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AGRONOMY

Maturity, Biomass Partitioning and Growth Response Indices in Cowpea (*Vigna unguiculata* L.) under Water Stress

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ABSTRACT

Water stress is the major abiotic constraint of cowpea production. The development of cowpea genotypes resilient to water stress is a practical approach to ameliorate the negative effects of water stress on the productivity. In the present study, a set of 20 genotypes of cowpea including 19 landraces collected from different areas of the Kashmir valley and one released variety *viz*, Shalimar Cowpea-1 released by SKUAST-Kashmir as check were evaluated under well watered and water stressed conditions.

Highlights

- Days to flowering and maturity did not undergo substantial changes between irrigated and water stressed treatments, however, pods partitioning index suffered largest decrease under stress (16.10 per cent) followed by plant height (12.27 per cent).
- Among growth response indices, days to seed fill (DSF) was positively correlated with seed yield only under well watered conditions, while as rest all indices biomass growth rate (BGR), seed growth rate (SGR), Economic growth rate (EGR) and relative sink strength) RSS were positively correlated with seed yield under both water stressed and well watered conditions.
- Highest values of correlation of indices with seed yield under water stressed and well watered conditions were recorded for EGR (r = 0.999 and 0.998 respectively) followed by SGR (r = 0.967 and 0.955 respectively) and BGR (r = 0.700 and 0.854 respectively), while as RSS had significant correlation with seed yield under water stress only.

Keywords: Cowpea, Water stress, Biomass partitioning, Growth response indices

Legumes are indispensable component of farming systems in both developing as well as developed countries and are important determinants of food, nutritional and livelihood security (Gowda *et al.* 2009). Currently food legumes occupy around 78 million hectares are with a production of about 85 million tonnes (FAO 2015). India accounts for 35% of the area and 25% of the production. Although, being the largest pulse crop cultivating country in the World, pulses share to total food grain is production is only 6-7% in the country. The availability of pulses has reduced from 60.7g/capita/day to 47.2 g/capita/day from 1950-51 to 2014-15 respectively. In terms of area, MP (22%), Rajasthan (15%), Maharastra (14%) and UP & Karnatka (10% each) are the largest contributors, similarly in terms of the production MP (27%), Maharastra (23%), Rajasthan (12%) and UP (10%) are the leading states of India.

Cowpea (*Vigna unguiculata* (L.) Walp.) (2n = 22) is one of the most important food legume crops in the Semi Arid Tropics covering Asia, Africa, Southern Europe and Central and South America (Pasquet and Baudoin, 2001). It is a relatively drought tolerant and warm weather crop that is well adapted to the drier regions of the tropics, where other food legumes do not perform well (Singh 2003). Since cowpea was known in India before Christ and it has Sanskrit name in early treatise dating back to 150 BC, cowpea must have moved from East Africa to Asia more than 2000 years ago where human selection led to modified forms of cowpea different from Africa. It has been suggested that cowpea probably moved from Eastern Africa to India before 150 BC, and to West Asia and Europe about 300 BC.

Globally cowpea is grown over an area of 12.61 million hectares, with a production of 5.59 million tones and a yield of 443.20 kg/ha. Africa leads both in area and production accounting for about 95 per cent, while as yields is highest in Europe and lowest in Africa and Asia. Niger and Nigeria are the leading producers of cowpea, together accounting for about 70% of area and 67% of production in the world. However, yields are highest in Egypt and Serbia (FAO, 2015). As per the report compiled by Ministry of Agriculture (GOI), India accounts for about 15.06 percent of global cowpea area and 8.45 per cent of global cowpea production (Singh 2014).

Despite all its economic and cultural importance, cowpea production is subjected to a wide range of biotic and abiotic constraints. Water stress is the major abiotic constraint of cowpea production. Since cowpea is grown mainly in the drier areas of the world with no or scanty irrigation facilities, irregular rainfall especially early in the season have adverse effects on the growth of the crop. There is wide variation in cowpea germplasm for maturity acceleration, biomass production and partitioning as well as reduction in yield parameters under water stress that opens up avenues for selection of resilient genotypes that can withstand varied levels of water stress. A number of studies have reported maturity acceleration, reduction in yield parameters (Kardile *et al.* 2018) as well as biomass accumulation and partitioning (Agele *et al.* 2017).

The development of cowpea genotypes resilient to water stress is a practical approach to ameliorate the negative effects of water stress on the productivity. Drought tolerance is defined as the ability of plants to grow and reproduce satisfactorily to produce harvestable yield with limited water supply (Fleury *et al.* 2010), while as Blum *et al.* (1989) has suggested yield stability as a better indicator of drought resistance compared to grain yield under stress. The efforts to understand differential genotypic response under stress in terms of their yield levels per se has not yielded fruitful results and the progress has not been encouraging as yield is a highly complex trait (Sinclair 2011). Moreover, the extreme level of drought stress could reduce seed yields to very low levels such that genotypic differences disappear, whereas insufficient stress could result in selection of non-resistant genotypes (Beebe *et al.* 2013).

Changes in biomass partitioning under stress determine plants ability to respond to environmental changes that alter resource availability and plants invariably respond by increasing its efficiency of the resource that tends to limit plant growth and finally change its yielding ability. The final economic yield achieved by plants indicates their efficiency to translate their accumulated biomass into yield. In common bean, the biomass is translocated from stems onto pods and finally into seeds and genotypic differences have been established for resource remobilisation traits in response to drought stress (Sofi and Iram Saba 2016).

Growth and developmental phases correspond to phenological events, and consequently the timing of photoassimilate partitioning is largely determined by phenology. There can be substantial and stable differences between species and varieties in the patterns of dry matter allocation (de Dorlodot *et al.* 2007) and these differences can be clearly related to crop performance. Certain varieties allocate more of its dry matter to growth of deep roots whereas another may give more priority to producing an extensive but shallow root system. Ramirez Vallejo and Kelly (1998) used various phenology based biomass accumulation and partitioning indices in common bean to elucidate response to water stress and reported that, the differential correlations between phenological, biomass and partitioning traits and the indices for yield and drought susceptibility would suggest that the most effective approach in breeding for drought tolerance. The present study was undertaken to assess the effect of water stress on yield parameters as well as biomass accumulation and partitioning in cowpea.

MATERIALS AND METHODS

Plant materials

A set of 20 genotypes of cowpea including 19 landraces collected from different areas of the Kashmir valley and one released variety *viz.*, Shalimar Cowpea-1 released by SKUAST-Kashmir as check were used for the present study.

Experimental setup

The present study was conducted during 2017-18 at the research fields of Division of Genetics & Plant Breeding, Faculty of Agriculture Wadura, SKUAST-K, Sopore. All the 20 genotypes were grown in the research field of Faculty of Agriculture, Wadura, Sopore (34° 17′ North and 74° 33 E at altitude of 1594 metres above sea level). The soil of the experimental site is a typical inceptisol with clay loam texture. The pH was almost neutral (7.2), with organic carbon 1.42%, electrical conductivity of 0.18 dS/m and CEC of 16 meq/kg. The soil nitrogen was 241.92 kg/ha, Phosphorus was 25.87 kg/ha while as Soil potassium was 127.71 kg/ha. Each genotype was represented by two rows of four meter length, with spacing of 40 cm × 15 cm, with two replications each for drought and irrigated treatments. Plants were irrigated regularly until the first fully opened trifoliate leaf and irrigation was withdrawn thereafter in drought treatment whereas the plants in irrigated treatment were watered regularly.

Data collection and analysis

Data was recorded on five traits including days to flowering, days to maturity, plant height, seed yield per plant, pod partitioning index and pod harvest index. Pod partitioning index was calculated at mid pod filling stage as:

PPI (%) = (Pod biomass at mid pod filling/total canopy biomass) × 100

Similarly pod harvest index was measured at harvest as:

PHI (%) = (Total seed weight / total pod biomass including seeds) × 100

Data was analysed through Winstat (Fitch Software, USA). Based on biomass accumulated, seed yield and maturity, following biomass partitioning indices were used for genotypic differentiation for response to water stress.

(i) Days to seed fill (DSF) = DM-DF (days)

(ii) Biomass growth rate (BGR)= SBM/DM (g/day)

(iii) Seed growth rate (SGR)= Seed yield/DSF (g/day)

(iv) Economic Growth rate (EGR)= Seed yield/DM

(v) Relative Sink Strength (RSS) = SGR/BGR

Where DM= days to maturity, DF= Days to 50 per cent flowering, SBM= shoot biomass,

Index	Formula	Relevance
Days of seed fill (DSF)	DSF =DM - DF	Measures the time period that is used by plant to accumulate and remobilise photosynthates after flowering
Biomass growth rate (BGR)	BGR = Biomass/DM	Measures daily growth rate of biomass accumulated during entire life cycle.
Economic growth rate (EGR)	EGR= Seed yield/DM	Measures the daily growth rate of the economic product viz. Seed yield
Seed growth rate (SGR)	SGR = Seed yield/DSF	Measures the growth rate of seed biomass post fertilisation.
Relative sink strength (RSS)	RSS= SGR/ BGR	Measures the relative growth rate of economic product vis-a-vis total biomass accumulated during life cycle.

RESULTS AND DISCUSSION

Mean performance and effect of water stress on traits

Days to flowering and maturity did not undergo substantial changes between irrigated and water stressed treatments (Table 1). Under well-watered conditions days to 50% flowering ranged from 48.00 (C14) to 54.00 (C22) with a mean value of 51.22.). While as under water stressed conditions it ranged from 47.00 (C1 and C14) to 54.00 (C13) with a mean value of 49.97. In case of days to maturity, the values ranged from 93.00 (C1) to 99.50 (SCP-1) with a mean value of 95.02.), While as under well watered conditions it ranged from 47.00 (C1 and C14) to 54.00 (C13) with a mean value of 49.97. Lawn (1982) observed that delayed flowering in cowpea plants under water stress but the time from flowering to maturity was shortened possibly on account of extreme dehydration avoidance of the crop (inhibition of the continued formation of nodes and/or flower buds). Therefore, earliness is difficult to define for cowpeas due to indeterminacy and complex flowering responses to drought (Bunting 1975). Muchow (1985) also stated that water deficit had little effect on date of flowering, but the duration of flowering and pod filling was reduced. Plant height ranged from 82.25-96.33 cm

Table 1: Mean performance of days to flowering (DF), days to maturity (DM), plant height (PH), pod partitioning index (PPI) and pod harvest index (PHI) under well watered (WW) and water stress (WS) conditions in cowpea landraces

Genotype	DF		DM		PH (cm)		PPI (%)		PHI (%)	
	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS
C1	48.50	47.00	93.00	90.50	87.50	84.50	17.87	13.74	67.79	69.05
C2	50.50	49.00	94.00	93.50	84.50	67.50	41.21	24.75	71.12	63.87
C3	50.00	51.00	93.50	94.50	82.25	75.83	44.94	37.88	65.53	60.50
C4	50.00	49.50	96.50	97.50	85.25	72.75	24.96	17.48	69.78	64.40
C5	51.50	49.00	93.00	91.50	92.00	80.50	25.35	14.83	71.02	66.16
C6	51.00	48.50	94.50	92.50	89.50	78.00	13.69	11.50	70.62	66.82
C7	53.50	51.00	96.00	95.50	86.25	76.00	26.13	24.56	55.45	61.45
C8	53.50	53.50	96.00	96.50	84.50	67.50	29.89	15.93	67.49	58.91
C9	51.00	48.50	94.50	92.00	96.33	80.84	20.12	16.38	59.06	43.24
C10	51.50	50.00	93.50	93.00	90.33	77.50	38.65	39.68	56.26	69.64
C11	50.50	53.50	95.50	97.50	89.83	82.25	25.47	24.89	56.45	63.67
C12	54.50	50.00	95.50	91.50	93.75	73.75	26.92	19.40	57.67	60.91
C13	50.00	54.00	94.00	96.50	90.83	75.00	19.87	15.41	61.95	63.78
C14	48.00	47.00	96.00	93.50	90.83	83.75	28.55	23.67	56.39	58.86
C22	54.00	50.50	94.50	91.00	82.33	75.75	18.25	23.73	57.46	54.14
C24	51.50	50.50	95.50	92.00	88.50	82.00	18.20	18.42	62.19	61.32
C25	49.00	47.50	96.50	93.50	91.50	84.00	28.12	22.60	57.05	60.14
C29	51.00	48.50	94.00	91.00	86.50	79.00	36.54	35.89	66.62	65.68
C32	52.50	50.00	95.00	92.00	91.00	79.00	26.41	25.09	61.39	64.20
SCP-1	52.50	51.00	99.50	97.00	85.25	76.25	22.68	21.99	65.88	64.47
MEAN	**51.22**	**49.97**	**95.02**	**93.62**	**88.44**	**77.58**	**26.69**	**22.39**	**62.86**	**62.06**
CD	**Genotype = 2.01** **Water = 0.52** **Interaction = 3.22**		**Genotype = 1.76** **Water = 0.51** **Interaction = 2.58**		**Genotype = 9.53** **Water = 1.98** **Interaction = NS**		**Genotype = 4.11** **Water = 0.75** **Interaction = 4.83**		**Genotype = 6.55** **Water = NS** **Interaction = 8.44**	
Per cent decrease under stress	**2.44**		**1.47**		**12.27**		**16.10**		**1.27**	

(mean of 88.44) under well watered and 67.50-84.50 cm (mean of 77.58) under water stressed conditions. The results of present study revealed substantial diversity in morphological and yield parameters in local landrace diversity of Kashmir valley. Among traits, seed yield per plant (23.44 percent) suffered largest damage under stress (24.37 per cent) followed by pod partitioning index (16.10 per cent) and plant height (12.27 per cent). Pod harvest index underwent lower reductions under water stress.

Pod partitioning index (PPI) and pod harvest index (PHI) were used as representative traits of photosynthate remobilization. Even though, significant variability among genotypes exists for pod harvest index, some genotypes fail at the very last step of resource remobilization viz., grain production, and when the plant has done the most difficult work already. This phenomenon has been designated as "***the lazy pod syndrome***" (Beebe *et al*. 2010) in common bean and is reason behind the fact that common bean genotypes, despite adequate photosynthetically active radiation (PAR) do not possess efficient proportionate remobilization of photosynthates to grain viz., poor harvest index. They have suggested that driven by evolutionary trends grain yield of bean often does not respond well to very favorable environments with good fertility and abundant moisture.. Drought results in poor remobilization of photosynthates to grain, at the same time that root growth, carbon accumulation in shoots, stay green stems, and late season re-flowering may increase. As such, drought stress triggers an alteration in partitioning towards survival and resource acquisition that may undesirably limit the grain filling and yield. Pod partitioning index and pod harvest index is an indicator of the remobilization of photosynthates from shoot biomass and pod biomass to the seed, respectively. Photo- assimilate remobilization is one of the characteristics indirectly selected during the development of drought resistant cultivars (Miklas *et al*., 2006).

Growth response indices and correlation coefficients

The data pertaining to biomass partitioning indices are presented in Table 2. Days to seed fill (DSF), under drought, was highest in C4 (48.00) and lowest in case of C22 (43.80). Under irrigated conditions, DSF was highest for C14 (48.00) while as lowest was recorded in case of C12 (41.00). Highest value of biomass growth rate (BGR) under drought was recorded for C25 (8.90) and lowest value recorded in C12 (0.98). However, under irrigated conditions, BGR was highest for C25 (4.56), while as lowest value was recorded in case of C12 (0.99). Seed growth rate (SGR) under drought was highest in case of C11 (0.95) but lowest in case of C12 (0.13). However, under irrigated conditions, highest value was recorded for C25 (1.11), while as lowest value was recorded for SCP-1 (0.29). Similarly, for economic growth rate (EGR), highest value under water stress was recorded for C25 (0.45) and lowest in case of C12 (0.06), but, under irrigated conditions, highest value was recorded for C25 (0.55), while as lowest value was recorded for C12 (0.12). Genotypes with higher yield inder stress viz., C25, C11, C6 and C7 had also higher values of both EGR and SGR, indicating usefulness of these indices.

Among growth response indices, DSF was positively correlated with seed yield only under well watered conditions, while as rest all indices BGR, SGR, EGR and RSS were positively correlated with seed yield under both water stressed and well watered conditions (Table 3). Highest values of correlation of indices with seed yield under water stressed and well watered conditions were recorded for EGR (r = 0.999** and 0.998** respectively) followed by SGR (r = 0.967** and 0.955** respectively) and BGR (r = 0.700** and 0.854** respectively), while

Table 2: Phenology based growth response indices under well watered (WW) and water stress (WS) conditions in cowpea landraces

Genotype	Days to Seed Fill		Biomass Growth Rate (g/day)		Seed Growth Rate (g/day)		Economic growth rate (g/day)		Relative sink strength (g/g)	
	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS
C1	44.50	43.50	2.14	1.56	0.57	0.45	0.27	0.22	0.27	0.29
C2	43.50	44.50	2.43	1.14	0.30	0.45	0.21	0.14	0.18	0.26
C3	43.50	43.50	1.87	1.68	0.42	0.20	0.19	0.09	0.22	0.12
C4	46.50	48.00	2.81	2.73	0.86	0.52	0.41	0.25	0.30	0.19
C5	41.50	42.50	1.40	1.27	0.50	0.30	0.22	0.14	0.36	0.23
C6	43.50	44.00	3.25	2.86	0.97	0.81	0.45	0.38	0.30	0.28
C7	42.50	44.50	5.72	3.12	0.98	0.79	0.43	0.37	0.17	0.25
C8	42.50	43.00	4.36	1.36	0.38	0.38	0.17	0.17	0.08	0.28
C9	43.50	43.50	2.69	2.21	0.91	0.55	0.42	0.26	0.34	0.25
C10	42.00	43.00	2.42	2.12	0.61	0.67	0.31	0.27	0.25	0.31
C11	45.00	44.00	3.38	2.43	0.90	0.95	0.43	0.41	0.27	0.39
C12	41.00	41.50	0.99	0.98	0.29	0.13	0.12	0.06	0.29	0.13
C13	44.00	42.50	3.04	1.32	0.48	0.60	0.27	0.22	0.16	0.45
C14	48.00	46.50	2.65	1.12	0.60	0.31	0.30	0.15	0.23	0.27
C22	40.50	40.50	1.79	1.64	0.48	0.43	0.20	0.19	0.27	0.26
C24	44.00	41.50	1.24	1.99	0.46	0.72	0.31	0.23	0.37	0.36
C25	47.50	46.00	8.90	4.56	1.11	0.93	0.55	0.45	0.12	0.20
C29	43.00	42.50	1.61	1.27	0.41	0.29	0.19	0.13	0.25	0.23
C32	42.50	42.00	1.76	1.50	0.65	0.63	0.29	0.29	0.37	0.42
SCP-1	47.00	46.00	1.51	1.24	0.29	0.30	0.14	0.14	0.19	0.24
Mean	43.80	43.65	2.79	1.90	0.61	0.52	0.29	0.23	0.22	0.27

Table 3: Correlation between seed yield and phenology based growth response indices

Trait	Water regime	DSF	BGR	SGR	EGR	RSS	SYPP
DSF	WW	—	0.368*	0.309	0.402*	-0.260	0.416*
	WS	—	0.401*	0.148	0.252	-0.262	0.285
BGR	WW		—	0.681**	0.688**	-0.609**	0.700**
	WS		—	0.772**	0.851**	-0.088**	0.854**
SGR	WW			—	0.966**	0.062	0.967**
	WS			—	0.959**	0.520**	0.955**
EGR	WW				—	0.047	0.999**
	WS				—	0.381	0.998**
RSS	WW					—	0.031
	WS					—	0.370*
SYPP	WW						—
	WS						—

**, ** Significant at 5 and 1 % level of significance.*

as RSS had significant correlation with seed yield under water stress only. Similar relationship between yield and yield and phenology based indices have been reported by Acosta-Gallegos (1989), Ramirez-Vallejo and Kelly (1998) and Sofi *et al.* (2017). The phenology based indices namely DSF, BGR, EGR, SGR and RSS have been used to understand the stress response in terms of biomass partitioning in relation to phenological stages. Ramirez Vallejo and Kelly (1998) used these indices in common bean and found that the indices were positively correlated with seeds per pod and seed number while as there was no clear relationship with seed yield and seed number under stress. Among physiological parameters, the indices were positively correlated with relative water content and stomatal conductance but negatively correlated with moisture retention capacity and water content. Sofi *et al*. (2017) also used these indices in common bean and reported that all the indices except DSF were positively correlated with seed yield under stress conditions. Similar observations were made in cauliflower for curd yield under water stress in terms of relative sink strength (Kage *et al*. 2004). However, there can be peculiar situations between various phenology based indices, reflected in the final yield response under stress. The relative growth rate can be limited more by the utilization rather than generation of photosynthates. Such sink limitation may lead to feedback inhibition of photosynthesis. Genotypes with a high relative growth rate (RGR) in any given environment are more likely to be able to respond to stress better than genotypes with a lower RGR for the same stress level.

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