Research Article Journal of Plantation Crops, 2013, 41(1): 40-45

Genotypic variations in chlorophyll fluorescence and stomatal conductance of cocoa in relation to drought tolerance

D. Balasimha*, S. Elain Apshara and C.T. Jose

Central Plantation Crops Research Institute
Regional Station, Vittal - 574243, Karnataka

(Manuscript Received: 28-01-13, Revised: 15-02-13, Accepted: 27-02-13)

Abstract

Cocoa plants are susceptible to environmental conditions, especially temperature and drought. The chlorophyll fluorescence and stomatal characteristics indicated the high adaptation of cocoa leaves to under-storey conditions. The present study was carried out to access the level of drought tolerance in newly introduced genotypes of cocoa. In general, the chlorophyll fluorescence indices and stomatal conductance were significantly decreased during stress period as compared to non-stress period. There were significant variations in these parameters among different genotypes. Similarly, the leaf water potential was also reduced and showed genotypic variations. The results based on cluster analysis indicated existence of 11 groups, based on Rescaled Value Distance (Euclidian distance 5). Among the cocoa clones, AMZ-10/A, AMZ-12 and AM-3/9 were most susceptible to drought. The most tolerant genotypes based on the difference in physiological variables and rank sums were in group 2, which included RIM-189, RIM-2, RB-49, RB-47 and JA-1/19. The results indicated genetic variability in cocoa in response to drought stress.

Keywords: Chlorophyll fluorescence, cocoa, drought, stress tolerance stomatal conductance, water potential

Introduction

Cocoa is endemic to Amazonian basin, although its cultivation has subsequently spread to other regions like Central and South America, West Africa and South-East Asia. In India, cocoa is grown in Southern India in the states of Karnataka and Kerala traditionally as mixed cropping in arecanut and coconut plantations. It is gaining importance and area expansion in other non-traditional regions of Tamil Nadu and Andhra Pradesh. Arecanut, to a considerable extent, and coconut, on a limited scale, are irrigated crops. The changes in climate make the crop vulnerable to drought.

Cocoa plants are susceptible to environmental conditions especially temperature and drought (Raja Harun and Hardwick, 1988a, 1988b; Joly and Hahn, 1989; Balasimha *et al.*, 1991). Efforts made to identify drought tolerance characters among cocoa accessions have resulted in identification of five tolerant clones (Balasimha *et al.*, 1985, 1988). Some of the parents were selected along with high yielding lines for selective breeding (Balasimha *et al.*, 1999). In cocoa, it was found that stomatal conductance was reduced by high photosynthetically active radiation, low relative humidity and moisture stress (Balasimha and Rajagopal, 1988). The photosynthetic rate was influenced by light, temperature and vapour pressure deficit (Balasimha *et al.*, 1991).

Chlorophyll fluorescence measurements are useful techniques for assessing plant stress responses (Daymond and Hadley, 2004). This technique has been used to study light and stress responses in cocoa (Balasimha, 1992). The chlorophyll fluorescence and stomatal characteristics indicate the high adaptation of cocoa leaves to understorey conditions.

Corresponding Author: balasimhad@rediffmail.com

The paper examines changes in chlorophyll fluorescence and stomatal characteristics among newly introduced genotypes of cocoa in relation to drought tolerance.

Materials and Methods

Fifty two genotypes of cocoa were imported from University of Reading, UK and planted in the field under shade of 2.7 x 2.7 m spaced arecanut at a distance of 2.7 x 5.4 m at CPCRI, Regional Station, Vittal during 2007. Field measurements were done using Plant Efficiency Analyzer (Hansatech Instruments Ltd., UK) for chlorophyll fluorescence, Portable Porometer AP4 (Delta -T Devices, UK) for stomatal conductance and Portable Pressure Chamber (Soil Moisture Corp., USA) for water potential as described (Scholander *et al*., 1965; Balasimha, 1992; Balasimha *et al*., 1999). Replicated plants from each genotype were sampled and six leaves were measured per plant with at least 4-6 values from each leaf. Fully expanded healthy third or fourth leaf from distal portion was used for the measurements. For chlorophyll fluorescence measurement, a leaf clip was attached to the leaf and shutter closed for dark adaptation for 30 minutes. The dark adapted leaf was fitted with sensor unit over the clip so that it sealed off light. Holding clip and sensor unit together, the shutter was opened and measurements taken at 60 per cent light level of LED. The stored data were later transferred to computer and analysed. The field measurements were done on these parameters at different seasons *i.e*. non-stress (December) and stress (March/April) conditions during 2009-2010. The stress was imposed by withdrawing irrigation during March-April period. The level of soil moisture was reduced to 60 per cent of field capacity (20%) to induce stress.

Growth characters were also observed in these genotypes. The plant height was taken from ground level upto the tip of the canopy and expressed in meter and girth was measured in the tree trunk at 15 cm height from base. The first branching or the jorquette height was measured on the main stem from ground level. Spread of the canopy was measured in both east west and north south directions. The canopy area was calculated from the mean growth parameters considering the canopy as cone shaped using the formula πrl, where, r= EW+NS/ 4 and l= $\sqrt{(r^2 + h^2)}$, h = canopy height.

Results and Discussion

Among the cocoa clones studied for growth habit, LP 4/32 recorded short stature with 1.6 m height whereas, AMAZ 10/1 and PA 56 grew to a maximum height of 3.7 m at the age of 4 years (Table1). Ten clones recorded high vigour with >30 cm stem girth and it ranged from a lowest of 16.0 cm in B 12/2 to 39.4 cm in PA 56. The first branching height showed non-significant results since primary training and pruning measures were undertaken almost uniformly to all the clones in their initial years of growth. Production of branches differed significantly between clones. PA 56 and SC 1 had more number of branches (9.6). East-West and North-South spread of canopy showed significant results. RIM 10 recorded highest spread both at East-West and North-South directions. JA 1/19 showed the lowest spread in East-West direction and LP 4/32 showed the least in North-South direction. The canopy volume was the minimum in LP 3/40 with 3.31 m^3 whereas big canopy (18.5 m^3) was observed in RIM 10. All clones started yielding and it ranged from a lowest of 5 to 31 pods/tree/year. These growth and yield observations are preliminary and need to be continued throughout the crop period to assess their adaptability, stability and productivity in the introduced environment. Selection of clones based on high yield along with drought tolerance and utilizing them in hybridization program is suggested.

The changes in physiological parameters are shown in Table 2. In general, the chlorophyll fluorescence indices and stomatal conductance were significantly decreased during stress period as compared to non-stress period. There were significant variations among the genotypes in these parameters. Some of the genotypes retained higher gs even under stress conditions showing that they are relatively less affected. However, the tolerance was evaluated based on the differences between the stress and non stress values for all the characters. Similarly, the leaf water potential also reduced and showed genotypic variations. The application of chlorophyll fluorescence as a tool to screen cocoa for drought tolerance has been reported earlier (Balasimha and Namboothiri, 1996). Similarly,

Table 1. Growth performance of Amazon cocoa clones at the age of four years

Sl. No.	Clones	Height (m)	Girth (cm)	HAFB (m)	Branches (no.)	EW (m)	NS (m)	Pods (no.)	Canopy area (m^2)
1	AM 1/8	2.10	19.00	1.08	3.50	2.10	1.85	8.67	4.40
2	AM 3/9	2.00	19.00	1.00	5.00	2.50	2.70	8.33	6.69
3	AMAZ 10/1	3.70	29.00	1.50	5.00	2.60	2.10	6.33	9.20
4	AMAZ 12	2.15	20.00	0.40	4.50	1.80	2.05	6.00	6.04
5	AMAZ 15	2.20	19.67	1.04	3.33	2.40	2.07	15.0	5.65
6	AMAZ 15/5	2.27	23.14	0.63	5.29	2.43	2.56	13.0	8.07
7	B 5/3	3.10	31.00	1.20	4.00	3.10	3.10	7.33	11.9
8	B 5/7	1.85	18.50	0.66	4.00	2.65	2.50	10.0	7.09
9	B 7/14	2.24	20.80	0.65	6.00	2.48	2.58	9.3	8.07
10	B 12/2	1.70	16.00	0.55	3.67	2.16	1.98	7.67	5.03
11	BE 2	2.50	24.67	0.95	4.67	2.67	2.57	13.0	8.35
12	EET 397	3.44	35.33	0.49	8.33	3.42	3.71	13.0	19.3
13	IMC 6	3.38	38.50	0.19	7.00	3.08	3.28	16.0	17.8
14	JA 1/9	1.85	20.00	0.71	3.50	2.35	1.85	8.33	5.11
15	JA 1/19	2.00	19.67	0.62	3.33	1.77	1.83	18.7	4.66
16	JA 5/25	3.15	23.00	1.27	3.00	2.40	2.00	6.67	7.52
17	JA 10/12	2.10	19.50	0.65	5.50	1.90	2.15	8.67	5.62
18	LP 3/40	2.00	20.00	1.08	4.00	2.18	1.20	11.3	3.31
19	LP 1/41	2.50	23.75	1.22	6.75	2.95	2.83	10.7	8.76
20	LP 4/32	1.60	17.00	0.72	3.00	1.87	1.68	15.0	3.48
21	LV 20	3.10	32.00	1.32	8.00	3.10	3.00	10.0	11.2
22	LV 28	2.40	22.00	0.87	4.50	2.40	2.35	9.00	7.22
23	LX 6	2.23	21.33	1.22	5.67	2.60	2.00	5.00	5.53
24	PA 56	3.70	39.40	1.42	9.60	3.60	3.72	24.7	16.8
25	POU 4/B	2.45	21.00	1.17	4.50	1.85	2.05	8.00	4.93
26	POU 7/B	2.65	26.25	1.05	5.00	2.18	2.28	12.7	6.83
27	POU 16/A	2.00	19.00	0.81	4.50	2.30	1.95	18.0	5.32
28	POU 16/B	2.55	22.00	0.61	5.00	2.30	2.05	11.7	7.59
29	POU 18	2.25	17.50	1.00	4.50	2.40	2.15	5.33	6.04
30	POU 18/A	2.35	20.00	0.58	5.25	2.28	2.24	11.0	7.45
31	POU 19/A	2.10	19.50	0.80	6.00	2.75	2.40	6.67	7.40
32	RB 29	2.75	28.00	1.28	4.50	2.55	2.55	22.0	7.79
33	RB 33/3	2.54	27.33	1.28	4.89	2.82	2.71	31.0	8.12
34	RB 46	2.50	24.00	0.97	3.63	2.29	2.43	12.3	7.16
35	RB 47	2.00	21.50	1.05	5.00	2.30	2.65	15.0	6.06
36	RB 49	2.40	20.00	0.79	4.30	2.16	2.23	18.0	6.71
37	REDAMEL	3.07	32.00	1.03	6.78	3.08	2.98	15.0	12.1
38	RIM 2	2.10	19.50	0.55	5.00	2.35	2.40	15.0	7.28
39	RIM 10	3.35	30.50	0.89	8.00	3.70	3.90	30.3	18.5
40	RIM 21	2.30	24.00	0.99	6.00	2.55	2.45	11.0	7.11
41	RIM 39	3.10	20.00	1.18	5.00	3.20	2.00	4.67	9.46
42	RIM 41	2.90	22.00	0.88	3.50	1.78	2.18	10.3	6.99
43	RIM 189	2.13	20.50	0.85	4.50	2.15	2.35	15.00	6.02
44	SC 1	2.80	26.07	0.83	9.57	3.29	3.26	14.0	13.2
45	SC 4	2.25	21.50	0.91	4.60	2.28	2.48	11.3	6.70
46	SC 9	2.28	22.00	0.91	4.25	2.51	2.55	12.0	7.41
47	SC 20	2.58	25.44	0.92	5.56	2.93	3.02	10.3	10.4
48	SJ 1/19	1.95	24.50	1.21	5.50	2.40	2.30	15.0	5.12
49	TSH 516	2.67	25.09	0.94	5.09	2.95	2.94	17.0	10.5
50	UF 11	3.35	33.50	0.35	8.50	3.35	3.35	25.0	18.1
51	UF 221	3.35	30.50	0.61	6.75	3.21	3.26	26.0	16.2
52	UF 667	3.47	34.71	0.60	6.86	3.20	3.27	13.0	16.7
	CV%	19.5	20.2	572	32.9	19.7	18.5	17.2	
	SEd	0.25	24.9	61.1	3.28	0.27	0.24	1.96	
	CD	1.03	10.2	NS	3.70	1.06	1.00	3.18	

HAFB: Height at first branching, EW: East West spread, NS: North South spread

Table 2. Changes in physiological parameters in two seasons

Genotype	Season	Fo (Units)	Fm (Units)	Fv (Units)	Fv/Fm	WP (bars)	Gs (mmol/ m^2/s)
AM-1/8	Non stress	729	3348	2619	0.780	-4.8	149.5
	Stress	756	3250	2527	0.769	-6.7	133.5
AM-3/9	Non stress	671	3742	3071	0.810	-5.1	75.0
	Stress	770	2665	1895	0.709	-9.0	181.0
AMZ-10/1	Non stress	743	3477	2734	0.784	-5.1	263.0
	Stress	763	2940	2178	0.740	-8.2	73.0
AMZ-12	Non stress	751	3677	2927	0.793	-5.5	229.5
	Stress	822	3204	2371	0.743	-8.8	145.5
AMZ-15	Non stress	767	3748	2966	0.792	-5.2	112.0
	Stress	730	3312	2582	0.775	-7.0	105.7
AMZ-15/15	Non stress	730	3612	2882	0.794	-5.3	187.0
	Stress	798	3266	2300	0.741	-7.9	163.5
B-5/3	Non stress	654	3283	2623	0.798	-5.6	226.0
	Stress	869	3320	2451	0.737	-6.1	99.0
B-5/7	Non stress	749	3835	3081	0.770	-6.4	240.3
	Stress	898	3539	2746	0.747	-7.2	182.0
B-7/14	Non stress	687	3701	3017	0.814	-5.6	144.3
	Stress	883	3032	2138	0.703	-7.8	99.7
B-12/2	Non stress	699	3384	2690	0.792	-6.3	184.3
	Stress	870	2964	2096	0.706	-7.5	122.3
BE-2	Non stress	711	3497	2809	0.795	-5.1	168.7
	Stress	857	3392	2390	0.740	-5.8	226.7
EET-397	Non stress	748	3623	2875	0.773	-4.7	272.3
	Stress	781	3118	2317	0.748	-5.6	101.3
IMC-6	Non stress	697	3453	2756	0.797	-6.4	221.0
	Stress	797	3185	2388	0.749	-7.7	78.0
JA-1/9	Non stress	711	3803	3091	0.803	-4.9	192.0
	Stress	912	3295	2382	0.723	-7.3	153.5
JA-1/19	Non stress	743	3499	2589	0.794	-5.6	146.5
	Stress	812	3729	2918	0.782	-6.6	111.0
JA-5/25	Non stress	747	2608	1863	0.713	-6.3	226.0
	Stress	866	3824	2958	0.772	-7.7	67.0
JA-10/12	Non stress	718	3101	2396	0.770	-5.4	232.5
	Stress	743	3241	2349	0.734	-8.7	229.5
LP-3/40	Non stress	764	3260	2449	0.765	-5.4	237.5
	Stress	879	2908	2031	0.697	-7.5	85.0
LP-1/41	Non stress	720	3406	2786	0.784	-5.8	151.3
	Stress	822	3316	2811	0.752	-7.9	140.7
LP-4/32	Non stress	675	3506	2832	0.808	-6.3	179.0
	Stress	719	3130	2406	0.768	-7.7	153.3
LV-20	Non stress	739	3525	2766	0.790	-6.3	218.0
	Stress	877	3056	2179	0.719	-6.8	186.0
LV-28	Non stress	790	3686	2931	0.787	-4.5	98.0
	Stress	777	3528	2751	0.784	-7.9	133.5
LX-6	Non stress	676	3693	3017	0.814	-6.1	298.0
	Stress	835	3058	2224	0.725	-6.3	140.0
PA-56	Non stress	831	3589	2757	0.764	-5.9	194.7
	Stress	937	3489	2339	0.697	-7.4	79.3
POU-4/B	Non stress	690	3454	2763	0.797	-5.1	203.5
	Stress	798	3408	2611	0.763	-7.8	207.5
POU-7/B	Non stress	803	3907	3104	0.794	-5.8	206.7
	Stress	915	3487	2517	0.733	-8.4	200.0
POU-16/A	Non stress	726	3556	2834	0.794	-6.7	174.0
	Stress	804	3026	2131	0.725	-7.5	166.7
POU-16/B	Non stress	706	3601	2928	0.811	-5.3	263.5
	Stress	748	3285	2397	0.727	-8.6	313.0
POU-18	Non stress	692	3470	2778	0.800	-5.3	212.0
	Stress	707	3158	2447	0.775	-7.6	224.0
POU-18/A	Non stress	676	3654	3311	0.814	-6.7	198.3
	Stress	813	3463	2645	0.763	-8.5	123.3
POU-19/A	Non stress	656	3420	2895	0.810	-5.0	221.5
	Stress	888	3144	2256	0.716	-7.8	240.0
RB-29	Non stress	667	3679	2923	0.812	-6.7	252.7
	Stress	806	3650	2860	0.782	-7.2	139.7
RB-33/3	Non stress	736	3453	2816	0.783	-5.9	201.0
	Stress	999	3571	2673	0.718	-6.5	211.3
RB-46	Non stress	763	3475	2712	0.779	-5.0	158.3
	Stress	1010	3304	2297	0.725	-7.5	124.3
RB-47	Non stress	753	2851	2068	0.731	-6.5	180.5
	Stress	829	3189	2357	0.738	-8.0	164.5
RB-49	Non stress	777	3166	2387	0.753	-6.4	201.0
	Stress	903	3425	2522	0.734	-7.6	202.7
Red Amel	Non stress	727	3373	2655	0.786	-5.0	252.0
	Stress	670	2957	2287	0.772	-7.7	151.3
RIM-2	Non stress	716	2844	2131	0.744	-6.3	179.0
	Stress	870	3433	2573	0.746	-7.5	81.0
RIM-10	Non stress	712	2886	2273	0.749	-6.1	290.5
	Stress	758	3137	2379	0.758	-7.9	169.5
RIM-21	Non stress	701	2882	2381	0.791	-5.5	236.5
	Stress	829	3064	2265	0.727	-7.9	185.5
RIM-39	Non stress	635	3331	2696	0.809	-5.6	139.0
	Stress	881	3461	2777	0.761	-7.4	175.0
RIM-41	Non stress	671	3483	2876	0.809	-6.0	196.3
	Stress	861	3466	2593	0.751	-6.8	181.3
RIM-189	Non stress	702	3111	2354	0.771	-5.9	214.0
	Stress	862	3472	2610	0.752	-6.6	137.0
SC-1	Non stress	649	3734	2997	0.820	-5.7	146.7
	Stress	799	3051	2252	0.708	-6.6	124.3
SC-4	Non stress	750	3248	2496	0.767	-6.8	277.7
	Stress	722	2999	2276	0.756	-6.7	192.0
SC-9	Non stress	715	3441	2748	0.791	-6.2	205.3
	Stress	854	3104	2250	0.720	-7.3	114.3
SC-20	Non stress	655	3450	2794	0.809	-6.3	170.0
	Stress	801	3258	2467	0.741	-7.1	128.3
SJ-1/19	Non stress	737	3314	2337	0.758	-5.8	172.5
	Stress	1017	3215	2198	0.683	-8.0	51.0
TSH-516	Non stress	740	3462	2944	0.781	-6.2	232.3
	Stress	722	3278	2555	0.778	-5.7	140.0
UF-11	Non stress	654	3690	3036	0.822	-5.0	242.0
	Stress	647	2787	2180	0.781	-6.5	109.0
UF-221	Non stress	754	3440	2753	0.779	-5.4	231.7
	Stress	680	3105	2417	0.790	-6.1	80.3
UF-667	Non stress	725	3281	2544	0.774	-5.5	276.7
	Stress	725	3173	2541	0.770	-7.4	185.7
Mean	Non stress	718	3437	2732	0.787	-5.7	203.5
	Stress	821	3247	2424	0.747	-7.4	148.3
Sig	Season	**					
	Genotype	**					

Contd...

study of genotypic differences in chlorophyll fluorescence in cocoa genotypes in response to high temperature has also been carried out (Daymond and Hadley, 2004). The ratio of variable to maximal fluorescence (Fv/Fm) is an important indicator of drought tolerance. The results indicated that the genotypes showing higher water potential and Fv/Fm ratio can be considered as drought tolerant.

A more detailed assessment of genotypic responses to water stress conditions was done using a grouping analysis based on the variables shown in Table 3. The ratios between values obtained from stress and non stress conditions among the 52 genotypes were used to build a similarity matrix and

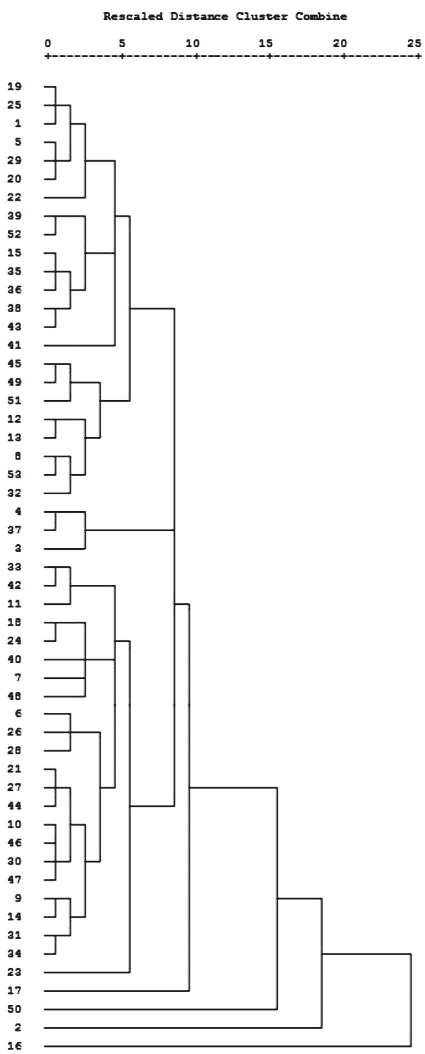

Fig. 1. Euclidian distance-based grouping analysis of 52 genotypes of cocoa subjected to stress, using the differences between non stress and stress values for physiological variables shown in Table 3

Table 3. Difference in values between non stressed and stressed plants

Sl. No.	Genotype	Fo	Fm	Fv	Fv/Fm	WP	Gs	Rank
1	AM-1/8	-22.0	98.0	66.5	0.012	1.9	16.0	16
2	AM-3/9	-99.0	1077.0	1176.0	0.101	3.9	-106.0	50
3	AMZ-10/1	-20.0	537.0	556.0	0.044	3.1	190.0	52
4	AMZ-12	129.5	473.5	555.5	0.050	3.4	84.0	51
5	AMZ-15	36.7	435.3	384.0	0.017	1.8	6.3	27
6	AMZ-15/15	-68.5	-54.0	581.5	0.053	2.6	23.5	33
7	B-5/3	-215.0	-37.0	172.0	0.061	0.5	127.0	11
8	B-5/7	-148.7	296.0	335.3	0.023	0.8	58.3	12
9	B-7/14	-196.3	669.3	878.3	0.112	2.2	44.7	49
10	B-12/2	-171.3	420.0	593.7	0.087	1.3	62.0	38
11	BE-2	-146.3	104.7	418.7	0.056	0.8	-58.0	10
12	EET-307	-33.3	504.7	558.0	0.042	0.8	171.0	44
13	IMC-6	-100.0	268.5	368.5	0.048	1.3	143.0	32
14	JA-1/9	-201.5	507.5	709.0	0.080	2.4	48.5	47
15	JA-1/19	-69.5	-230.0	-329.0	0.012	1.0	35.5	7
16	JA-5/25	-119.0	-1216.0	-1095.0	0.059	1.4	159.0	17
17	JA-10/12	-25.0	-140.0	-337.0	0.061	3.4	3.0	21
18	LP-3/40	-115.5	131.5	418.5	0.068	2.1	152.5	42
19	LP-1/41	-101.7	90.0	-25.7	0.032	2.1	10.7	14
20	LP-4/32	-36.7	376.0	426.0	0.040	1.4	25.7	29
21	LV-20	-138.0	469.0	587.0	0.071	0.5	32.0	31
22	LV-28	12.5	158.0	220.0	0.003	3.4	-35.5	20
23	LX-6	-158.5	635.0	868.5	0.089	0.7	158.0	48
24	PA-56	-106.0	100.3	418.3	0.067	1.5	115.3	36
25	POU-4/B	-107.5	46.0	109.5	0.035	2.3	-4.0	13
26	POU-7/B	-111.7	420.7	614.0	0.060	2.6	6.7	40
27	POU-16/A	-77.7	530.3	702.0	0.069	0.9	7.3	39
28	POU-16/B	-42.0	315.5	531.0	0.084	3.4	-49.5	45
29	POU-18	-15.0	312.0	331.0	0.025	2.3	-12.0	26
30	POU-18/A	-137.0	190.7	666.3	0.051	1.7	75.0	34
31	POU-19/A	-232.0	275.5	639.0	0.094	2.8	-18.5	35
32	RB-29	-139.3	29.3	63.0	0.030	0.6	113.0	9
33	RB-33/3	-263.0	-118.0	143.0	0.065	0.6	-10.3	4
34	RB-46	-247.0	171.7	415.0	0.054	2.5	34.0	24
35	RB-47	-76.0	-338.0	-289.0	-0.008	1.5	16.0	6
36	RB-49	-125.7	-258.7	-135.0	0.019	1.3	-1.7	3
37	Red Amel	57.0	416.0	367.7	0.014	2.7	100.7	43
38	RIM-2	-154.0	-589.5	-442.5	-0.002	1.2	98.0	2
39	RIM-10	-45.5	-250.5	-106.0	-0.005	1.8	121.0	15
40	RIM-21	-128.0	-182.0	116.0	0.064	2.4	51.0	22
41	RIM-39	-246.0	-130.0	-81.0	0.048	1.8	-36.0	5
42	RIM-41	-190.0	-156.7	283.3	0.059	0.8	15.0	8
43	RIM-189	-159.7	-361.0	-256.7	0.025	0.7	77.0	1
44	SC-1	-150.0	683.0	745.0	0.112	1.1	22.3	41
45	SC-4	28.0	249.3	220.0	0.036	-0.1	85.7	23
46	SC-9	-138.7	304.3	498.3	0.071	1.2	91.0	37
47	SC-20	-146.3	191.7	276.0	0.068	0.8	41.7	18
48	SJ-1/9	-279.0	99.0	372.5	0.075	2.2	121.5	28
49	TSH-156	17.3	184.0	388.3	0.003	-0.5	92.3	19
50	UF-11	7.0	903.0	856.0	0.041	-1.5	133.0	46
51	UF-221	73.7	335.7	336.0	-0.011	1.0	151.3	30
52	UF-667	-0.3	108.0	4.7	0.004	1.9	91.0	25

dendrogram (Fig.1). Among these AMZ-10/A, AMZ-12 and AM-3/9 were most susceptible. The most tolerant genotypes based on the difference of physiological variables and rank sums were in group 2, which included RIM-189, RIM-2, RB-49, RB-47 and JA-1/19 (Table 3 and Fig. 1).

The results on genetic variations in cocoa are consistent with earlier studies on photosynthetic characteristics (Balasimha, 1991 & 1999; Daymond and Hadley, 2004; Baligar *et al*., 2008; Daymond *et al*., 2011). These genetic differences can be further utilized in breeding and selection programmes with chlorophyll fluorescence as a selection tool (Balasimha and Nampoothiri, 1996; Daymond and Hadley, 2004). Thus, the 52 genotypes used in this study revealed a general decrease in physiological parameters under stress and showed superiority of RIM-189, RIM-2, RB-49, RB-47 and JA-1/19 for drought tolerance and they recorded >15 pods/tree/ year in their initial years of growth.

Acknowledgment

We are grateful to International Cacao Quarantine Centre, University of Reading, Reading, UK for supplying the cocoa germplasm materials.

References

Balasimha, D. 1992. Net CO_2 assimilation and chlorophyll fluorescence in cocoa trees. *Plant Physiology and Biochemistry* **19**: 23-26.

Balasimha, D. and Namboothiri, C.G.N. 1996. Chlorophyll fluorescence of cocoas in relation to drought tolerance. *Plant Physiology and Biochemistry* **23**: 64-66.

Balasimha, D. and Rajagopal, V. 1988. Stomatal responses of cocoa to changes in climatic factors. *Journal of Agricultural Science* **58**: 213-216.

Balasimha, D., Anil Kumar, V., Viraktamath, B.C. and Ananda, K.S. 1999. Leaf water potential and stomatal resistance in cocoa hybrids and parents. *Plantations Recherche Developpement* **6**: 116-120.

Balasimha, D., Daniel, E.V. and Bhat, P.G. 1991. Influence of environmental factors on photosynthesis in cocoa trees. *Agricultural and Forest Meteorology* **55**: 15-21.

Balasimha, D., Rajagopal, V., Daniel, E.V., Nair, R.V. and Bhagavan, S. 1988. Comparative drought tolerance of cocoa accessions. *Tropical Agriculture* **65**: 271-274.

Balasimha, D., Subramonian, N. and Subbaiah, C.C. 1985. Leaf characteristics in cocoa (*Theobroma cacao* L.) accessions. *Cafe Cacao The* **29**: 95-98.

Baligar, V.C., Bunce, J.A., Machado, R.C.R. and Elson, M.K. 2008. Photosyntheic photon flux density, carbon dioxide concentration and vapor pressure deficit effects on photosynthesis in cacao seedlings. *Photosynthetica* **46**: 216-221.

Daymond, A. and Hadley, P. 2004. The effects of temperature and light integral on early vegetative growth and chlorophyll fluorescence of four contrasting genotypes of cacao (*Theobroma cacao*). *Annals of Applied Biology* **145**: 257-262.

Daymond, A., Tricker, P.J. and Hadley, P. 2011. Genotypic variation in photosynthesis in cacao is correlated with stomatal conductance and leaf nitrogen. *Biologia Plantarum* **55**: 99-104.

Joly, R.J. and Hahn, D.T. 1989. Net CO_2 assimilation of cocoa seedlings during periods of plant water deficit. *Photosynthesis Research* **21**: 151-159.

Raja Harun, R.M. and Hardwick, K. 1988a. The effects of prolonged exposure to different light intensities on the photosynthesis of cocoa leaves. In: *Proc. 10th International Cocoa Research Conference*.May 17-23rd 1987, Santo Domingo, Dominican Republic, COPAL, Lagos, Nigeria. pp. 205-209.

Raja Harun, R.M and Hardwick, K. 1988b. The effect of different temperature and water vapour pressure deficit on photosynthesis and transpiration of cocoa. pp. 211-214. In: *Proc. 10th International Cocoa Research Conference*. May 17-23rd 1987, Santo Domingo, Dominican Republic, COPAL, Lagos, Nigeria.

Scholander, P.F., Hammel, H.T., Bradstreet, E.D. and Hemingen, E.A. 1965. Sap pressure in vascular plants. *Science* **148**: 339-346.