Research Article *Journal of Plantation Crops, 2008, 36 (1): 8-11*

Photosynthetic characteristics and yield in cocoa hybrids

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(Manuscript Received: 20-03-07, Revised: 26-06-07, Accepted: 07-02-08)

Abstract

In cocoa, crossing work involving high yielding and drought tolerant parent trees were undertaken. Nine promising hybrid lines were developed under this programme. These have been planted in the field in a RBD at CPCRI Research Centre, Kidu along with parents. Measurements were made in the field using portable photosynthetic system (Li - 6200), Plant Efficiency Analyzer (Hansatech) and portable pressure chamber for leaf water potential. Photosynthetic parameters were studied in nine hybrids and seven parents with high yield and drought tolerant characteristics. There was variability among the hybrids with respect to photosynthetic characters. Significant differences in these parameters with respect to season were also noted. Drought tolerance was observed among I-21 x NC 42/94 and I-29 x NC 23/43. The results showed that these hybrids retained higher water potential and stomatal regulation comparable to drought tolerant parents. Variability in bean yields among hybrids and parents were noted. High yields were recorded in I-21 x NC 29/66, II-67 x NC 29/66 and II-67 x NC 42/94.

Keywords: cocoa hybrids, drought tolerance, photosynthesis

Introduction

Cocoa is grown in Karnataka and Kerala traditionally as mixed crop in arecanut and coconut plantations. It is gaining importance in other non-traditional regions of Tamil Nadu and Andhra Pradesh. As arecanut to a considerable extend and coconut on a limited scale are irrigated crops, the microclimatic conditions in these areas are congenial for cocoa cultivation.

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 tolerant characters among cocoa accessions have resulted in identification of five tolerant ones (Balasimha *et al*., 1985,1988). Some of the parents were selected along with high yielding lines for selective breeding (Balasimha *et al*., 1999). Balasimha and Rajagopal (1988) found that stomatal conductance was reduced by high photosynthetically active radiation, low relative humidity and moisture stress. 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, 2003). This technique has been used to study light and stress responses in cocoa (Balasimha, 1992). The chlorophyll fluorescence and photosynthesis data indicate the high adaptation of cocoa leaves to understory conditions. This paper examines changes in photosynthetic characteristics and yield in hybrids and parents of cocoa in relation to drought tolerance.

Materials and Methods

Four high yielding trees viz., I-14 (Red axil), I-21, I-29 (Amel x Na33) and II-67 (Landas 364) were selected as female parents. They were crossed with three drought tolerant pollen parents viz., NC 23/43 (P3 x P), NC 29/66 (P6 x P4) and NC 42/94 (T 86/2). From this nine hybrids were obtained and planted along with seven parents in a RBD with three replications in 1991 at CPCRI Research Centre, Kidu, Karnataka. The detailed methods are described in earlier paper (Balasimha e*t al*. 1999).

Field measurements were done using Li-6200 Portable Photosynthesis System (Li Cor, USA) and Portable Pressure Chamber as described (Scholander *et al*., 1965; Balasimha *et al*., 1991). Two plants from each plot were sampled and six leaves were measured per plant with at least 4 - 6 values in each leaf. In each case, fully expanded healthy third to fourth leaf from distal portion were used. The measurements were done using one liter chamber enclosing up to 30 cm^2 leaf area and equilibrated for 1-2 min. Water use efficiency (*Pn/E*) and other ratios viz., *Pn/gs* and *Pn/Ci* were also computed. Leaf water potential was measured in a pressure chamber (Soil Moisture Corp., USA). Chlorophyll fluorescence was measured using Plant Efficiency Analyzer (Hansatech, UK). A leaf clip was attached to the leaf and shutter closed for dark adaptation for 30 min. 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 were taken at 80 per cent light level of LED. The stored data were later transferred to computer and analysed. The measurements were made during unstressed (October) and stressed (February/March) conditions during 1995-1997. Chlorophyll pigments were extracted in 85 per cent acetone, filtered and measured using a UV-Visible spectrophotometer (Arnon, 1949). Yield data of dry beans collected for three years (1995-1998) and tabulated as means.

Results and Discussion

The leaf chlorophylls, carotene and leaf water potential were measured in nine hybrids and seven parents of cocoa (Table 1). There were significant differences in these parameters between unstressed (November) and stressed (March) seasons. Pigment contents and water potential decreased during March. Among the hybrids II-67 x 29/66 and I-21 x 42/94 showed higher pigment contents, while parents II-67 and 29/66 had higher values. Higher water potential was recorded in I-29 x 23/43, I-21 x 42/94, I-29 x 42/94, II-67 and 23/43.

Net photosynthesis and related parameters were measured during the un-stress (October) and stress (March) seasons in cocoa hybrids and parent plants. Net photosynthesis did not show significant differences

Table 1. Water potential and chlorophyll contents

Treatment Variety	Water Potential (Mpa)	Chl a (mg/g)	Chl b (mg/g)	Carotene (mg/g)
I-14 x NC 29/66	-1.25	1.417	0.631	0.353
I-14 x NC 42/94	-1.03	1.574	0.689	0.380
I-21 x NC 23/43	-0.96	1.427	0.634	0.364
I-21 x NC 29/66	-1.16	1.332	0.611	0.364
I-21 x NC 42/94	-1.05	1.475	0.642	0.407
I-29 x NC 23/43	-0.89	1.266	0.550	0.385
I-29 x NC 42/94	-1.01	1.234	0.539	0.349
II-67 x NC 29/66	-1.14	1.575	0.692	0.409
II-67 x NC 42/94	-1.10	1.368	0.664	0.403
I-14	-1.17	1.346	0.617	0.314
I-21	-1.01	1.220	0.574	0.323
I-29	-1.09	1.310	0.569	0.366
II-67	-0.90	1.436	0.641	0.374
23/43	-0.98	1.464	0.645	0.406
29/66	-1.08	1.445	0.649	0.387
42/94	-1.10	1.561	0.659	0.431
Season				
Unstressed	-0.82	1.554	0.665	0.389
Stressed	-1.30	1.252	0.588	0.365
CD (P < 0.01)	-0.05	0.108	0.68	NS

among the treatment (Table 2), while transpiration and conductance showed significant variations. However, *Pn* and transpiration were lower in hybrids, which showed significantly lower stomatal conductance. The hybrids viz., I-29 x NC 23/43 and I-29 x NC 42/94 showed this trait retaining higher leaf turgor. There were significant differences with respect to seasons. The *Pn* and transpiration were lowered due to stress conditions in all hybrids and parents to variable degrees. Stomatal conductance also showed similar decreases. This fact confirms the earlier results that transpirational water loss is reduced with increased stomatal closure, which is a favourable drought trait in cocoa (Balasimha *et al*., 1991,1999). Similar results on stomatal resistance and drought resistance association (Nunes 1967; Joly and Hahn, 1989) and lesser transpiration rate (Segbor *et al*., 1981) were reported. It is possible that the ability to tolerate drought results from stomatal regulation, thus reducing transpirational water loss.

The *Pn/gs* ratio increased with stress that showed variations among the hybrids (Table 3). This increase leads to decrease in *Ci* suggesting that mesophyll factors are not affected much in cocoa. The depression in *Pn* was primarily due to lowered *gs* as they are positively correlated (Fig.1). Consequently any fluctuations in gs will reflect in values of *Pn* and transpiration. Despite stomatal control limiting *Pn*, there was small change in WUE during stress as compared to non-stress conditions. The highest WUE was recorded in I-21 x NC 42/94 followed by NC 29/66, which also showed lower *gs*.

Table 2. Net photosynthesis and related parameters

Treatment	*Pn* (µmol m² s-¹)		*Transpiration* (mmol m² s⁻¹)		*gs* (mol m² s⁻¹)		CO_2 internal (ppm)	
	US	S	US	S	US	S	US	S
I-14 x NC 29/66	5.13	3.54	5.80	5.14	0.43	0.31	297	278
I-14 x NC 42/94	6.05	3.23	5.45	4.46	0.41	0.11	294	275
I-21 x NC 23/43	5.50	3.38	5.88	4.57	0.25	0.12	287	283
I-21 x NC 29/66	5.78	3.40	5.90	4.98	0.25	0.12	274	272
I-21 x NC 42/94	5.46	4.10	5.04	3.77	0.22	0.10	268	264
I-29 x NC 23/43	4.75	2.43	4.16	2.59	0.24	0.08	291	280
I-29 x NC 42/94	3.67	3.53	4.79	3.88	0.33	0.12	307	275
II-67 x NC 29/66	6.42	3.49	6.04	5.36	0.28	0.12	296	253
II-67 x NC 42/94	5.44	4.27	6.11	5.57	0.34	0.19	278	296
I-14	5.56	3.99	4.96	4.62	0.47	0.11	307	262
I-21	4.58	3.60	4.87	4.45	0.18	0.12	290	276
I-29	6.55	3.83	5.68	5.67	0.27	0.15	282	272
II-67	5.71	4.66	6.01	4.62	0.45	0.14	301	263
NC 23/43	5.45	3.92	5.68	5.57	0.24	0.10	285	270
NC 29/66	5.36	3.80	5.07	3.11	0.33	0.08	250	253
NC 42/94	5.66	3.64	4.94	4.03	0.27	0.10	278	271
Mean	5.44	3.67	5.37	4.56	0.30	0.14	287	271
CD (P=0.05)								
Treatment	NS		0.98		0.11		13.5	
Season	0.45		0.47		0.05		6.1	

US – Unstressed; S - Stressed

Mean microclimatic variables :

Variable	Unstressed	Stress
PAR µmol/m²/s	494.9	847.5
RH %	59.53	42.83
VPD kPa	20.31	38.67
Temp. Leaf ºC	32.88	38.47
Temp. Air ºC	32.97	37.62

Table 3. Photosynthesis and relations with other stomatal parameters

Treatment	*Pn/E* (WUE)		*Pn/gs*		*Pn/Ci*	
	US	S	US	S	US	S
I-14 x NC 29/66	0.608	0.688	8.20	11.41	0.012	0.013
I-14 x NC 42/94	1.110	0.707	14.75	29.36	0.021	0.012
I-21 x NC 23/43	0.935	0.678	22.00	28.16	0.019	0.012
I-21 x NC 29/66	0.979	0.902	23.12	28.33	0.021	0.012
I-21 x NC 42/94	1.083	1.583	24.80	41.00	0.020	0.015
I-29 x NC 23/43	1.141	0.626	19.79	30.37	0.016	0.009
I-29 x NC 42/94	0.766	0.658	11.12	29.41	0.012	0.013
II-67 x NC 29/66	1.062	0.626	22.90	28.60	0.013	0.014
II-67 x NC 42/94	0.890	0.924	16.00	22.23	0.019	0.014
I-14	1.121	0.896	11.82	33.52	0.018	0.015
I-21	0.941	0.635	25.44	29.75	0.016	0.013
I-29	1.153	0.829	24.25	25.19	0.023	0.014
II-67	0.950	1.008	12.68	32.13	0.019	0.018
NC 23/43	0.959	0.704	22.70	25.45	0.019	0.014
NC 29/66	1.057	1.222	16.24	47.50	0.021	0.015
NC 42/94	1.145	0.903	20.96	36.40	0.020	0.013
Mean	0.993	0.849	18.54	29.92	0.118	0.013

US - unstressed; S - stressed

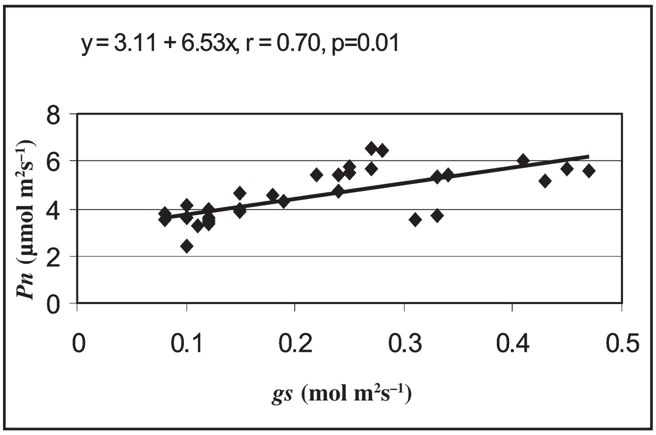

Fig. 1. Correlation of *Pn* with *gs* in cocoa

Because of linear relationship of *Pn* and I, the *Ci/Cair* remained relatively constant (0.80-0.88) despite seasonal or treatment variations. This type of relationship has been attributed to adaptation for water stress conditions in cocoa (Balasimha *et al*., 1988; Balasimha, 1993). The ratio of *Pn/Ci* decreased during stress period. A regression model of *Pn/E* vs *Pn/Ci* showed a positive linear and significant relationship ($r = 0.63$, $P<0.01$). This shows that high intrinsic WUE was associated with high carboxylation efficiency, which can contribute to higher productivity and adaptability. The positive relationship of *Pn* to WUE ($r = 0.59$, $P< 0.01$) confirms this conclusion.

Chlorophyll fluorescence indices also showed differences between treatments and seasons (Table 4). Due to stress the values decreased suggesting the photochemical reaction was affected due to stress. Hybrids II-67 x NC 29/66 and II-67 x NC 42/94 were least affected showing their relative stability. However, no clear variations could be noticed among the hybrids and parents with reference to drought tolerance.

Table 4. Chlorophyll fluorescence parameters (units)

Treatment	Fo	Fm	Fv	Fv/Fm
I-14 x NC 29/66	712	2551	1838	0.715
I-14 x NC 42/94	680	2399	1717	0.709
I-21 x NC 23/43	686	2054	1685	0.708
I-21 x NC 29/66	746	2386	1654	0.680
I-21 x NC 42/94	689	2363	1673	0.701
I-29 x NC 23/43	878	2608	1733	0.653
I-29 x NC 42/94	711	2352	1640	0.692
II-67 x NC 29/66	634	2653	2018	0.750
II-67 x NC 42/94	615	2515	1899	0.743
I-14	718	2462	1759	0.710
I-21	698	2479	1782	0.698
I-29	758	2259	1500	0.669
II-67	727	2547	1819	0.704
NC23/43	731	2245	1514	0.645
NC29/66	760	2549	1788	0.694
NC42/94	691	2320	1625	0.700
CD (P=0.05)	95	NS	NS	0.052
Season	666	2442	1776	0.720
Unstressed	763	2401	1680	0.677
Stress				
CD (P=0.05)	51	NS	NS	0.021

The dry bean yield was recorded in all the hybrids and parents during this period (Table 5). There were significant variations in yield among the treatments. The hybrids II-67 x NC 29/66, II-67 x NC 42/94 I-21 x NC 29/66, showed the highest yields. The hybrid I-29 x NC 23/43, which showed moderately high yield (0.883 kg) also had the highest positive physiological traits for drought tolerance. Based on these studies these four hybrids can be recommended for cultivation in water limited conditions.

Table 5. Dry bean weight of 3 years mean (kg/plant/year)

Treatment	dry bean yield
I-14 x NC 29/66	0.921
I-14 x NC 42/94	0.804
I-21 x NC 23/43	1.000
I-21 x NC 29/66	1.283
I-21 x NC 42/94	0.653
I-29 x NC 23/43	0.883
I-29 x NC 42/94	0.645
II-67 x NC 29/66	2.048
II-67 x NC 42/94	1.515
I-14	1.248
I-21	0.738
I-29	0.751
II-67	1.038
NC 23/43	0.648
NC 29/66	0.526
NC 42/94	1.003
Mean	0.983
CD (P= 0.05)	0.136

Acknowledgments

We thank ICAR, New Delhi for grant of Scheme under AP Cess Fund for these studies.

References

Arnon, D.I. 1949. Copper enzymes in isolated chloroplasts. Polyphenol oxidase in *Beta vulgaris*. *Plant Physiol*. **24**: 1-15.

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

Balasimha, D. 1993. Stomatal conductance and photosynthesis in cocoa trees. *Plant Physiol. Biochem*. **20**: 16-18.

Balasimha, D. and Rajagopal, V. 1988. Stoamatal responses of cocoa to changes in climatic factors. *J. Agric. Sci*. **58**: 213-216.

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

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

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

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 Developement* **6**: 116-120.

Daymond, A. and Hadley, P. 2003. Physiological charactersation of cocoa germplasm. pp. 103-109. In: *Proc. International Workshop Cocoa Breeding for Improved Production systems*. (Eds. F. Bekele, M.J. End and A.B. Eskes).19-21 October 2003., Accra, Ghana.

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

Nunes, M.A. 1967. A comparative study of drought resistance in cacao plants. *Ann. Bot*. **31**:189-193.

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

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 17-23, 1987, Santo Domingo, Dominican Republic, COPAL, Lagos, Nigeria.

Segbor, A., Djiekpor, E.K., Amefia, Y.K. and Partiot, M. 1981. Amelioration du cacaoyer; mise au point d'un test d'evaluation precoce de la resistance a la secheresse. pp. 131-133. In: *Proc. 7th International Cocoa Research Conference*. 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.