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Genetic diversity for plant water relations, gaseous exchange, leaf anatomical characteristics and seed yield in cowpea under receding soil moisture

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Abstract

Drought stress is the major constraint in cowpea grown on stored soil moisture conditions especially during the pod formation period. The long term sustainable and environmentally desirable solution is development of new varieties with drought tolerance. To generate information on the effect of receding soil moisture on physiological traits and yields would be helpful in identifying and developing drought-tolerant cowpea genotypes. A field experiment was conducted on 25 diverse genotypes of cowpea at CCS Haryana Agricultural University, Hisar. The genotypes were grouped on the basis of flowering initiation and the physiological observations were recorded during the flowering stage. Highly significant genotypic differences were detected between and within the group for physiological traits, biomass, yield attributes and seed yield. The early flowering genotypes (Group-I) showed lower leaf water potential (LWP), higher leaf water content (RWC), canopy temperature depression (CTD) and photosynthetic rate (P_N) compared to medium (Group-II) and late (Group III) flowering genotypes. RWC and CTD were significantly associated with seed yield. RWC was also correlated with P_N Therefore, the traits RWC and CTD, which are simple to measure, could be used for screening cowpea germplasm for drought tolerance.

Key words: Canopy temperature depression, cowpea, drought tolerance, relative water content

Introduction

Cowpea (*Vigna unguiculata* L. Walp.), an important arid legume crop is mainly grown in arid and semi arid regions of the country for pulse and forage production. The crop grown on conserved soil moisture often encounters drought during reproductive phase of development constraining high productivity either due to long dry spell or early withdrawal of monsoon rains. Breeding improved genotypes for the arid and semiarid tropics by selection solely for seed yield is difficult, because of the variability in amount and temporal distribution of available moisture from year to year. The genotypic variation in yield is low under these conditions. Researchers now believe that better adapted and high yielding genotypes could be bred more efficiently and effectively if traits that confer yield under drought conditions could be identified [1]. Limited progress made in cowpea breeding for unfavorable environments is largely attributed to lack of techniques to handle large number of germplasm lines. Simple and rapid techniques can facilitated selection of moisture stress tolerant genotypes at early stages of breeding. Early maturing varieties that escape terminal drought and heat stress need to be developed to break ceiling on the potential yield as well as to exploit the extended growth period as a result of late monsoon rains received during the pod filling stage. Frequent drought, besides lowering the crop yield also impairs the seed quality by reducing the seed size. Field research has been showing differences in growth and grain yield among cowpea cultivars when subjected to drought conditions during the growing season [2]. Therefore, it can be supposed that differences exist among them that could be linked to differences in adaptive drought mechanisms. The two main mechanisms of drought resistance in plants are drought avoidance and drought tolerance. In short duration cowpea genotypes, the mechanisms of drought tolerance are needed in obtaining high yield under stored soil moisture because the water resources are not available or they are too expensive. To produce these new cultivars, plant breeding efforts must be diverted to identify germplasm with increased drought tolerance, and must be selected for drought tolerance traits cheaply and efficiently. The component traits of drought tolerance in pulse crops include dry matter partitioning, root traits and plant water status [3]. Hence the present experiment was conducted to evaluate the genotypic differences in plant water relations and seed yield in cowpea under receding soil moisture conditions. An effort was also made to explore the utility of physiological traits as a selection criterion for screening cowpea genotypes tolerant to moisture stress. This will help in identification and development of improved cowpea genotypes with better adaptation and high yield for drought prone areas.

Materials and methods

The experiment was conducted at Crop Physiology Field Laboratory, CCS Haryana Agricultural University, Hisar (29° 10'N latitude, 75° 46' E longitude and 215 M altitude), India. Twenty five cowpea genotypes (received from Project Coordinator, Arid Legumes, CAZRI, Jodhpur, Table 1) were grown in concrete drought plots (30 m length x 6 m width x 2 m depth) filled with light textured dunal sand. Four rows of 2.5 m length with row to row and plant to plant spacing of 45 x 15 cm of each genotype were sown under rainfed conditions adopting randomized block design with four replications. Seeding was performed on 26 July 2006. At seeding, 195 cm soil profile retained 16.5% soil moisture (v/v basis). During the growing season, 112.2 cm rainfall was received. No post sowing irrigation was applied to the crop. Recommended agronomical practices were adopted to raise the crop. The soil moisture content was determined by a neutron moisture meter (Model 2651 Troxler laboratories, Releigh, NC, USA) in 0-165 cm soil depth. The soil moisture content at the time of observations were 5.21± 0.65% (v/v, mean ±SD) at the 0-15 cm, 6.76±0.52% at the 15-45 cm, 8.24±0.48 at the 45-75 cm, 9.56±0.34 at the 75-105 cm, 12.72±0.67 at the 105-135 cm, 15.54±0.37 at the 135-165 cm soil depth on the average basis.

The cowpea genotypes were grouped on the basis of days taken to flowering. The Group I initiated flowering 45 Days after sowing (DAS), Group II in 54 DAS and Group III in 63 DAS. Agro-physiological traits and leaf anatomical characteristics were measured group-wise at flowering stage. The leaf area was measured at 45 DAS by portable area meter (Model LI 3050, LI-COR, Lincoln, Nebraska). The plant water relation parameters were recorded at flowering stages (45, 54 and 63 DAS) between 13.00 to 13.30 h. A fully expanded youngest leaf from the top of the plant on the main shoot was used for the measurements. The leaf water potential (ψ_w) was measured by Pressure Chamber (PMS Instrument Co., Oregon, USA), and canopy temperature depression (CTD) using Infra-red thermometer (Model AG-42 Tela-temp Corp.CA). RWC was estimated by using the equation [4]:

RWC = f.wt - d.wt / m.wt - d.wt,

Where, f.wt, d.wt and m.wt are the fresh, oven-dry and fully-hydrated (maximum) weights of the leaf disks. A sharp cork borer was used to take 8 leaf disks of 15 mm diameter. Leaf anatomically characteristics such as specific leaf weight (SLW) and succulence index (Sucl) were calculated with the help of the following equations:

SLW = d.wt / total sampled leaf area

Sucl = (f.wt - d.wt) / total sampled leaf area

The net photosynthetic rate (P_N) and transpiration rate (E) were measured using Infra-red Gas Analyzer (IRGA, CIRAS-1, PP System, UK). The IRGA measurements were made on fully expanded leaves between 10.00-11.00 h of day on the portion of leaves exposed directly to sunlight on five plants in random in each plot.

All mature pods in each plot were harvested, and the number and length of pods/plant, biomass and seed yield/plot was recorded. Biomass and seed yield were converted to values per unit area. The number of seeds/pod (from 20 pods in each plot) and 100-seed weight were measured. The statistical analysis for different parameters was worked out on the basis of their flowering group as per standard procedures.

Results and discussion

The dry matter and leaf area differed significantly at 45 days after sowing. The dry weight was highest in Group-I followed by Group-III and least in Group-II. However leaf area was recorded higher in Group-III followed by Group-I and II (Table 2). Among the genotypes, NDS 39890, RL-19, VKG 21/52, V 240 and EC 472291 recorded highest dry matter and leaf area irrespective of the different groups. Our findings on dry matter accumulation confirm to earlier observations that higher leaf area helped to maintain higher total dry matter in cowpea [5]. The differences among genotypes were significant between the groups and within the groups. On an average, Group-I showed lower leaf water potential (LWP), higher RWC and higher CTD compared to Group-II and III. Photosynthetic rate (P_N) was also higher in Group-I than Group-II and III (Table 1). However, transpiration rate (E) was higher in Group-II than Group-I and III genotypes. Specific leaf weight (SLW) and succulence index (Sucl) was observed to be higher in Group-III than the genotypes of Group-I

Table 1. Leaf water potential (LWP), relative water content (RWC), canopy temperature depression (CTD), photosynthetic rate (P_N), transpiration rate (E), specific leaf weight (SLW) and succulence index (Sucl) of cowpea genotypes. Measurements were made at flowering stage (45 DAS in Group-I, 54 DAS in Group-II and 63 DAS in Group-III)

Genotype	LWP (MPa)	RWC (%)	CTD (°C)	P_N (μ mol $m^{-2}s^{-1}$)	E (m mol $m^{-2}s^{-1}$)	SLW (mg DW cm^{-2})	Sucl (mg H_2Ocm^{-2})
				Group-I			
EC 39853	–0.98	91.50	4.70	23.86	4.95	25.27	90.69
EC 39888	–0.93	87.00	3.90	23.53	4.77	21.87	85.23
EC 472254	–0.73	83.93	2.00	24.00	5.58	21.31	94.28
EC 472267	–1.13	86.45	3.00	17.26	3.94	31.49	117.28
EC472268	–0.73	93.33	4.80	24.56	4.97	25.45	109.36
NDS 39890	–0.65	81.04	3.60	19.90	4.79	18.67	79.76
EC 496737	–1.02	85.75	2.80	20.60	4.37	35.07	171.02
HKP 7/54	–1.02	80.25	2.00	23.13	4.57	28.09	92.39
VKG 2 1/52	–1.12	84.70	3.40	18.00	4.26	22.63	88.81
GC 3 (C)	–1.22	86.59	4.60	18.00	4.71	26.02	114.45
RL-19(C)	–0.78	88.09	2.50	23.83	5.19	24.13	99.37
C.D. (5%)	0.10	4.78	0.61	1.78	0.83	7.77	23.38
C.V. (%)	6.21	3.30	9.02	4.97	10.14	17.81	13.12
				Group-II			
EC 472280	–0.73	83.10	0.76	24.00	4.96	28.09	124.82
V 585 (C)	–0.87	75.42	0.77	19.10	5.36	21.87	88.43
EC 472270	–0.77	83.85	1.00	21.50	5.73	21.49	98.05
EC 472293	–0.90	84.83	0.80	15.90	5.91	26.40	122.94
EC 472266	–1.07	75.95	0.73	15.00	6.27	28.09	112.19
EC 472253	–0.82	77.82	0.70	20.63	5.48	25.08	108.04
V 240 (C)	–1.05	77.14	1.10	15.00	4.75	22.44	93.90
EC 472250	–0.97	75.63	0.70	15.30	4.23	27.34	108.04
C.D. (5%)	0.07	11.81	0.16	3.04	0.52	3.81	17.38
C.V. (%)	6.57	12.06	11.29	11.86	7.87	12.32	13.14
				Group-III			
EC 472273	–0.98	79.43	2.30	15.90	3.91	33.19	132.93
NDS 547	–0.88	76.08	1.50	12.87	3.59	23.57	95.60
EC 472288	–1.15	78.68	2.90	13.13	4.26	28.28	107.47
EC 472291	–1.22	78.98	3.70	13.17	3.67	27.72	98.42
EC 472295	–1.05	64.00	3.30	9.33	2.83	29.98	102.38
EC 472296	–0.93	82.72	3.96	15.00	3.43	27.53	106.34
C.D. (5%)	0.096	9.35	0.60	1.12	0.60	7.33	20.65
C.V. (%)	6.15	6.95	17.34	6.89	12.86	20.11	14.98

and II. Among the genotypes the highest LWP was observed in NDS 39890 closely followed by EC 472268. Whereas, genotype EC 472268 also maintained higher RWC and P_N among the Group-I. The genotype EC 472280 maintained the highest LWP and P_N in Group-II. Among the Group-III, the genotype NDS 547 maintained the lowest LWP and CTD. The genotypes which displayed lower LWP maintained higher RWC either by developing a LWP gradient from soil to plant or by reduced water loss from the plant organs. The

Table 2. Leaf area, yield-attributes, biomass and seed yield of cowpea genotypes

Genotypes	45 DAS		At harvest				
	Leaf area (cm^2/plant)	Biomass (g/plant)	Pod length (cm)	Number of seeds/pod	100-seed weight (g)	Biomass (g m^{-2})	Seed yield (g m^{-2})
			Group-I				
EC 39853	1294.1	8.40	10.95	12.67	6.57	566.70	180.83
EC 39888	1043.0	7.95	11.50	13.67	7.00	633.35	148.34
EC 472254	1195.2	8.77	14.82	10.17	15.97	333.35	50.00
EC 472267	668.6	6.84	15.42	12.66	16.68	433.35	105.00
EC 472268	1381.6	8.17	15.00	13.33	15.05	616.65	180.84
NDS 39890	1697.2	11.89	10.78	12.17	6.45	483.30	125.83
EC 496737	561.7	7.03	15.88	10.33	17.42	400.00	86.67
HKP 7/54	732.8	5.22	13.15	11.50	6.40	350.00	60.00
VKG 2 1/52	1560.3	10.61	11.73	10.67	9.10	516.70	105.00
GC 3(C)	853.3	7.25	14.55	14.17	8.41	441.65	140.00
RL-19(C)	1564.9	10.16	12.30	13.00	8.40	316.70	85.84
			Group-II				
EC 472280	727.8	5.33	15.40	8.50	23.46	516.65	79.17
V 585(C)	1341.3	9.00	13.90	12.33	6.93	516.65	29.50
EC 472270	899.3	5.33	16.10	12.67	13.81	283.30	32.50
EC 472293	945.0	6.33	14.85	11	13.96	556.65	51.67
EC 472266	639.3	3.67	13.58	8.33	10.29	275.00	16.33
EC 472253	964.4	7.52	12.38	8.83	14.18	533.30	113.33
V 240 (C)	1500.4	9.85	17.25	13.17	10.89	466.65	75.83
EC 472250	1446.8	8.87	18.62	15.00	13.63	350.00	45.00
			Group-III				
EC 472273	1131.0	9.33	15.28	10.33	18.19	683.35	101.67
NDS 547	1398.9	7.33	17.43	16.50	10.49	350.00	18.34
EC 472288	742.5	5.17	15.25	11.67	12.03	391.70	17.84
EC 472291	1468.8	10.50	17.45	13.67	12.57	600.00	62.50
EC 472295	1593.4	7.50	12.53	6.50	12.40	300.00	14.33
EC 472296	1248.6	7.33	15.98	12.00	14.14	416.70	32.50
C.D. (5%)	387.62	2.15	2.22	2.60	3.91	150.61	35.85
C.V. (%)	20.57	16.69	13.38	19.24	15.48	16.00	22.04

genotypes which had higher ability to extract moisture at low soil water content due to reduced LWP contributed to the maintenance of higher RWC. Whereas, on the other side, some genotypes also maintained higher RWC may be due to reduced transpiration rate without affecting the photosynthetic efficiency. In cowpea, osmotic adjustment had also been found to be responsible in preventing the detrimental effects of drought in leaves [6, 7]. The values of SLW and Sucl were recorded highest in genotypes EC 496737, EC 472280 and EC 472273 respectively among each group. Higher SLW and Sucl indicate the lesser water loss due to leaf thickness and more leaf water content respectively. Enhanced RWC, SLW and Sucl helped the plants to perform various physiological processes like photosynthesis, CTD and biochemical metabolism to continue more efficiently even under low soil moisture conditions [8]. Cooler canopy of these genotypes might be associated with better water uptake/ efficient root system and higher water status for longer period suggesting that the genotypes may be better for soils where water is available in deeper layers due to their increased water extracting capacity and maintained higher plant water status due to reduced water loss and therefore may perform better under conserved soil moisture conditions [9].

The differences among genotypes among and within groups were significant for seed yield and its attributes (Table 2). In general, Group-I genotypes were higher yielder than the genotypes in Group-II and III. The pod length and 100-seed weight was more in Group-III followed by Group-II and I whereas, number of seeds/pod was higher in Group-I genotypes over the other groups tested. The pod length, number of seeds/pod, 100-seed weight, biomass and seed yield showed significant genotypic differences. Genotypes EC 472250, V 240, EC 472291 and NDS 547 produced more than 17 cm pod length. Most of the genotypes produced more than 10 seeds/pod except genotypes EC 472253, EC 472280, EC 472266 and EC 472295, in which the number of seeds/pod was less than 9. The genotypes EC 472280, EC 472273 and EC 496737 exhibited the boldest seeds (> 17 g 100-seed weight) while genotypes V 585, EC 39853, NDS 39890 and HKP 7/54 had the smallest test weight (< 7g 100-seed weight). The genotypes EC 472273, EC 39888, EC 472268 and EC 472291 showed significantly higher biomass/m^2 irrespective of different groups. The highest seed yield (> 180 g per m^2) was recorded in genotypes EC 472268 and EC 39853 which were at par statistically but significantly higher than the remaining genotypes in Group-I. Among the Group-II and III, genotypes EC 472253 and EC 472273 yielded significantly higher (> 100g/m^2) respectively over the other tested genotypes in both the groups. The highest seed yield in Group-II and III was because of high 100-seed weight and biomass yield. However, in Group-I the increase may be because of higher pod length and number of seeds/pod. The high yielding genotypes in Group-I maintained higher LWP, RWC and P_N under stressed environment. These results confirm the findings of Sharma *et al.* [10].

The test of the utility of genotypes containing drought tolerant characters would be their improved yield performance. Seed yield showed significant association with RWC and CTD (Fig. 1). RWC was also associated with P_N (Fig. 2a). The high seed yield of short duration genotypes was associated with maintenance of higher leaf water potential, RWC, CTD and photosynthetic efficiency. A significant correlation of leaf area with biomass was found at 45 DAS (Fig. 2b). This showed

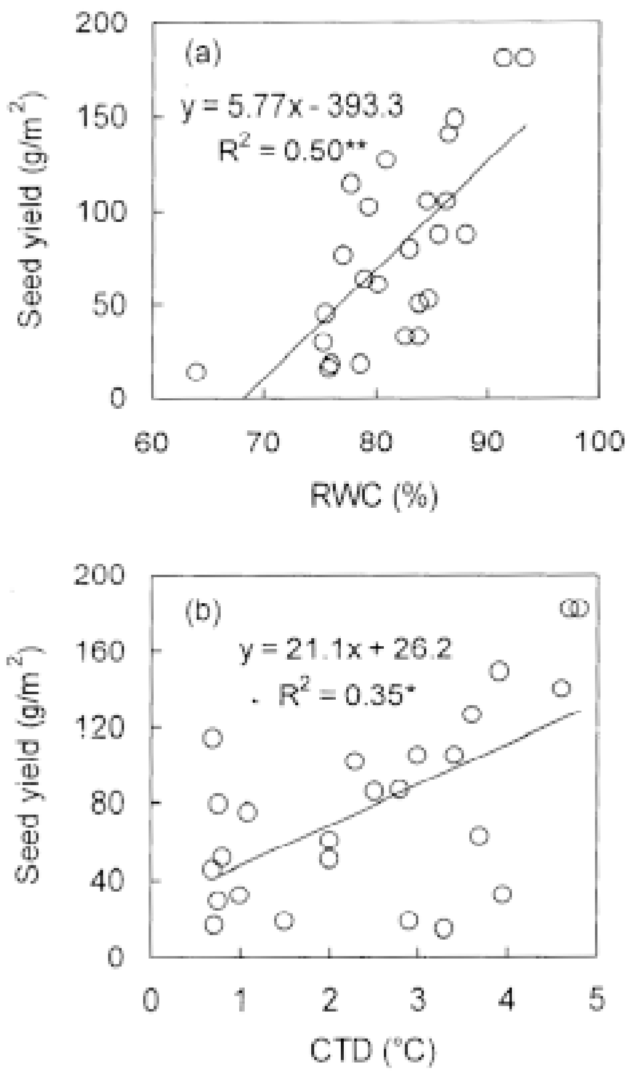

Fig. 1. Relationship between (a) leaf relative water content (RWC) and seed yield and (b) canopy temperature depression (CTD) and seed yield. RWC and CTD recorded at flowering stage in 25 genotypes and seed yield recorded at harvest were used for establishing the relationships. *P<0.05, **P<0.01.

that plant water relation parameters had direct bearing on yield formation via yield attributes whereas leaf area contributed to biomass production. Therefore, the measurement of RWC, SLW and CTD during midday hours which is simple and rapid could be exploited in cowpea improvement programmes for screening of relatively large numbers of germplasm lines for drought tolerance. However, further work is required to identify and manipulate the genes controlling these traits in plant breeding programmes.

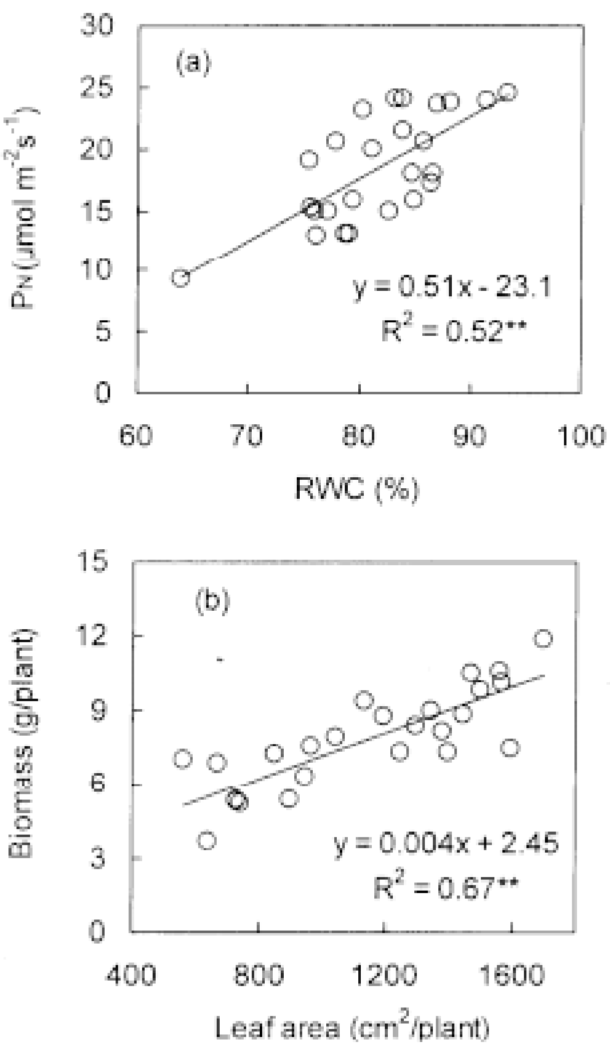

Fig. 2. Relationship between (a) relative water content (RWC) and photosynthetic rate (P_N) measured at flowering stage and (b) biomass and leaf area recorded at 45 DAS in 25 genotypes of cowpea. *P<0.05, **P<0.01.

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