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Phenology Based Biomass Accumulation and Partitioning Indices in Relation to Water Stress in Common Bean (*Phaseolus vulgaris* L.)

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ABSTRACT

*In the present study, phenology based biomass partitioning indices were used to identify genotypes tolerant to water stress by evaluating 20 common bean lines in green house and field under water stressed and well watered conditions. Invariably shoot biomass and shoot to total biomass were higher under irrigated conditions as compared to their corresponding values under drought and vice versa in case of root biomass and root to total biomass. Shoot biomass and shoot to total biomass decreased under drought, whereas, root biomass and root to total biomass increased under drought. Among biomass partitioning indices, DSF was negatively correlated with seed yield while as rest all indices BGR, SGR, EGR and 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 = 0.981** and 0.963** respectively) followed by SGR (r = 0.978** and 0.953** respectively) and RSS (r = 0.881** and 0.711** respectively), while as BGR had lower values of correlation coefficient. The principal component analysis could identify three PCs based on Eigen values accounting for about 88 % variation. The Eigen values for PC1, PC2 and PC3 were 4.853, 2.556 and 1.425 respectively. In PC1, SGR, EGR, RSS and seed yield were important, while as in case of PC2, most of the traits were negative except shoot biomass. Genotypes WB-1634, WB-341 and WB-185 were identified as tolerant and WB-6 and WB-1587 as susceptible to water stress. Since crop phenology is very important in determining ability of genotypes to respond to water stress, it is suggested that these indices can be used in combination with other yield based indices to identify genotypes that are tolerant to water stress.*

Key words: *Common bean, Water Stress, Phenology, Biomass partitioning, Growth rate*

INTRODUCTION

Water stress is a major global production constraint of common bean[1] and is the most damaging for bean and causes an increased frequency of barren plants and incomplete seed setting. Water stress, especially during the flowering and grain filling periods are reported to reduce the seed yield and seed weight and accelerate maturity of dry bean[2].

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Use of seed yield per se as a selection index under water stress is invariably not fruitful on account of complexity of the trait. Selection based solely on yield under extreme stress is a poor estimate of drought resistance, since resistance to severe stress may be associated with reduced yield in non-stress environments[3]. However, seed yield is the final outcome of the all the physiological and mechanistic efficiency of plants under stress. Therefore various indices of biomass accumulation and partitioning that indicate efficiency of resource acquisition and remobilisation are used to identify tolerant genotypes. There is growing evidence substantiated by experimental data that biomass partitioning can be used as effective selection criteria for analyzing variation for drought response in different crops including common beans. Plants have been reported to maintain a balance in the biomass invested in roots to shoot which can change under stress conditions and phenomenon is called as ontogenic drift. Pearsall [4] was the first to propose the concept of biomass partitioning through the use of allometric analysis using log transformed values of root and shoot biomass. Poorter[5] provided an excellent overview of this phenomenon as a plant response to environmental conditions. 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[6].

There can be substantial and stable differences between species and varieties in the patterns of dry matter allocation [7] 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.. Rosales-Serna *et al.* [8] found that larger values for plant biomass accumulation were observed across well watered treatments at the basal plant phytomers in all cultivars. Ramirez Vallejo and Kelly[9] 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 in common bean. The objectives of this study were to evaluate the relationship of various biomass accumulation and partitioning indices based on phenology with response to water stress in common bean; measure the phenotypic variability of these traits under water-stress and well watered conditions; and, to determine the usefulness of an index based on such relationship.

MATERIALS AND METHODS

Plant materials

Twenty genotypes of common bean were evaluated in the present study. The genotypes used were selected on the basis of their performance in the yield screening trials and represented diverse market classes in terms of use category, growth habits and seed characteristics. The material comprised of 17 breeding lines and three released varieties namely SR-1, SFB-1 and Arka Anoop. While the SR-1 and SFB-1 have been released by SKUAST-Kashmir, Arka Anoop has been released by IIHR, Bengaluru.

Greenhouse experiment

The experiment was conducted under ambient temperature to prevent the confounding effects on account of heat stress. The plants were grown in PVC root columns of dimensions 1.3 meter height and 20 cm internal diameter in a completely randomised design with three replications each for drought and irrigated treatments. Initially four seeds each were sown after surface sterilisation with 10 % NaOCl for

5 minutes and subsequent rinsing by distilled water. After the plants reached the first trifoliate leaf stage, only two competitive plants per column were maintained. Drought was imposed at first fully expanded trifoliate leaf stage by withholding water in drought treatment while as irrigated treatment was regularly watered. The control plants were maintained at 100% field capacity by irrigation with water from sowing to final harvest. For the drought treatment, plants were stressed by withholding water from trifoliate stage to pod development stage (48 days after sowing; DAS). The duration of drought stress was 35 days. During the drought stress period, all genotypes showed leaf rolling symptom. The moisture content of medium in water stressed treatment at the end of the stress treatment was 30%, which was quantified on weight basis. The roots and shoots were harvested after forty eight days of sowing. The roots thus harvested were washed with a mild detergent solution to remove sand and other impurities, rinsed with tap water to remove excess soap and dried in shade and weighed for root biomass fraction. Roots were carefully separated from the growing medium without any breakage in the root system. The shoot of each plant was separated by cutting at the base of the stem.

Field experiment

Genotypes were grown in the research field of Faculty of Agriculture, Wadura, Sopore. The soil of the experimental site is a typical inceptisol with clay loam texture. The pH was almost neutral (7.2), with organic carbon 0.65 %, electrical conductivity of 0.18 deci-siemens/m and CEC of 16 meq/kg. Each genotype was grown as a single row of four meter length, with spacing of 15 cm x 40 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. Days to flowering and days to maturity were measured on plot basis whereas above ground biomass and seed yield was measured on five competitive plants from each replication under both water stressed and well watered conditions. The following biomass partitioning indices[9] were used for genotypic differentiation for response to water stress.

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.

Data analysis

The data pertaining to root traits was analysed through OPSTAT-1 (CCS HAU, Hisar). Correlation coefficients were worked out by XLSTAT version 19.2 (Addinsoft Corp.) and principal component analysis was done by MINITAB version 13.31 (MINITAB INC.)

RESULTS AND DISCUSSION

Root and Shoot biomass

The results pertaining to root and shoot traits scored in green house column experiment is presented in table 1. Root biomass under drought was highest in WB-112 (29.81 g) followed by SFB-1 (25.92 g) and WB-1634 (22.99 g) and lowest was recorded in WB-222 (12.32 g). Under irrigated conditions, highest root biomass was recorded in case of WB-216 (47.92) followed by WB-956 (39.01) and WB-1446 (34.39) and lowest value recorded for WB-1643 (7.59). Highest shoot biomass, under drought, was recorded in case of WB-112 (28.03) followed by WB-956 (25.37) and WB-1446 (21.70) and lowest recorded for SR-1 (16.07), while as under irrigated conditions, highest value of shoot biomass was observed in WB-956 (91.23) followed by WB-1634 (66.73) and WB-112 (60.07) while as lowest was recorded for WB-1643 (17.60). Root to total biomass was highest for WB-1634 (0.58), followed by SFB-1 (0.57 and Arka Anoop (0.57) and lowest for WB-451 (0.39), whereas under irrigated conditions, highest value was recorded for WB-216 (0.45) followed by WB-1446 (0.41) and lowest value recorded for Arka Anoop (0.20). Similarly, shoot to total biomass was highest for WB-451 (0.60) followed by WB-222 (0.57) and lowest in case WB-1634 (0.42) under drought, but recorded highest values for Arka Anoop (0.79) followed by WB-185 and WB-401 (0.78) and lowest value was recorded for WB-216 (0.55) under irrigated conditions. Invariably shoot biomass and shoot to total biomass were higher under irrigated conditions as compared to their corresponding values under drought and vice versa in case of root biomass and root to total biomass, however, in certain genotypes root biomass was lower under drought conditions. Shoot biomass and shoot to total biomass decreased under drought by 168.69 and 27.41 per cent respectively, whereas, root biomass and root to total biomass increased under drought by 9.14 and 76.81 per cent respectively. Huang et al [10] reported that deficiencies of soil water resulted in high root : shoot ratio. Relatively, more biomass was allocated to the root than to the shoot, and plant allocated more resource to the belowground growth. The same pattern of partitioning has also been observed in other plants [11]. The current evidence including the results in our study indicates that plant growth and development in general and rooting depth and root biomass in particularly were strongly affected by water stress. The reduction in root:shoot ratio in the well-watered treatment was probably in response to more favourable growing conditions, and an increase in the root:shoot ratio, on the other hand, would indicate that the plant was probably growing under less favourable conditions [12]. Furthermore, plants developed a deeper and thicker root system with greater water uptake from drying soil in response to and most likely as an adaptation to decreasing water availability[13].

Biomass partitioning indices

Data pertaining to biomass partitioning indices are presented in table 2. Days to seed fill (DSF), under drought, was highest in WB-6 and WB-22 (48.50 followed by WB-1492 (45.00) and lowest in case of WB-185 (33.50). Under irrigated conditions, DSF was highest for WB-6 (48.00) followed by WB-22 (46.00) and WB-1492 (44.50), while as lowest was recorded in case of WB-956 (33.00). Highest value of biomass growth rate (BGR) under drought was recorded for WB-1446 (2.53) followed by WB-956 (2.35) and lowest value recorded in WB-401 (1.11). However, under irrigated conditions, BGR was highest for WB-1446 (2.36) followed by WB-1492 (2.35) and WB-451 (2.33), while as lowest value was recorded in case of WB-401 (0.95). Seed growth rate (SGR) under drought was highest in case of WB-1634 (0.88) followed by WB-341 (0.68) and WB-451 (0.67) but lowest in case of WB-401 (0.27). However, under irrigated conditions, highest value was recorded for WB-1634 (0.97) followed by WB-341 (0.93) and WB-222 (0.88), while as lowest value was recorded for WB-216 (0.37). Similarly, for economic growth rate (EGR), highest value under water stress was recorded for WB-1634 (0.41) followed by WB-341

(0.34) but lowest in case of WB-6 and WB-1587 (0.09). Under well watered conditions, highest value was recorded for WB-1634 and WB-185 (0.46) followed by WB-341 (0.40) but lowest in case of WB-1587 (0.15). Relative sink strength (RSS) was highest under drought for WB-1634 and WB-185 (0.40) followed by WB-341 (0.37) but lowest in case of WB-6 and WB-1587 (0.13 and 0.14 respectively). However, under well watered conditions, (RSS) was highest under drought for WB-1634 (0.52) followed by WB-185 (0.51) and WB-341 (0.49) but lowest in case of WB-1587 (0.21). Seed yield was highest in case of WB-1634 followed by WB-185 and WB-451 under irrigated conditions while as under drought highest seed yield was recorded for WB-1634 followed by WB-341 and WB-451. Lowest seed yield under both water regimes was recorded for WB-1587. Acosta-Gallegos [14] and Ramirez Vallejo and Kelly[9] have also reported the usefulness of phenology based biomass partitioning indices in delineating differential genotypic response to water stress in common bean. In the present study, WB-1634, WB-341 and WB-185 have been identified as water stress tolerant genotypes while as WB-6 and WB-1587 are susceptible to water stress. Water stress caused significant reduction in seed yield followed by RSS and SGR (> 30%), while as no significant change was recorded in case of DSF and BGR. This indicates that changes under stress are more related to efficiency in partitioning the biomass. This may be the reason why some of the genotypes with higher BGR had lower yield as they had poor partitioning reflected by lower values of SGR, EGR and RSS.

Trait correlations

Correlation and trait associations among the biomass accumulation and partitioning indices are presented in table 3. Root biomass was positively correlated with shoot biomass and root to total biomass under both water stressed and well watered conditions, but negatively correlated with shoot to total biomass. However, none of the biomass traits scored in greenhouse correlated with biomass partitioning indices and seed yield. Among biomass partitioning indices, DSF was negatively correlated with seed yield while as rest all indices BGR, SGR, EGR and 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 = 0.981** and 0.963** respectively) followed by SGR (r = 0.978** and 0.953** respectively) and RSS (r = 0.881** and 0.711** respectively), while as BGR had lower values of correlation coefficient. In terms of inter se correlation between biomass partitioning indices, BGR was negatively correlated with DSF under water stressed conditions but had no correlation under well watered conditions. EGR and BGR were negatively correlated with DSF under both water stressed and well watered conditions. EGR was positively correlated with BGR and SGR, however, the value of correlation coefficient was higher in case of SGR as compared to BGR. RSS was positively correlated with SGR and EGR but had no correlation with BGR. Similar relationship between yield and yield and phenology based indices have been reported by Acosta-Gallegos [14] and Ramirez Vallejo and Kelly[9].

Principal component analysis

The principal component analysis could identify three PCs based on Eigen values (Table 4) accounting for about 88 % variation. The criteria followed for selecting the number of principal components (PC) to be included in the future analysis was based on the height of Eigen values of PC or needed Summary communality in percentage [15]. The fact that Eigen values are above 1 indicates that the evaluated principle component weight values are reliable[16]. The Eigen values for PC1, PC2 and PC3 were 4.85, 2.56 and 1.42 respectively. In PC1, SGR, EGR, RSS and seed yield were important (Table 5), while as in case of PC2, most of the traits were negative except shoot biomass. In PC3, root biomass was important. The Principal component analysis helps in identification of potential traits for selection based on their contribution to PCs as well as correlation with the target trait. In the present study SGR, EGR and RSS were significant traits in PC1 and also had very high correlation with seed yield under both water stressed and well watered conditions that substantiate the premise that they can be suitably used along with other indices based on seed yield for identification of water stress tolerant genotypes. Ramirez Vallejo and Kelly[9] reported that, although seed yield derived indices such as geometric mean (GM) and drought susceptibility index (DSI) can be used to identify tolerant genotypes, selection based on a combination of both types of indexes may provide a more useful criterion for improving water stress resistance of common bean. This is all the more important in view of the fact that phenological traits play a critical role in adaptation and are considered to be key traits in managing water supply[17].

Table 1: Mean performance of common bean (*Phaseolus vulgaris* L.) genotypes for root and shoot traits under different water regimes and effect of drought under green house screening

Genotype	Root biomass (g)		Shoot biomass (g)		Root to total biomass ratio		Shoot to total biomass ratio	
	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated
WB-6	16.536	21.156	20.200	58.333	0.450	0.266	0.549	0.733
WB-22	21.266	18.186	20.667	34.233	0.507	0.346	0.492	0.653
WB-83	19.286	13.346	16.867	51.500	0.533	0.205	0.466	0.794
WB-112	29.810	23.466	28.033	60.767	0.515	0.278	0.484	0.721
WB-185	18.260	14.190	20.833	51.400	0.467	0.216	0.532	0.783
WB-216	18.116	47.923	18.567	57.833	0.494	0.453	0.506	0.546
WB-222	12.320	17.490	16.433	52.000	0.428	0.251	0.571	0.748
WB-257	15.803	20.203	16.767	45.200	0.485	0.308	0.514	0.691
WB-341	12.100	10.670	16.033	35.000	0.430	0.233	0.569	0.766
WB-401	14.960	11.440	19.633	42.467	0.432	0.212	0.567	0.787
WB-451	13.016	13.750	19.967	42.267	0.394	0.245	0.605	0.754
WB-956	21.560	39.013	25.367	91.233	0.459	0.299	0.540	0.700
WB-1446	23.723	34.393	21.700	48.500	0.522	0.414	0.477	0.585
WB-1492	17.600	10.816	18.967	33.033	0.481	0.246	0.518	0.753
WB-1587	16.133	23.430	21.267	70.633	0.431	0.249	0.568	0.750
WB-1634	22.990	23.980	16.733	66.733	0.578	0.264	0.421	0.735
WB-1643	20.606	7.590	16.767	17.603	0.551	0.301	0.448	0.698
SR-1	16.536	23.466	16.067	59.600	0.507	0.282	0.492	0.717
SFB-1	25.923	19.396	19.367	54.333	0.572	0.263	0.427	0.737
Arka Anoop	17.233	14.044	12.967	54.900	0.570	0.203	0.429	0.796
Mean	**18.688**	**20.397**	**19.160**	**51.378**	**0.465**	**0.263**	**0.535**	**0.737**
% change under drought	**-9.144%**		**-168.152%**		**+76.806**		**-27.408**	
C.D (p ≤ 0.05%)	**Genotype= 6.384** **Water regime = 3.024**		**Genotype= 10.696** **Water regime = 19.784**		**Genotype= 0.103** **Water regime = 0.032**		**Genotype= 0.103** **Water regime = 0.032**	

Table 2: Biomass accumulation and sink efficiency in common bean (*Phaseolus vulgaris* L.) under irrigated and water stressed conditions

Genotype	Days to seed fill		Biomass growth rate (g/day)		Seed growth rate (g/day)		Economic growth rate		Relative sink strength		Seed yiel	
	Stress	Non-Stress	Stress	Non-Stress	Stress	Stress	Stress	Non-Stress	Stress	Non-Stress	Stress	Non-Stress
WB-6	48.50	48.00	1.36	1.67	0.18	0.40	0.09	0.21	0.13	0.24	8.78	19.55
WB-22	48.50	46.00	1.54	2.28	0.29	0.63	0.15	0.30	0.19	0.27	14.35	29.32
WB-83	36.50	36.50	1.72	1.98	0.44	0.67	0.18	0.27	0.25	0.34	16.33	24.67
WB-112	43.00	38.50	1.65	1.93	0.34	0.67	0.17	0.28	0.21	0.35	14.97	26.06
WB-185	33.50	34.50	1.61	1.93	0.64	0.99	0.30	0.46	0.40	0.51	21.74	34.44
WB-216	41.50	43.50	1.75	1.53	0.29	0.37	0.14	0.18	0.16	0.24	12.17	16.28
WB-222	35.50	35.00	1.99	2.03	0.59	0.88	0.26	0.37	0.30	0.43	21.23	31.1
WB-257	42.50	42.50	1.81	1.83	0.41	0.59	0.19	0.28	0.22	0.32	17.41	25.38
WB-341	39.50	40.00	1.84	1.68	0.68	0.83	0.34	0.40	0.37	0.49	27.24	33.18
WB-401	43.00	41.00	1.11	0.95	0.27	0.36	0.14	0.17	0.24	0.38	11.68	15.10
WB-451	34.50	36.00	2.32	2.33	0.67	0.93	0.28	0.39	0.29	0.40	23.17	33.72
WB-956	35.00	33.00	2.35	2.06	0.53	0.77	0.26	0.33	0.22	0.37	18.61	25.41
WB-1446	38.50	38.00	2.53	2.36	0.46	0.65	0.24	0.32	0.18	0.27	17.84	24.96
WB-1492	45.00	44.50	1.78	2.35	0.29	0.61	0.16	0.30	0.16	0.26	13.16	27.35
WB-1587	43.00	40.50	1.34	1.53	0.19	0.33	0.09	0.15	0.14	0.21	8.26	13.50
WB-1634	36.00	37.00	2.21	1.85	0.88	0.97	0.41	0.46	0.40	0.52	31.96	36.05
WB-1643	38.50	38.50	1.99	1.81	0.53	0.66	0.27	0.31	0.26	0.36	20.69	25.52
SR-1	42.50	42.50	1.66	1.68	0.31	0.47	0.16	0.23	0.19	0.28	13.43	20.18
SFB-1	37.50	40.00	1.77	1.33	0.49	0.55	0.25	0.28	0.27	0.41	18.57	22.11
Arka Anoop	33.50	36.00	1.68	1.55	0.37	0.49	0.17	0.23	0.22	0.31	12.50	17.69
Mean	**39.80**	**39.57**	**1.80**	**1.83**	**0.44**	**0.64**	**0.21**	**0.29**	**0.24**	**0.35**	**17.20**	**25.07**
% change under stress	**+ 0.56**		**- 1.77**		**- 30.96**		**- 28.21**		**- 31.10**		**- 31.39**	

Table 3: Correlation matrix for above and below ground biomass and biomass partitioning indices

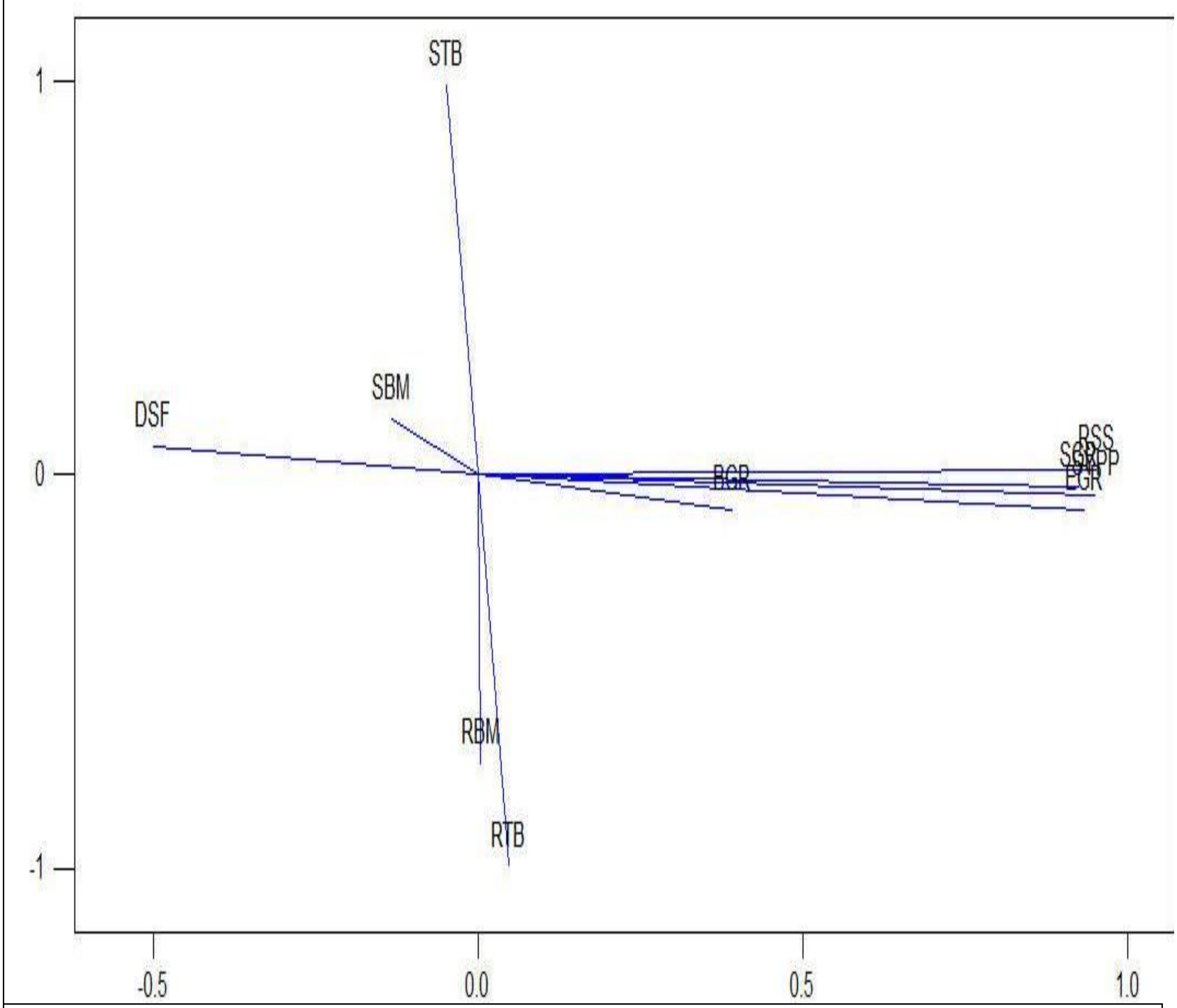
Trait	Treatment	Root biomass (g)	Shoot biomass (g)	Root to total biomass ratio	Shoot to total biomass ratio	Days to seed fill	Biomass growth rate (g/day)	Seed growth rate (g/day)	Economic growth rate	Relative sink strength	Seed yield (g/plant)
RBM (g)	Drought	1	0.553**	0.677**	-0.677**	0.031	0.182	-0.006	0.066	-0.093	0.020
	Irrigated	1	0.649**	0.758**	-0.758**	0.021	0.038	-0.215	-0.219	-0.333	-0.278
SBM (g)	Drought		1	-0.226	0.226	0.215	0.050	-0.189	-0.157	-0.244	-0.184
	Irrigated		1	0.026	-0.025	-0.303	-0.132	-0.062	-0.122	-0.042	-0.227
RTBM (%)	Drought			1	-1.000**	-0.148	0.145	0.100	0.153	0.044	0.112
	Irrigated			1	-1.000**	0.305	0.227	-0.215	-0.165	-0.434	-0.144
STBM (%)	Drought				1	0.148	-0.145	-0.100	-0.154	-0.045	-0.113
	Irrigated				1	-0.305	-0.228	0.215	0.165	0.435*	0.144
DSF fill	Drought					1	-0.558**	-0.727**	-0.668**	-0.646**	-0.587**
	Irrigated					1	-0.161	-0.626**	-0.520**	-0.604**	-0.371*
BGR (g/day)	Drought						1	0.657**	0.660**	0.281	0.632**
	Irrigated						1	0.567**	0.532**	-0.039	0.627**
SGR (g/day)	Drought							1	0.982**	0.898**	0.978**
	Irrigated							1	0.974**	0.792**	0.953**
EGR	Drought								1	0.882**	0.981**
	Irrigated								1	0.799**	0.963**
RSS (	Drought									1	0.881**
	Irrigated										0.711**
SYPP (g)	Drought										1
	Irrigated										1

Table 4: Eigen values (Latent roots) and percent variation explained by PC's

Principal component	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**	**PC 7**	**PC 8**	**PC 9**	**PC 10**
Eigen value	4.853	2.556	1.425	0.682	0.451	0.015	0.008	0.006	0.002	0.000
Percent variation	48.50	25.60	14.30	6.80	4.50	0.10	0.10	0.10	0.00	0.00
Cumulative variation (%)	48.50	74.10	88.40	95.20	99.70	99.80	99.90	100.00	100.00	100.00

Table 5: Rotated component loadings (values of principal component traits of common bean)

Trait	**PC1**	**PC2**	**PC3**
RBM	0.005	-0.734	0.669
SBM	-0.132	0.143	0.978
RTB	0.047	-0.994	-0.079
STB	-0.048	0.994	0.079
DSF	0.500	-0.072	0.101
BGR	0.391	-0.090	0.089
SGR	0.925	0.030	0.063
EGR	0.934	-0.089	-0.026
RSS	0.952	0.013	0.126
SYPP	0.953	-0.050	-0.062



Biplot of PC 1 and PC 2 for identification of potential traits

CONCLUSION

In the present study, phenology based biomass partitioning indices were used along with other biomass traits to identify genotypes that perform better under water stress. The phenology based indices including DSF, BGR, SGR, EGR and RSS were efficient in delineating differential genotypic response in terms of biomass accumulation and its partitioning into economic product. Except DSF, all the indices especially EGR, SGR and RSS were highly efficient in terms of significant correlations under both water stressed and well watered conditions (r > 0.900 **). Since crop phenology is very important in determining ability of genotypes to respond to water stress, it is suggested that these indices can be used in combination with other yield based indices to identify genotypes that are tolerant to water stress and give higher yields under stress.

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