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Evaluation of physiological and yield traits in cowpea for screening of drought tolerance lines

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ABSTRACT

Drought (soil and/ atmospheric water deficit) is the most environmental constraints among abiotic stresses. Cowpea is inherently more drought tolerant than other vegetables, but it also suffers to a considerable yield loss when the moisture deficit is imposed during flowering and pod setting. The experiment was carried out at IIVR, Varanasi during spring-summer of 2012 and 2013. A total of 29 diverse cowpea genotypes, comprising of vegetable and grain types were selected for study. Drought stress was imposed 35 days after sowing by withholding the irrigation for 25 days. All genotypes were also kept under well watered control. Experimental findings revealed that under drought stress, some genotypes, *viz*., EC-30590, EC-37988, EC-390241, EC-15296, EC-472283 and Gomti expressed significantly higher relative leaf water content (>80%), photosynthesis (14.7 to 18.2 μmol m^{-2} s^{-1}), stomatal conductance (0.443 to 0.818 μmol m^{-2} s^{-1}), quantum yield of PSII photochemistry, *i.e.* *Fv*/ *Fm* (0.467 to 0.727) and transpiration rate (0.0321 to 0.0467). These genotypes also showed less yield and dry matter reduction under drought stress as compared to susceptible cultivars/genotypes. The commercial cultivars such as, Akra Garima, Kashi Nidhi, Kashi Shyamal and Kashi Kanchan were found more susceptible to drought. It may concluded that genotypes EC-30590, EC-37988, EC-390241, EC-15296, EC-472283 and Gomti were fairly drought tolerant, and may be utilized for cultivation under water limited condition or for breeding of drought tolerant cultivars.

Key words: *Cowpea*, *Vigna unguiculata*, gas exchange, physiological traits, drought tolerance.

INTRODUCTION

Cowpea (*Vigna unguiculata* L. Walp.) is an important legume vegetable and pulse crop mostly grown in the arid and sub-arid zones of the tropical world where the production mostly depends upon rain or water supply. Its green pod is a good source of protein, mineral and dietary fibers in many developing countries. Abiotic stresses are the primary cause of crop loss worldwide, and are responsible for over 50% reduction in agricultural production (Wang *et al*., 15). Among the abiotic stresses, drought causes around 17% of total losses. Cowpea is inherently more tolerant to drought than other vegetables (Singh *et al*., 14); however, it is sensitive to drought, particularly during pod set and pod filling (Garg *et al*., 8; Abayomi and Abidoye, 1). During the vegetative phase, cowpea react to drought by limiting growth and reducing leaf area, changing leaf orientation and closing the stomata, whereas during flowering and podding, drought causes flower and pod abscission. During drought stress, plant experience a number of physiological and metabolic changes such as, reduction of photosynthetic activity, accumulation of organic acids and osmolytes, and changes in carbohydrate metabolism. Cowpea exhibits broad adaptation mechanism to drought such as drought escape, drought avoidance by decreasing leaf area, dehydration avoidance and vegetative stage drought tolerance by delaying leaf senescence (Hall, 10). Significant genotypic variations in cowpea have been observed on leaf gas exchange and yield parameters, which can give some indications of superiority among cowpea genotypes for agronomic fitness under drought (Anyia and Herzog, 2; Abayomi and Abidoye, 1). The objective of this study was to evaluate the dynamics of photosynthetic and yield parameters in 29 diverse cowpea genotypes (vegetable or pulse type) under well watered and drought stress condition, and to identify genotype(s) suitable for growing under limited water condition or utilization of such genotypes for evolving drought tolerant cultivars in vegetable type cowpea.

MATERIALS AND METHODS

A field experiment was carried out at Indian Institute of Vegetable Research, Varanasi during spring-summer of 2012 and 2013. A total of 29 diverse cowpea genotypes, mostly erect bushy types comprising both vegetable and pulse types were taken for study. Seeds of cowpea were sown on 5th March each year in flat beds at row-to-row spacing of 30 cm and plant-to-plant 20 cm. Drought stress (DS) was induced before flower initiation (35 days

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after sowing, DAS) by maintaining constant low soil water potential for 15 days (withholding irrigation for 20 days). All genotypes were also kept under well watered (WW) control, wherein irrigation was applied at 5-6 day intervals. The average values of weather parameters during the experiment period (5th March to 5th June) in 2012 and 2013 were- maximum temperature 38.7°C, minimum temperature 21.9°C; maximum RH 71%, minimum RH 26%; sunshine hour 7.8, open pan evaporation 10.1 mm and no rainfall. The average soil moisture content before release of the stress was 3.8, 7.4 and 8.8%, respectively in 0-15, 15-30 and 30-45 cm depth. Moisture content (25 cm depth) at field capacity (-0.33 bars) and permanent wilting point (-15 bars) was 22.3 and 6.8%, respectively. Soil moisture and temperature was recorded at 25 cm depth with soil moisture and temperature sensor (Decagon Devices, Pullman, WA, USA).

Gas exchange parameters (photosynthesis, stomatal conductance and transpiration) were measured with portable photosynthesis system (LICOR 6200, Lincoln, Nebraska, USA), and chlorophyll fluorescence (F_v/F_m) was measured in 20 min. dark adapted leaves by Plant Efficiency Analyzer (Hansatech Instrument Co. Norfolk, UK). These measurements were made on the 3rd or 4th fully expanded leaves from the apex between 10:00 and 12:00 h, just before release of drought stress (on the 15th day of stress). Gas exchange parameters, chlorophyll fluorescence, relative water content in leaf (RWC) and plant canopy temperatures were recorded at 55 DAS. The plant canopy temperature was recorded by Infra-red gun between 14:00 to 15:00 h at 3-4 days intervals started 5 days after irrigation. Total dry matter (TDM) production and yield were worked out between 55-75 DAS from three plants in each genotype.

RESULTS AND DISCUSSION

A total of 29 cowpea genotypes were taken for study; however, in this paper the results have been presented for six most tolerant and four most susceptible lines/ genotypes to drought stress. The rest of the genotypes showed intermediately or mixed response towards drought. Gas exchange or photosynthetic parameters such as photosynthesis rate, stomatal conductance, transpiration, and fluorescence in term of quantum yield of PS-II photochemistry (*Fv*/*Fm*) were significantly varied both under stressed and non-stressed conditions (Table 1). All photosynthetic parameters declines in all genotypes of cowpea as drought stress induced, but the reduction in EC-30590, EC-37988, EC-390241, EC-15296, EC-472283 and Gomti genotypes were less as compared to other cultivars. Under drought stress, these genotypes expressed significantly higher photosynthesis (14.7 to 18.2 µmol m^{-2} s^{-1}), stomatal conductance (0.654 to 0.761 mol m^{-2} s^{-1}), transpiration rate (0.0385 to 0.0467 mol m^{-2} s^{-1}) and F*v*/F*m* (0.625 to 0.727); whereas commercial cultivars such as Arka Garima, Kashi Nidhi, Kashi Shyamal and Kashi Kanchan exhibited sharp reduction in these photosynthetic traits. Under drought stress condition, the least reduction in photosynthetic rate (10%), stomatal conductance (31%), transpiration (10%) and F*v*/F*m* (8%) was observed in EC-15296 followed

Table 1. Effect of drought stress on gas exchange and fluorescence parameters in cowpea.

Line/ genotype	Photosynthesis (µmol m^{-2} s^{-1})		Stomatal conductance (mol m^{-2} s^{-1})		Transpiration (mol m^{-2} s^{-1})		F*v*/F*m*	
	WW	DS	WW	DS	WW	DS	WW	DS
EC 30590	24.0	17.3	1.404	0.818	0.0551	0.0467	0.788	0.625
EC 37988	17.6	10.3	0.968	0.443	0.0430	0.0321	0.707	0.467
EC 390241	19.6	16.5	1.079	0.754	0.0440	0.0395	0.825	0.705
EC 15296	20.3	18.2	1.205	0.827	0.0515	0.0415	0.791	0.727
EC 472283	21.4	14.7	1.019	0.713	0.0507	0.0385	0.812	0.725
Gomti	19.2	14.8	0.994	0.761	0.0414	0.0392	0.771	0.544
Arka Garima	14.5	9.3	0.855	0.297	0.0471	0.0291	0.581	0.389
Kashi Nidhi	19.3	4.6	1.303	0.220	0.0410	0.0266	0.450	0.418
Kashi Shyamal	18.6	6.3	1.212	0.196	0.0415	0.0185	0.712	0.377
Kashi Kanchan	21.7	4.4	1.250	0.177	0.0421	0.0221	0.728	0.391
$CD_{0.05}$	2.13	1.27	0.240	0.108	NS	0.0132	0.068	0.056

by EC-390241; whereas the maximum reduction in photosynthesis (80%), stomatal conductance (86%), transpiration (47%) and F*v*/F*m* (46%) as compared to WW was observed in cultivar Kashi Kanchan followed by Kashi Nidhi.

In corroborate to our findings, earlier Anyia and Herzog (3) also reported that drought stress caused a reduction in the leaf assimilation rate, transpiration rate and stomatal conductance in cowpea with genotypic variances of 75.4, 57.9 and 83.3%, respectively. According to them, drought tolerant genotypes maintained higher RWC or leaf water potentials by stomata closure and reduction in leaf area. In our study also the tolerant genotypes showed only 6.0 to 9.2% decline in RWC under DS conditions, while susceptible cultivars exhibited a sharp decline (18.4 to 23.3%) in RWC as compared to WW (Fig. 1). Findings of Hamidou *et al.* (11) revealed that the cowpea genotypes showing drought avoidance mechanism by decreasing the stomatal conductance and transpiration. They also reported that accumulation of solutes mostly proline and maintenance of total protein may contribute for turgor maintenance and protection of photosynthetic apparatus (PS II) against denaturation during water deficit. Reductions in leaf water potential as a consequence of drought positively correlated with a decline in assimilation rate, which is associated with stomatal closure. In our study, tolerant genotypes maintained relatively higher leaf water content (>75%) before release of stress than the susceptible genotypes (68-71%). Drought induces an array of morphological, physiological, biochemical and molecular responses, in which photosynthesis is one of the primary physiological target (Chaves, 6). Furthermore, relatively higher values of F*v*/F*m* in tolerant cowpea genotypes may be due to the increased activity and concentration of superoxide dismutase isoforms (Mn-SOD and Fe-SOD) induced by water deficit, which is associated with protection of photosystem II photochemistry and whole plant growth against oxidative stress (Brou *et al*., 5).

Canopy temperature is an important trait to work out the crop water stress index (CWSI) as it is the relationship between canopy-air temperature difference and the air vapour pressure deficit. Gonzalez-Dugo *et al.* (9) demonstrated that canopy temperature variability may be used an indicator for drought stress severity, particularly for low and moderately stressed crops. In our study, canopy temperatures of stressed and non-stressed plant varied significantly among the cowpea genotypes (Fig. 2). Genotypes such as EC-30590, EC-37988, EC-390241, EC-15296, EC-472283 and Gomti (tolerant to drought stress) registered an average increase in canopy temperature by 1.5°C, while in susceptible cultivars an increase by 2.5°C was recorded over respective WW plants. Soil temperatures recorded at 20 cm depth revealed that it varied significantly in

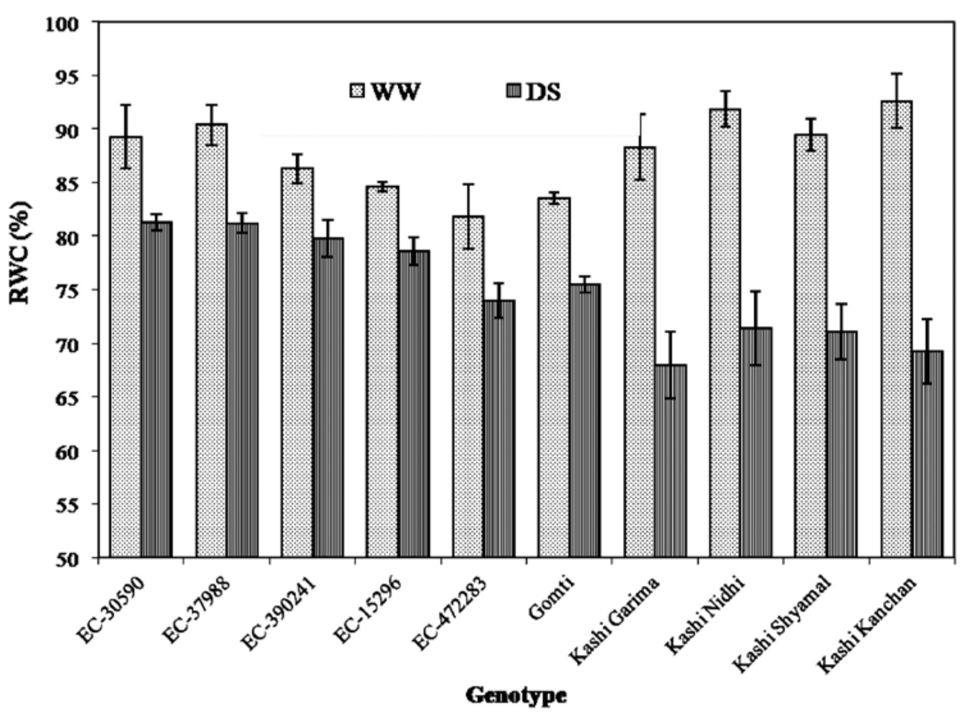

Fig. 1. Effect of drought stress on relative leaf water content in cowpea genotypes.

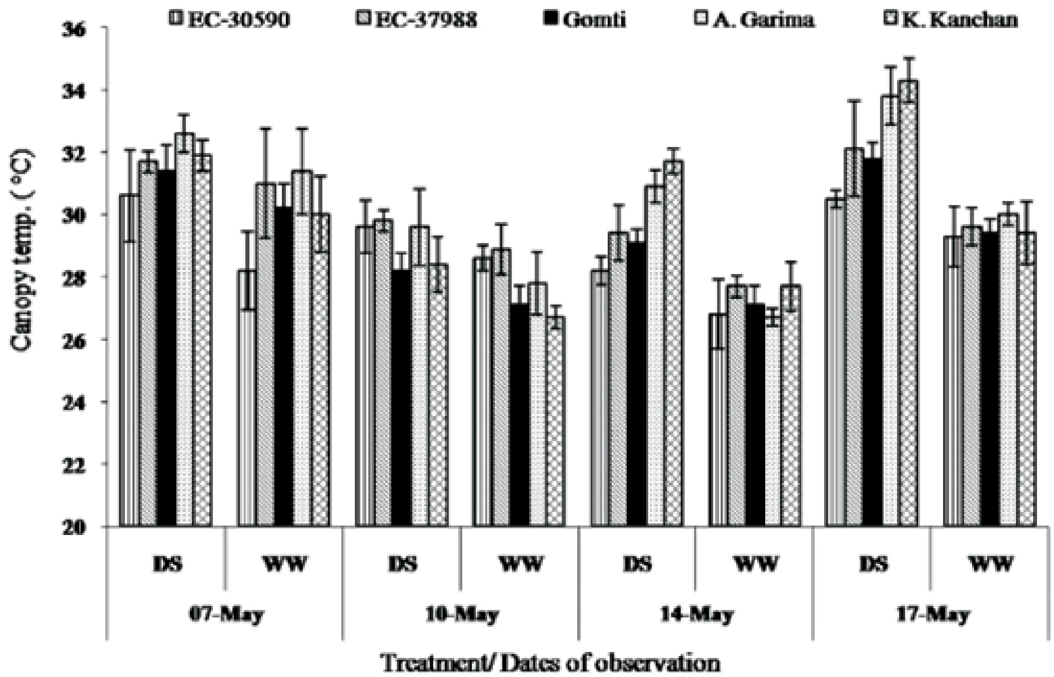

Fig. 2. Effect of drought stress on plant canopy temperature in cowpea genotypes.

stressed *vis-a-vis* non-stressed plots, but did not vary among the cowpea genotypes. The average mid-day soil temperatures in WW plot was 32.4°C (n = 9), while in DS plots it was 37.7°C.

Leaf /canopy temperature has been related to crop and soil water stress based on the fact that under stress-free conditions the water transpired by the plants evaporates and cools the leaves, while in water-deficit situation little water is transpired thus, leaf temperature increases. When the plant evapotranspiration (ET) rate is reduced, such as by soil water depletion, the rate of heat removal is reduced and the canopy temperature increases. This process links canopy temperature with crop water stress and ET. Colaizzi *et al.* (7) also showed that canopy temperature is strongly correlated to important quantifiable crop outputs such as yield, water use efficiency, seasonal ET, midday leaf water potential and irrigation rates.

Yield attributes such as TDM and pod yield were also varied significantly both under WW and DS conditions. It is obvious from Table 2 that TDM production under WW ranged between 87.54 (Arka Garima) to 188.68 g (Gomti), while in DS condition it ranged between 68.2 (Kashi Kanchan) to 168.60 g (Gomti). A significant reduction in TDM (28-43%) was observed in susceptible genotypes, whereas only 7-19% reduction in biomass under drought stress was observed in tolerant genotypes. Similar trends were also noticed in pod production. Both under WW and DS conditions, the susceptible or otherwise commercial cultivars have produced higher yields than the tolerant genotypes which were obliviously due to their higher genetic yield potentials. The cowpea genotypes that showed tolerance to drought in this study were either pulse grain type or shy bearing. Decline in yield due to drought stress was less (about 11%) in tolerant genotypes than in susceptible genotypes (53% reduction). Anyia and Herzog (2) reported that across the cowpea genotypes water deficit condition caused reduction in biomass between 11 to 40%. Similar to our findings, Bastos *et al.* (4) also reported that a water deficit reduced the yield of cowpea genotypes to the tune of 60% as compared to well irrigated plants.

Maintenance of high leaf turgidity, net photosynthetic rate and stomatal conductance during stress period along with less alteration in leaf metabolites in the tolerant genotypes were reflected in its yield compared to other lines/ genotypes. Mendes *et al.* (13) revealed that the water deficit condition did not influence the source capacity (leaf number, leaf area and specific leaf area) and reproductive efficiency, but reduced the sink size (number of pods, number and weight of seeds per plant) in cowpea. According to Likoswe and Lawn (12) cowpea maintains leaf water status above lethal levels for longer periods through different means, and cowpea

Table 2. Effect of drought stress on biomass production and yield in cowpea genotypes.

Variety/ Genotype	Total dry matter (g/ plant)		Single pod weight (g)		Pod yield/ plant (g)	
	WW	DS	WW	DS	WW	DS
EC 30590	88.12	71.30	6.41	6.15	70.6	65.4
EC 37988	115.23	114.13	3.90	3.31	80.0	60.5
EC 390241	180.50	158.44	4.47	4.67	47.6	42.0
EC 15296	156.80	132.42	3.20	2.76	73.3	64.3
EC 472283	134.40	124.54	3.87	3.67	67.3	65.6
Gomti	188.68	168.60	3.91	3.57	125.5	115.0
Arka Garima	87.54	49.41	5.67	4.47	190.3	90.6
Kashi Nidhi	118.20	84.60	7.97	7.35	220.3	135.5
Kashi Shyamal	134.40	85.60	7.55	6.80	225.7	105.0
Kashi Kanchan	96.22	68.20	9.80	8.67	283.5	88.6
SEm ±	3.25	2.44	0.31	0.27	2.11	1.85
$CD_{0.05}$	8.91	7.06	0.95	0.82	5.60	4.87

produced higher TDM under water deficit as compared to soybean and pigeon pea.

In conclusion, the genotypic variations in the gas exchange measurements, relative leaf water content RWC), canopy temperatures and yield traits were observed in this study indicates that cowpea genotypes EC-30590, EC-37988, EC-390241, EC-15296, EC-472283 and Gomti have shown tolerance against drought, and may be utilized for breeding drought tolerant cultivars in bush type vegetable cowpea. These genotypes showed significantly higher photosynthetic traits, RWC, biomass and yield, and relatively lower canopy temperatures than the susceptible or otherwise commercial cultivars.

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