ceratobasidium theobromae*) (Samuels *et al.*, 2012) a unique fungal pathogen which is near obligate, wind borne, leaf penetrating and xylem

infecting. Fungicidal control has little value in checking the incidence and severity of the disease (Ajaykumar, 1996; Abraham *et al.*, 2000). The main approach to control the disease involves propagation and planting of resistant clones and hybrid seedlings. Many workers (Tan and Tan, 1988; Keane and Prior, 1992; Bong and Lee, 1999; Efron *et al.*, 2002) reported that the resistance to VSD is predominantly additive indicating that the disease is polygenically controlled, highly heritable and hybrid progenies of resistant parents are likely to be resistant. Evolving resistant varieties was very effective in controlling this disease in Papua New Guinea (Tan and Tan, 1988). Based on this, elaborate resistance breeding programme was undertaken at the Cocoa Research Centre, Kerala Agricultural University (Mallika *et al.*, 2000).

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Materials and Methods

The hybridization programme was started during 1995-96. Thirty one female and four male parents, which showed resistance, were selected from the germplasm collection based on disease intensity. This was done using 0-9 scale based on percentage of twigs infected in a tree as detailed below (Abraham *et al.*, 2000; Marfu *et al.*, 2004).

Disease scale	Intensity of infection
0	No infection
1	< 25 per cent of twig infected
3	25-50 percent infection
5	50-75 percent infection
7	>75 percent infection
9	Mortality of the plant

The female parents used in the study were:

1. M 13.12 (CCRP 2)
2. G II 19.5 (CCRP 4)
3. G VI 4 (C 76)
4. G VI 54 (SIAL 93)
5. G VI 125 (ICS 95)
6. G VI 126 (Scavina 6)
7. G VI 137 (local collection)
8. G VI 139 (local collection)
9. G VI 140 (local collection)
10. G VI 142(local collection)
11. G VI 143 (local collection)
12. G VI 146 (local collection)
13. G VI 147 (local collection)
14. G VI 148 (local collection)
15. G VI 167 (local collection)
16. G VI 169 (local collection)
17. G VI 170 (local collection)
18. G VI 171 (AMAZ 3-2)R. Amazonas, Loreto, Peru
19. G VI 172 (AMAZ 6-3) Amazonas, Loreto, Peru
20. G VI 174 (BE 3) R. Guama, Para, Brazil
21. G VI 176 (CC 11)
22. G VI 178 (EQX 69)
23. G VI 182 (IMC 20) IQUITOS MIXED 20
24. G VI 185 (LCT EEN 162- 1010) Coca, Napo, Ecuador

25. G VI 186 (MAN 15-2)
26. G VI 187 (MAN 15-60)
27. G VI 188 (PA 7) PARINARI 7 [PER]
28. G VI 189 (PA 56)
29. G VI 190 (SC 1) COLOMBIA
30. G VI 191 (TJ 1)
31. G VI 193 (UF 667)

The male parents were G IV 18.5 (CCRP 5), G VI 55 (IMC 10), M 13.12 (CCRP 2) and G VI 4 (C 76) (CCRP Report, 1998-99).

Assisted hand pollination was done as per the procedure suggested by Wood and Lass (1985) after slight modification of the pollination hood (Ammal *et al.*, 2009). Cross pollination was attempted depending upon the availability of flowers in selected female parents on the trunk and thick fan branches at convenient heights during dry period from September 1995 to March 1996. The hybrid pods were sown in the nursery from March 1996 onwards in a shade house with very high humidity. VSD infected seedlings were kept all around the healthy hybrid seedlings produced from the hybrid pods. The seedlings were thus subjected to natural inoculum load and also high humidity favorable for spread of the disease upto May 1998. In the meantime, many seedlings which took up the disease perished. The survivors were transplanted to the main field under the shade of uneven stand of old rubber trees. A total of 566 seedlings derived from 58 crosses were established in the field during June 1998. These plants were maintained under uniform level of management during the entire observation period (2004 to 2014). The plants were observed for number of pods per tree per year and disease intensity (0-9 scoring method) during the entire period. The data were tabulated and the plants with complete resistance (score: 0) and with more than 100 pods per tree per year were identified. Selection differential (S) of these hybrids were estimated by 'average superiority of selected individuals over the mean of population' (Allard, 1960), since the hybrid population itself is segregating due to the use of heterozygous individuals as parents.

Results and discussion

The data on number of flowers pollinated per cross, number of fruits set, number of hybrid seedlings produced, number of seedlings survived

Table 1. Hybridization programme for production of VSD resistant hybrids in cocoa

Sl. No.	Cross	No. of flowers pollinated	No. of fruits developed	Percentage fruit set	No. of beans	No. of seedlings obtained	No. field planted after nursery screening	Recovery of resistant hybrids after nursery screening (%)	No. of resistant plants after 15 years	Percentage recovery of resistant hybrids after 15 years (%)	Recovery of resistant hybrids (%)
1.	M 13.12 x G IV 18.5	117	5	4.3	125	84	1	1.2	0	0	0.0
2.	M 13.12 x G VI 55	39	4	10.3	136	98	27	27.6	3	11	3.1
3.	G II 19.5 x G IV 18.5	142	4	2.8	94	37	5	13.5	2	40	5.4
4.	G II 19.5 x G VI 55	27	6	22.2	161	111	1	0.9	1	100	0.9
5.	G VI 4 x G IV 18.5	31	7	22.6	179	149	10	6.7	6	60	4.0
6.	G VI 4 x G VI 55	13	4	30.8	117	81	12	14.8	4	33	4.9
7.	G VI 54 x G IV 18.5	77	5	6.5	100	38	1	2.6	0	0	0.0
8.	G VI 125 x G IV 18.5	73	9	12.3	244	196	20	10.2	2	10	1.0
9.	G VI 125 x G VI 55	44	10	22.7	347	229	20	8.7	13	65	5.7
10.	G VI 126 x G IV 18.5	81	8	9.9	160	147	64	43.5	13	20.	8.8
11.	G VI 126 x G VI 55	43	17	39.5	443	151	65	43.1	29	45	19.2
12.	G VI 137 x G IV 18.5	60	1	1.7	34	18	2	11.1	0	0	0.0
13.	G VI 137 x G VI 55	29	4	13.8	120	96	16	16.7	7	44	7.3
14.	G VI 139 x G VI 55	31	1	3.2	11	7	1	14.3	0	0	0.0
15.	G VI 140 x G IV 18.5	50	3	6.0	107	105	10	9.5	5	50	4.8
16.	G VI 140 x G VI 55	41	1	2.4	44	40	23	57.5	17	74	42.5
17.	G VI 142 x G VI 55	61	1	1.6	24	21	5	23.8	2	40	9.5
18.	G VI 143 x G IV 18.5	42	3	7.1	73	51	4	7.8	3	75	5.9
19.	G VI 143 x G VI 55	38	18	47.4	581	331	40	12.1	29	73	8.8
20.	G VI 146 x G IV 18.5	20	3	15.0	55	16	1	6.3	0	0	0.0
21.	G VI 146 x G VI 55	26	5	19.2	150	100	15	15.0	8	53	8.0
22.	G VI 147 x G IV 18.5	44	6	13.6	146	23	2	8.7	2	100	8.7
23.	G VI 147 x G VI 55	37	6	16.2	173	92	8	8.7	5	63	5.4
24.	G VI 148 x G IV 18.5	36	7	19.4	153	127	6	4.7	4	67	3.2
25.	G VI 148 x G VI 55	32	8	25.0	219	137	29	21.2	10	35	7.3
26.	G VI 167 x G IV 18.5	53	5	9.4	156	120	1	0.8	1	100	0.8
27.	G VI 169 x G VI 55	56	1	1.8	28	11	1	9.1	0	0	0.0
28.	G VI 170 x G IV 18.5	56	4	7.1	84	63	6	9.5	6	100	9.5
29.	G VI 170 x G VI 55	17	6	35.3	159	81	5	6.2	1	20	1.2
30.	G VI 171 x G IV 18.5	33	7	21.2	220	116	18	15.5	5	28	4.3
31.	G VI 171 x G VI 55	27	6	22.2	203	143	8	5.6	4	50	2.8
32.	G VI 172 x M 13.12	18	5	27.8	81	53	1	1.9	0	0	0.0
33.	G VI 172 x G IV 18.5	26	7	26.9	236	155	2	1.3	2	100	1.3
34.	G VI 172 x G VI 4	40	1	2.5	40	28	1	3.6	1	100	3.6
35.	G VI 174 x G IV 18.5	44	4	9.1	113	57	1	1.8	1	100	1.8
36.	G VI 176 x G IV 18.5	22	4	18.2	129	91	11	12.1	4	36	4.4
37.	G VI 178 x G IV 18.5	99	5	5.1	143	78	1	1.3	0	0	0.0
38.	G VI 182 x M 13.12	27	3	11.1	119	93	3	3.2	2	67	2.2

39.	G VI 182 x G IV 18.5	70	5	7.1	172	137	5	3.7	3	60	2.2
40.	G VI 182 x G VI 4	24	3	12.5	118	100	6	6.0	3	50	3.0
41.	G VI 182 x G VI 55	32	3	9.4	135	108	6	5.6	3	50	2.8
42.	G VI 185 x M 13.12	30	4	13.3	118	76	5	6.6	3	60	4.0
43.	G VI 185 x G IV 18.5	60	12	20.0	420	276	10	3.6	8	80	2.9
44.	G VI 185 x G VI 4	35	4	11.4	185	120	2	1.7	1	50	0.8
45.	G VI 186 x M 13.12	163	2	1.2	64	48	3	6.3	1	33	2.1
46.	G VI 186 x G IV 18.5	157	6	3.8	200	152	8	5.3	6	75	4.0
47.	G VI 186 x G VI 55	39	3	7.7	130	110	10	9.1	9	90	8.2
48.	G VI 187 x G VI 4	88	2	2.3	84	72	3	4.2	1	33	1.4
49.	G VI 187 x G VI 55	26	5	19.2	118	84	4	4.8	2	50	2.4
50.	G VI 188 x M 13.12	81	8	9.9	239	176	6	3.4	1	17	0.6
51.	G VI 188 x G IV 18.5	60	9	15.0	190	161	14	8.7	8	57	5.0
52.	G VI 188 x G VI 55	27	6	22.2	196	137	12	8.8	8	67	5.8
53.	G VI 189 x G IV 18.5	66	5	7.6	106	94	2	2.1	2	100	2.1
54.	G VI 189 x G VI 55	34	6	17.7	222	171	9	5.3	8	89	4.7
55.	G VI 190 x G VI 4	16	4	25.0	142	112	2	1.8	2	100	1.8
56.	G VI 191 x M 13.12	54	5	9.3	202	154	2	1.3	1	50	0.7
57.	G VI 191 x G VI 55	41	1	2.4	46	36	5	13.9	5	100	13.9
58.	G VI 193 x G IV 18.5	94	1	1.1	30	23	5	21.7	0	0	0.0
Total		2949	298		8824	5921	566		267		
Mean				10.1				9.6		48	4.5

after nursery screening, number of plants recovered after field screening for 15 years (1999 to 2014) is furnished in Table 1. The number of flowers cross pollinated using the four male parents in 31 female parents was 2949. The number of flowers pollinated per cross varied depending upon the availability of flowers in the parents. Maximum number of 163 flowers were pollinated in the cross GVI 186 x M 13.12, followed by 157 flowers in the cross GVI 186 x GIV 18.5. Thus under Vellanikkara conditions, GVI 186 (MAN 15-2), a Brazilian type proved to be highly floriferous during the pollination season of 1995-96.

Out of 2949 flowers cross pollinated in different crosses, 298 developed into ripe fruits, which were utilized for production of hybrid seedlings. Among the different crosses, the highest fruit set (47.4%) was recorded by GVI 143 x GVI 55 followed by GVI 126 x GVI 55 (39.5%). Posnette and Entwistle (1958) observed 1-5 per cent fruit set under natural conditions. In assisted pollination, Edwards (1973) obtained 40-50 per cent fruit set in Ghana. In the present study, the fruit set varied from

1.1 to 47.4 per cent. The data showed that out of 58 crosses attempted, more than 100 flowers were produced by only four female parents. But, the percentage of fruit set was low in plants which produced more flowers (1.2-4.3).

The 298 hybrid pods gave 5921 hybrid seedlings during 1996. Maximum seedlings (331) were obtained from the cross GVI 143 x GVI 55, followed by GVI 185 x GVI 18.5 with 276 seedlings. Gene action was reported to be predominantly additive in nature (Tan and Tan, 1988), indicating that selection of progenies showing resistance to VSD is effective in a population. Hence, rigorous screening of these seedlings was carried out in the nursery for two years from March 1996 to June 1998. It resulted in selection of 566 resistant seedlings (9.5%) and rejection of remaining 91.5 per cent seedlings. Among the crosses, maximum number of resistant seedlings field planted *i.e.*, 65 seedlings, was recorded by the cross GVI 126 x GVI 55, followed by 64 seedlings in the cross GVI 126 x GIV 18.5. GVI 126 (Scavina 6) is a very viable source of

Table 2. Efficiency of mother plants in producing resistant hybrids

Sl. No.	Female parent	No. of flowers pollinated	Number of fruits developed	Percentage fruit set	No. of beans	No. of seedlings obtained	No. field planted after nursery screening	Resistant hybrids after nursery screening (%)	Resistant plants after 15 years	Resistant hybrids after 15 years (%)	Recovery of resistant hybrids (%)
1.	M 13.12	156	9	5.8	261	182	28	15.4	3	10.7	1.7
2.	G II 19.5	169	10	5.9	255	148	6	4.1	3	50.0	2.0
3.	GVI 4	44	11	25.0	296	230	22	9.6	10	45.5	4.4
4.	G VI 54	77	5	6.5	100	38	1	2.6	0	0.0	0.0
5.	GVI 125	117	19	16.2	591	425	40	9.4	15	37.5	3.5
6.	GVI 126	124	25	20.2	603	298	129	43.3	42	32.6	14.1
7.	GVI 137	89	5	5.6	154	114	18	15.8	7	38.9	6.1
8.	G VI 139	31	1	3.2	11	7	1	14.3	0	0.0	0.0
9.	G VI 140	91	4	4.4	151	145	33	22.8	22	66.7	15.2
10.	G VI 142	61	1	1.6	24	21	5	23.8	2	40.0	9.5
11.	G VI 143	80	21	26.3	654	382	44	11.5	32	72.7	8.4
12.	G VI 146	46	8	17.4	205	116	16	13.8	8	50.0	6.9
13.	G VI 147	81	12	14.8	319	115	10	8.7	7	70.0	6.1
14.	G VI 148	68	15	22.1	372	264	35	13.3	14	40.0	5.3
15.	G VI 167	53	5	9.4	156	120	1	0.8	1	100.0	0.8
16.	G VI 169	56	1	1.8	28	11	1	9.1	0	0.0	0.0
17.	G VI 170	73	10	13.7	243	144	11	7.6	7	63.6	4.9
18.	G VI 171	60	13	21.7	423	259	26	10.0	9	34.6	3.5
19.	G VI 172	84	13	15.5	357	236	4	1.7	3	75.0	1.3
20.	G VI 174	44	4	9.1	113	57	1	1.8	1	100.0	1.8
21.	G VI 176	22	4	18.2	129	91	11	12.1	4	36.4	4.4
22.	G VI 178	99	5	5.1	143	78	1	1.3	0	0.0	0.0
23.	G VI 182	153	14	9.2	544	438	20	4.6	11	55.0	2.5
24.	G VI 185	125	20	16.0	723	472	17	3.6	12	70.6	2.5
25.	G VI 186	359	11	3.1	394	310	21	6.8	16	76.2	5.2
26.	G VI 187	114	7	6.1	202	156	7	4.5	3	42.9	1.9
27.	G VI 188	168	23	13.7	625	474	32	6.8	21	65.6	4.4
28.	G VI 189	100	11	11.0	328	265	11	4.2	10	90.9	3.8
29.	G VI 190	16	4	25.0	142	112	2	1.8	2	100.0	1.8
30.	G VI 191	95	6	6.3	248	190	7	3.7	6	85.7	3.2
31.	G VI 193	94	1	1.1	30	23	5	21.7	0	0	0
Total		5345	565		8824	5921	566		271		
Mean			11.6				6.4		47.9	4.6	

resistance to the disease (Bong and Phua, 1989; Phua *et al.*, 1990) and has been widely utilized globally for resistance breeding.

After the entire period of investigation, maximum number of resistant hybrids survived (29) was recorded in two crosses, GVI 126 x GVI 55

and GVI 143 x GVI 55. When the percentage of recovery was worked out, the percentage to the total number of resistant hybrids field planted in these crosses was too low to confirm their supremacy. As reported by Efron *et al.* (2002) hybrids of the same cross turned out to be highly susceptible and highly

Table 3. Efficiency of male plants in producing resistant hybrids

Sl. No.	Male parent	No. of flowers pollinated	Number of fruits developed	Percentage fruit set	No. of beans	No. of seedlings obtained	No. field planted after nursery screening	Resistant hybrids after nursery screening (%)	Resistant plants after 15 years	Resistant hybrids after 15 years (%)	Resistant hybrids out of number produced (%)
1.	GIV 18.5	1613	135	8.4	3669	2514	210	8.4	83	39.5	3.3
2.	GVI 55	760	122	16.1	3763	2375	322	13.6	168	52.2	7.1
3.	M 13.12	373	27	7.2	823	600	20	3.3	12	60.0	2.0
4.	GVI 4	203	14	6.9	569	432	14	3.2	8	57.1	1.9
Total			2949	298		8824	5921	566		271	
Mean				10.1				9.6		47.9	4.6

Table 4. Pooled mean yield of field resistant hybrids over eleven years (2004-2014)

Hybrid no.	Parentage	Av. pods tree ⁻¹ year ⁻¹	Hybrid no.	Parentage	Av. pods tree ⁻¹ year ⁻¹	Hybrid no.	Parentage	Av. pods tree ⁻¹ year ⁻¹
H1	M 13.12 X G VI 55	19	H46	G VI 126 X GVI 55	71	H91	G VI 140 X G VI 55	72
H2	M 13.12 X G VI 55	116	H47	G VI 126 X GVI 55	145	H92	G VI 140 X G VI 55	3
H3	M 13.12 X G VI 55	133	H48	G VI 126 X GVI 55	111	H93	G VI 140 X G VI 55	39
H4	GII 19.5 X G IV 18.5	82	H49	G VI 126 X GVI 55	94	H94	G VI 140 X G VI 55	27
H5	GII 19.5 X G IV 18.5	161	H50	G VI 126 X GVI 55	52	H95	G VI 140 X G VI 55	9
H6	G II 19.5 X G VI 55	169	H51	G VI 126 X GVI 55	156	H96	G VI 140 X G VI 55	2
H7	G VI 4 X GIV 18.5	123	H52	G VI 126 X GVI 55	23	H97	G VI 140 X G VI 55	34
H8	G VI 4 X GIV 18.5	18	H53	G VI 126 X GVI 55	33	H98	G VI 140 X G VI 55	192
H9	G VI 4 X GIV 18.5	9	H54	G VI 126 X GVI 55	43	H99	G VI 140 X G VI 55	69
H10	G VI 4 X GIV 18.5	107	H55	G VI 126 X GVI 55	44	H100	G VI 140 X G VI 55	63
H11	G VI 4 X GIV 18.5	194	H56	G VI 126 X GVI 55	48	H101	G VI 140 X G VI 55	8
H12	G VI 4 X GIV 18.5	7	H57	G VI 126 X GVI 55	34	H102	G VI 140 X G VI 55	104
H13	G VI 4 X GVI 55	2	H58	G VI 126 X GVI 55	30	H103	G VI 142 X G VI 55	10
H14	G VI 4 X GVI 55	11	H59	G VI 126 X GVI 55	102	H104	G VI 142 X G VI 55	101
H15	G VI 4 X GVI 55	178	H60	G VI 126 X GVI 55	65	H105	G VI 143 X G IV 18.5	12
H16	G VI 4 X GVI 55	4	H61	G VI 126 X GVI 55	42	H106	G VI 143 X G IV 18.5	11
H17	G VI 125 X G IV 18.5	8	H62	G VI 126 X GVI 55	12	H107	G VI 143 X G IV 18.5	11
H18	G VI 125 X G IV 18.5	1	H63	G VI 126 X GVI 55	13	H108	G VI 143 X G VI 55	6
H19	G VI 125 X GVI 55	37	H64	G VI 126 X GVI 55	60	H109	G VI 143 X G VI 55	33
H20	G VI 125 X GVI 55	8	H65	G VI 126 X GVI 55	32	H110	G VI 143 X G VI 55	6
H21	G VI 125 X GVI 55	19	H66	G VI 126 X GVI 55	121	H111	G VI 143 X G VI 55	21
H22	G VI 125 X GVI 55	26	H67	G VI 126 X GVI 55	83	H112	G VI 143 X G VI 55	56
H23	G VI 125 X GVI 55	12	H68	G VI 126 X GVI 55	73	H113	G VI 143 X G VI 55	4
H24	G VI 125 X GVI 55	9	H69	G VI 126 X GVI 55	17	H114	G VI 143 X G VI 55	72
H25	G VI 125 X GVI 55	23	H70	G VI 126 X GVI 55	89	H115	G VI 143 X G VI 55	81
H26	G VI 125 X GVI 55	4	H71	G VI 126 X GVI 55	71	H116	G VI 143 X G VI 55	34
H27	G VI 125 X GVI 55	15	H72	G VI 126 X GVI 55	3	H117	G VI 143 X G VI 55	63
H28	G VI 125 X GVI 55	5	H73	G VI 126 X GVI 55	11	H118	G VI 143 X G VI 55	65
H29	G VI 125 X GVI 55	6	H74	G VI 137 X G VI 55	135	H119	G VI 143 X G VI 55	65

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H30	G VI 125 X GVI 55	18	H75	G VI 137 X G VI 55	99	H120	G VI 143 X G VI 55	67
H31	G VI 125 X GVI 55	5	H76	G VI 137 X G VI 55	34	H121	G VI 143 X G VI 55	91
H32	G VI 126 X GIV 18.5	105	H77	G VI 137 X G VI 55	51	H122	G VI 143 X G VI 55	60
H33	G VI 126 X GIV 18.5	169	H78	G VI 137 X G VI 55	13	H123	G VI 143 X G VI 55	112
H34	G VI 126 X GIV 18.5	154	H79	G VI 137 X G VI 55	48	H124	G VI 143 X G VI 55	75
H35	G VI 126 X GIV 18.5	140	H80	G VI 137 X G VI 55	7	H125	G VI 143 X G VI 55	137
H36	G VI 126 X GIV 18.5	175	H81	G VI 140 X G IV 18.5	11	H126	G VI 143 X G VI 55	48
H37	G VI 126 X GIV 18.5	116	H82	G VI 140 X G IV 18.5	161	H127	G VI 143 X G VI 55	28
H38	G VI 126 X GIV 18.5	88	H83	G VI 140 X G IV 18.5	48	H128	G VI 143 X G VI 55	16
H39	G VI 126 X GIV 18.5	70	H84	G VI 140 X G IV 18.5	61	H129	G VI 143 X G VI 55	8
H40	G VI 126 X GIV 18.5	163	H85	G VI 140 X G IV 18.5	8	H130	G VI 143 X G VI 55	63
H41	G VI 126 X GIV 18.5	75	H86	G VI 140 X G VI 55	118	H131	G VI 143 X G VI 55	46
H42	G VI 126 X GIV 18.5	165	H87	G VI 140 X G VI 55	112	H132	G VI 143 X G VI 55	103
H43	G VI 126 X GIV 18.5	121	H88	G VI 140 X G VI 55	27	H133	G VI 143 X G VI 55	27
H44	G VI 126 X GIV 18.5	137	H89	G VI 140 X G VI 55	10	H134	G VI 143 X G VI 55	5
H45	G VI 126 X GVI 55	2	H90	G VI 140 X G VI 55	40	H135	G VI 143 X G VI 55	29
H136	G VI 143 X G VI 55	39	H180	G VI 171 X GVI 55	20	H224	G VI 186 X G VI 55	102
H137	G VI 146 X G VI 55	7	H181	G VI 171 X GVI 55	87	H225	G VI 186 X G VI 55	105
H138	G VI 146 X G VI 55	43	H182	G VI 171 X GVI 55	134	H226	G VI 186 X G VI 55	34
H139	G VI 146 X G VI 55	44	H183	G VI 172 X G IV 18.5	124	H227	G VI 186 X G VI 55	25
H140	G VI 146 X G VI 55	40	H184	G VI 172 X G IV 18.5	56	H228	G VI 186 X G VI 55	2
H141	G VI 146 X G VI 55	35	H185	G VI 172 X G VI 4	57	H229	G VI 186 X M 13.12	86
H142	G VI 146 X G VI 55	6	H186	G VI 174 X G IV 18.5	31	H230	G VI 187 X G VI 55	23
H143	G VI 146 X G VI 55	26	H187	G VI 176 X GIV 18.5	9	H231	G VI 187 X G VI 55	88
H144	G VI 146 X G VI 55	2	H188	G VI 176 X GIV 18.5	38	H232	G VI 187 X G VI 4	37
H145	G VI 147 X G IV 18.5	85	H189	G VI 176 X GIV 18.5	10	H233	G VI 188 X G VI 55	97
H146	G VI 147 X G IV 18.5	75	H190	G VI 176 X GIV 18.5	49	H234	G VI 188 X G VI 55	186
H147	G VI 147 X G VI 55	76	H191	G VI 182 X G VI 55	75	H235	G VI 188 X G VI 55	251
H148	G VI 147 X G VI 55	3	H192	G VI 182 X G VI 55	55	H236	G VI 188 X G VI 55	117
H149	G VI 147 X G VI 55	6	H193	G VI 182 X G VI 55	15	H237	G VI 188 X G VI 55	2
H150	G VI 147 X G VI 55	8	H194	G VI 182 X GIV 18.5	31	H238	G VI 188 X G VI 55	13
H151	G VI 147 X G VI 55	24	H195	G VI 182 X GIV 18.5	7	H239	G VI 188 X G VI 55	21
H152	G VI 148 X G IV 18.5	52	H196	G VI 182 X GIV 18.5	42	H240	G VI 188 X G VI 55	34
H153	G VI 148 X G IV 18.5	19	H197	G VI 182 X M 13.12	11	H241	G VI 188 X G IV 18.5	60
H154	G VI 148 X G IV 18.5	86	H198	G VI 182 X M 13.12	58	H242	G VI 188 X G IV 18.5	80
H155	G VI 148 X G IV 18.5	80	H199	G VI 182 X G VI 4	10	H243	G VI 188 X G IV 18.5	185
H156	G VI 148 X GVI 55	4	H200	G VI 182 X G VI 4	7	H244	G VI 188 X G IV 18.5	198
H157	G VI 148 X GVI 55	68	H201	G VI 182 X G VI 4	14	H245	G VI 188 X G IV 18.5	198
H158	G VI 148 X GVI 55	32	H202	G VI 185 X G IV 18.5	8	H246	G VI 188 X G IV 18.5	26
H159	G VI 148 X GVI 55	84	H203	G VI 185 X G IV 18.5	27	H247	G VI 188 X G IV 18.5	51
H160	G VI 148 X GVI 55	99	H204	G VI 185 X G IV 18.5	14	H248	G VI 188 X G IV 18.5	12
H161	G VI 148 X GVI 55	8	H205	G VI 185 X G IV 18.5	6	H249	G VI 188 X M 13.12	33
H162	G VI 148 X GVI 55	6	H206	G VI 185 X G IV 18.5	35	H250	G VI 189 X G VI 55	5
H163	G VI 148 X GVI 55	8	H207	G VI 185 X G IV 18.5	107	H251	G VI 189 X G VI 55	5

H164	G VI 148 X GVI 55	26	H208	G VI 185 X G IV 18.5	185	H252	G VI 189 X G VI 55	5
H165	G VI 148 X GVI 55	188	H209	G VI 185 X G IV 18.5	176	H253	G VI 189 X G VI 55	51
H166	G VI 167 X G IV 18.5	114	H210	G VI 185 X M 13.12	4	H254	G VI 189 X G VI 55	14
H167	G VI 170 X G IV 18.5	11	H211	G VI 185 X M 13.12	12	H255	G VI 189 X G VI 55	133
H168	G VI 170 X G IV 18.5	36	H212	G VI 185 X M 13.12	5	H256	G VI 189 X G VI 55	135
H169	G VI 170 X G IV 18.5	16	H213	G VI 185 X G VI 4	34	H257	G VI 189 X G VI 55	192
H170	G VI 170 X G IV 18.5	78	H214	G VI 186 X G IV 18.5	16	H258	G VI 189 X G IV 18.5	8
H171	G VI 170 X G IV 18.5	5	H215	G VI 186 X G IV 18.5	22	H259	G VI 189 X G IV 18.5	33
H172	G VI 170 X G IV 18.5	39	H216	G VI 186 X G IV 18.5	19	H260	G VI 190 X G VI 4	7
H173	G VI 170 X G VI 55	61	H217	G VI 186 X G IV 18.5	23	H261	G VI 190 X G VI 4	70
H174	G VI 171 X G IV 18.5	31	H218	G VI 186 X G IV 18.5	29	H262	G VI 191 X G VI 55	23
H175	G VI 171 X G IV 18.5	20	H219	G VI 186 X G IV 18.5	10	H263	G VI 191 X G VI 55	12
H176	G VI 171 X G IV 18.5	31	H220	G VI 186 X G VI 55	72	H264	G VI 191 X G VI 55	78
H177	G VI 171 X G IV 18.5	52	H221	G VI 186 X G VI 55	16	H265	G VI 191 X G VI 55	25
H178	G VI 171 X G IV 18.5	27	H222	G VI 186 X G VI 55	17	H266	G VI 191 X G VI 55	34
H179	G VI 171 X GVI 55	22	H223	G VI 186 X G VI 55	65	H267	G VI 191 X M 13.12	32
Average yield of hybrids		:	54.9 pods tree ⁻¹ year ⁻¹					

resistant. In nine crosses, all plants succumbed to disease within the 15 year period, even though they showed resistance in nursery screening. Ahmad *et al.* (2004) reported that hybrids showing resistance during early period of growth lost the resistance in due course of cultivation. The other crosses recorded highly variable figures. Out of 566 resistant plants field planted, 267 hybrids continued to remain as resistant, the percentage being 47.9. Cocoa exhibits horizontal resistance to VSD, which is highly polygenic and largely inherited as additive genes (Tan and Tan 1988; Keane and Prior 1992; Samuels *et al.*, 2012). This reflects that the resistance is highly heritable and may be the reason for the recovery of a good amount of resistant hybrid progenies. 100 per cent recovery was recorded by ten crosses (G II 19.5 x G VI 55). But, among these, only two crosses had five or more than five number of progenies (G VI 191 x G VI 55 and G VI 170 x G IV 18.5).

Table 2 compares the relative efficiency of the mother plants to transfer resistance to their progenies. The data showed that flowering was profuse in GVI 186, in which maximum number of flowers (359) could be pollinated. Though flowering was sparse in GVI 190, fruit set was comparatively higher. Out of 16 flowers pollinated, four pods developed. Maximum fruit set was recorded by GVI 143 (26.3%). GVI 4 also produced

11 fruits on hand pollinating 44 flowers (6.9%). The number of beans obtained was highest from GVI 185 (723 beans). After nursery screening for two years, maximum number of resistant seedlings were produced by GVI 126 (Scavina 6) with 43.3 per cent recovery. The clone has been identified as one of the valuable sources for transferring resistance to VSD (Bong and Phua, 1989; Phua *et al.*, 1990). The field screening for 15 years showed the superiority of this clone in transferring resistance and it recorded the maximum number (42) resistant hybrids. Attempts to identify mother plants which can produce progenies with high resistance showed that out of 31 female parents used, five parents did not yielded any resistant hybrids, the maximum (42) being produced by GVI 126. However, the percentage recovery of resistant hybrids out of total number of seedlings was highest in GVI 140 (15.2) followed by GVI 126 (14.1). Among the pollen parents, the highest recovery of resistant was recorded by GVI 55 (13.6%), followed by GVI 18.5 (8.4%) resistant plants after nursery screening (Table 3). But, after field screening for 15 years, M 13.12 gave maximum recovery percentage (60%) hybrids.

Pooled mean yield of the hybrids for eleven years (2004-2014) showing 'scale 0' in field screening are depicted in Table 4. Only 51 hybrids out of 267 showed yield of more than 100 pods tree⁻¹ year⁻¹. The plot average yield was only

Table 5. Selection differential of selected hybrids

Sl. No.	Hybrid no	Hybrid	Selection differential
1.	H2	M 13.12 X G VI 55	61
2.	H3	M 13.12 X G VI 55	78
3.	H5	GII 19.5 X G IV 18.5	106
4.	H6	G II 19.5 X G VI 55	114
5.	H7	G VI 4 X GIV 18.5	68
6.	H10	G VI 4 X GIV 18.5	52
7.	H11	G VI 4 X GIV 18.5	139
8.	H15	G VI 4 X GVI 55	123
9.	H32	G VI 126 X GIV 18.5	50
10.	H33	G VI 126 X GIV 18.5	114
11.	H34	G VI 126 X GIV 18.5	99
12.	H35	G VI 126 X GIV 18.5	85
13.	H36	G VI 126 X GIV 18.5	120
14.	H37	G VI 126 X GIV 18.5	61
15.	H40	G VI 126 X GIV 18.5	108
16.	H42	G VI 126 X GIV 18.5	110
17.	H43	G VI 126 X GIV 18.5	66
18.	H44	G VI 126 X GIV 18.5	82
19.	H47	G VI 126 X GVI 55	90
20.	H48	G VI 126 X GVI 55	56
21.	H51	G VI 126 X GVI 55	101
22.	H59	G VI 126 X GVI 55	47
23.	H66	G VI 126 X GVI 55	66
24.	H74	G VI 137 X G VI 55	80
25.	H82	G VI 140 X G IV 18.5	106
26.	H86	G VI 140 X G VI 55	63
27.	H87	G VI 140 X G VI 55	57
28.	H98	G VI 140 X G VI 55	137
29.	H102	G VI 140 X G VI 55	49
30.	H104	G VI 142 X G VI 55	46
31.	H123	G VI 143 X G VI 55	57
32.	H125	G VI 143 X G VI 55	82
33.	H132	G VI 143 X G VI 55	48
34.	H165	G VI 148 X GVI 55	133
35.	H166	G VI 167 X G IV 18.5	59
36.	H182	G VI 171 X GVI 55	79
37.	H183	G VI 172 X G IV 18.5	69
38.	H207	G VI 185 X G IV 18.5	52
39.	H208	G VI 185 X G IV 18.5	130
40.	H209	G VI 185 X G IV 18.5	121
41.	H224	G VI 186 X G VI 55	47
42.	H225	G VI 186 X G VI 55	50

43.	H234	G VI 188 X G VI 55	131
44.	H235	G VI 188 X G VI 55	196
45.	H236	G VI 188 X G VI 55	62
46.	H243	G VI 188 X G IV 18.5	130
47.	H244	G VI 188 X G IV 18.5	143
48.	H245	G VI 188 X G IV 18.5	143
49.	H255	G VI 189 X G VI 55	78
50.	H256	G VI 189 X G VI 55	80
51.	H257	G VI 189 X G VI 55	137

54.87 pods tree⁻¹ year⁻¹. Progenies of same cross when examined for yield showed variation among them. For example, hybrids 1, 2 and 3 are progenies of same cross M13.12 x GVI 55, out of which 2 and 3 are high yielders while one is a low yielder with average of only nineteen pods per year. A similar kind of result was reported in their study by Pang and Lockwood (2007) in cocoa.

Selection differential is considered as a parameter which directly influences the given base population for long term genetic gain (Burdon and Shelbourne, 1971). Hence, selection differential of high yielders were estimated and values are presented in Table 5. All hybrids with high yield expressed high value for selection differential. Selection differential is to be maximized for maximum genetic gain (Burdon and Shelbourne, 1971). These hybrids can be used for establishing a new population of polyclonal garden.

Conclusion

The study showed wide variations in the ability of resistant parents to transfer disease resistance to their progenies. Though some local selections yielded resistant progenies upon crossing in the nursery, the resistance was not reproduced under field condition. This may be due to the presence of only a few resistant genes present in the local parent and they showed susceptibility when new races of the pathogen were introduced. Stable resistance was recorded in 47.9 per cent of field established resistant plants. Assessment of yield of these resistant plants showed that only 19.1 per cent of the plants recorded satisfactory yield levels. However, the 16 year study could generate a big population of plants with stable resistance, which could be utilized for further studies employing conventional and molecular breeding methods.

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