agronomy

MDPI

Article

Agronomic Performance of Chickpea Affected by Drought Stress at Different Growth Stages

Supriya Sachdeva [1], Chellapilla Bharadwaj [1,*], Basavanagouda Siddanagouda Patil [1], Madan Pal [2], Manish Roorkiwal [3,4] and Rajeev K. Varshney [3,5]

1 Division of Genetics, ICAR-Indian Agricultural Research Institute, Pusa, New Delhi 110012, India; supriyasachdeva19@gmail.com (S.S.); bs_patil2000@yahoo.com (B.S.P.)
2 Division of Plant Physiology, ICAR-Indian Agricultural Research Institute, Pusa, New Delhi 110012, India; madanpal@yahoo.com
3 Centre of Excellence in Genomics & Systems Biology, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502324, India; mroorkiwal@uaeu.ac.ae (M.R.); rajeev.varshney@murdoch.edu.au (R.K.V.)
4 Khalifa Center for Genetic Engineering and Biotechnology (KCGEB), United Arab Emirates University, Abu Dhabi P.O. Box 15551, United Arab Emirates
5 Murdoch's Centre for Crop & Food Innovation, WA State Agricultural Biotechnology Centre, Food Futures Institute, Murdoch University, Murdoch, WA 6150, Australia
* Correspondence: drchbharadwaj@gmail.com

Abstract: Susceptibility to drought stress has restrained chickpea productivity at a global level, and the development of drought-tolerant varieties is essential to maintain its productivity. Therefore, the present study was conducted to evaluate genetic divergence in selected genotypes of chickpea and their morpho-physiological responses under irrigated and stressed conditions to identify the traits that account for the better performance of these genotypes under stressed conditions, as well as genotypes with improved drought tolerance. The genotypes were evaluated for two years under irrigated and drought stressed conditions, and significant variation was found amongst the genotypes for different morpho-physiological and yield traits. The maximum reduction was observed for plant yield (33.23%) under stressed conditions. Principle component analysis (PCA)-based biplots and correlation studies established its strong positive correlation with relative water content (RWC), membrane stability index (MSI), chlorophyll index (CI), secondary branches (SB) and yield traits and negative correlations with drought susceptibility index (DSI), days to maturity (DM) and 100 seed weight (100 SW) under drought stress, suggesting their use in selecting drought-tolerant germplasm. Ten genotypes with high values of RWC, MSI, CI, SB, yield traits and lower DSI were identified as drought-tolerant and might serve as ideal donors in the forthcoming breeding of elite chickpea cultivars. The seed-filling stage began earlier in these genotypes, with significantly reduced days to maturity under stressed conditions. Our results indicate selection for earliness offers a promising strategy for the development of drought-tolerant chickpea cultivars.

Keywords: chickpea; drought stress; plant yield; drought susceptibility index; earliness

Citation: Sachdeva, S.; Bharadwaj, C.; Patil, B.S.; Pal, M.; Roorkiwal, M.; Varshney, R.K. Agronomic Performance of Chickpea Affected by Drought Stress at Different Growth Stages. *Agronomy* **2022**, *12*, 995. https://doi.org/10.3390/agronomy12050995

Academic Editors: Seung Hwan Yang and Mick Fuller

Received: 17 February 2022
Accepted: 18 April 2022
Published: 21 April 2022

1. Introduction

Chickpea (*Cicer arietinum* L.) or garbanzo bean is one of the ancient edible legume crops having high nutritional and economic significance [1–3]. India being the largest producer of chickpea produces 70% of the total world production [4], and about 9.21 Mha area is under chickpea cultivation, producing 8.88 Mt [5]. The lack of genetic divergence and resistance to different stresses has been a major impediment in the development of improved chickpea varieties [6].

Growth and photosynthesis are primarily affected by drought stress, and to minimize these yield losses, it is vital to evaluate parameters of growth such as chlorophyll index, plant height, relative water content (RWC), membrane stability index (MSI), biomass, 100-seed weight and plant yield and to understand the morphological and physiological basis of yield variation [7,8]. Breeding for drought tolerance has been a difficult task for chickpea breeders due to presence of a limited number of good selection indices, mainly morphological and physiological responses that can be effectively used [9,10]. More than 200 different chickpea accessions were screened for 3 consecutive years taking into consideration the drought tolerance index (DTI) and identified large variability for plant biomass, yield, days to flowering and maturity under drought conditions [11]. Erratic distribution of rainfall hampers chickpea productivity, and losses up to 50% have been documented [5]. Previous reports confirm that drought largely affects plant physiological processes, viz., photosynthesis, chlorophyll content and relative water content [12]. Interactions with the environment make the selection for yield difficult under field conditions [13], and chickpea breeders are now targeting the identification of high-yielding early chickpea cultivars showing tolerance to drought to reduce yield losses in chickpea.

The drought susceptibility index (DSI) is the major criterion for identifying superior genotypes adapted to stress situations that identifies a genotype with the least reduction in a particular trait vis-à-vis yield, indicating that yield penalty with respect to trait under comparison is the lowest if the DSI value is low. The DSI is a ratio signifying the extent of reduction in the performance of genotypes when exposed to drought stress as compared to non-stressed environments. Conversely, it does not point towards the comparative susceptibility of different characters to drought stress. With an aim to recognizing the traits that are least affected when exposed to drought, both morphological and physiological, the drought susceptibility was expressed as per cent decrease in the performance of traits under stressed and non-stressed conditions. The screening of 211 chickpea accessions for 3 consecutive years taking into consideration the drought tolerance index (DTI) identified large variability for plant biomass, yield, days to flowering and maturity under drought conditions [11]. Ten drought-tolerant genotypes were identified on the basis of their drought susceptibility index (DSI) and percentage of drought-tolerant efficiency (DTE%) [14]. Forty desi and kabuli chickpeas (24 desi and 12 kabuli type) were screened for drought tolerance at pre-flowering stage by creating artificial drought stress under glasshouse conditions [15].

Phenology is another important component of crop adaptation to different environments and varies based on the genotype, moisture in the soil, period of sowing, latitude and longitude. About 73% of chickpea worldwide area in different parts of Asia, where chickpea grows on declining soil moisture and, as a rain-fed crop, experiences terminal drought and heat stresses [16–18] during its vegetative and reproductive growth stages [19]. Thus, the development of superior early maturity cultivars is one of the key objectives of chickpea breeding programs of research institutes in India and several other countries [20]. The present study was conducted to identify the genotypes that are better performing and compatible with adverse drought conditions and combine earliness with the genotypes with the best drought tolerance attributes.

2. Materials and Methods

2.1. Experimental Material, Selection of Soil and Stress Treatment

The experiment was carried out under a rainout shelter during the growing seasons of 2017–2018 and 2018–2019 at the National Phytotron Facility, ICAR-Indian Agricultural Research Institute, New Delhi (28°08′ N 77°12′ E). Forty chickpea cultivars obtained from Pulse Research Laboratory, Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi, were used as experimental materials (Table 1). These cultivars included breeding lines, varieties released by different research institutes and short duration and stable lines from ICRISAT training population with different phenology and yield potentials under ideal field conditions. Uniform seeds of selected cultivars were surface sterilized by dipping in Bavistin at the rate of 2 gms per kg seed and Chlorpyriphos 20EC at the rate of 10 mL per kg seed, followed by washing carefully with deionized water and then drying prior to sowing. Surface-sterilized seeds were planted in free-flowing plastic pots of 3 inches. Each pot comprised of 600 gs air-dried, (2 mm) sieved and composite clay loam soil with 70% soil moisture. Recommended doses of 18 kg N ha^{-1} and 20 kg P ha^{-1} was applied in the experiment. Five seeds per plot were sown in 13 cm diameter pots containing peat compost to vermiculite (1:1) and kept in a plant growth chamber with critical environment having a diel cycle of 16 h light/8 h dark with 20 ± 2 °C and 60–70% relative humidity (Figure 1). Thinning was carried out 14 days after germination to 4 seedlings per pot. Second thinning was performed after a week, and three uniform seedlings per pot were retained for consequent studies. Each pot was irrigated to 75–80% field capacity (FC) with tap water having 7.6 pH, 0.4 dsm electrical conductivity (EC) until the start of the drought stress treatments.

Table 1. List of chickpea genotypes.

SNo.	Variety	Biological Status	Source	Pedigree	Seed Type
1	ICCV09313	Training population	ICRISAT, Hyderabad	ICCV92311 × ICC14198	Kabuli
2	ICCV10313	Training population	ICRISAT, Hyderabad	ICCV92337 × ICC14194	Kabuli
3	ICCV08310	Training population	ICRISAT, Hyderabad	ICCV95311 × ICC17109	Kabuli
4	ICCV097309	Training population	ICRISAT, Hyderabad	(ICC2588 × ICCC32) × [(ICCC49 × ICC15980) × ICCV3]	Kabuli
5	ICCV03311	Training population	ICRISAT, Hyderabad	ICCV92328 × [(ICCC32 × ICC12034) × ICC19686]	Kabuli
6	ICCV01309	Training population	ICRISAT, Hyderabad	(ICC4973 × ICC14196) × ICCV92329	Kabuli
7	ICCV09312	Training population	ICRISAT, Hyderabad	ICCV92337 × ICC7344	Kabuli
8	ICCV9314	Training population	ICRISAT, Hyderabad	ICCV92311 × ICC17109	Kabuli
9	ICCV10304	Training population	ICRISAT, Hyderabad	ICCV92311 × ICC14215	Kabuli
10	ICCV10307	Training population	ICRISAT, Hyderabad	ICCV92311 × ICC17109	Kabuli
11	ICCV10306	Training population	ICRISAT, Hyderabad	ICCV92311 × ICC17109	Kabuli
12	ICCV10316	Training population	ICRISAT, Hyderabad	ICCV92337 × ICC17109	Kabuli
13	ICCV92337	Training population	ICRISAT, Hyderabad	(ICCV2 × ICC12034) × ICC7344	Kabuli
14	ICCV00109	Training population	ICRISAT, Hyderabad	ICC18746 × ICCV10	Desi
15	ICCV03103	Training population	ICRISAT, Hyderabad	[ICCV92014 × JG23) × BG1032]	Kabuli
16	ICCV09307	Training population	ICRISAT, Hyderabad	ICCV92337 × ICC17109	Kabuli
17	ICCV95423	Training population	ICRISAT, Hyderabad	(ICC7676 × ICCC32) × ((ICCC49 × ICC15980) × ICCV3)	Kabuli
18	ICCV97404	Training population	ICRISAT, Hyderabad	(ICCC32 × ICC4967) × [(ICCC49 × ICC15980) × ICCV3]	Kabuli
19	ICCV10	Released variety	ICRISAT, Hyderabad	ICC1376 × ICC1443	Desi
20	ICC1882	Breeding line	ICRISAT, Hyderabad	Traditional landrace P1506-4 from ICRISAT	Desi
21	BGD72	Released variety	ICAR-IARI, New Delhi	P1231 × P1265	Desi
22	Pusa1103	Released variety	ICAR-IARI, New Delhi	(Pusa256 × *Cicerreticulatum*) × Pusa362	Desi
23	ICC4958	Breeding line	ICRISAT, Hyderabad	GW 5/7, a drought tolerant breeding line from ICRISAT	Desi
24	ICCV00301	Training population	ICRISAT, Hyderabad	ICCV92502 × ICCV2	Kabuli

Table 1. *Cont.*

SNo.	Variety	Biological Status	Source	Pedigree	Seed Type
25	ICCV0302	Training population	ICRISAT, Hyderabad	FLIP 91-18C × ICCV2	Kabuli
26	ICCV01301	Training population	ICRISAT, Hyderabad	GNG1044 × (ICCC32 × ICC12034)	Kabuli
27	L550	Breeding line	PAU, Ludhiana	PBG7 × Rabat	Kabuli
28	ICCV03403	Training population	ICRISAT, Hyderabad	(ICC4973 × ICC14196) × ICCV92329	Kabuli
29	C235	Released variety	PAU, Ludhiana	IP58 × C1234	Desi
30	ICCV03404	Training population	ICRISAT, Hyderabad	(ICC4973 × ICC14196) × ICCV92329	Kabuli
31	ICCV03310	Training population	ICRISAT, Hyderabad	BG70 × ICCV92329	Kabuli
32	ICCV07301	Training population	ICRISAT, Hyderabad	ICCC95334 × (ICCV2 × ICCV98506)	Kabuli
33	ICCV05312	Training population	ICRISAT, Hyderabad	ICCV2 × ICCV92325	Kabuli
34	ICCV5308	Training population	ICRISAT, Hyderabad	ICCV2 × ICCV92311	Kabuli
35	ICCV5313	Training population	ICRISAT, Hyderabad	ICCV2 × ICCV92325	Kabuli
36	ICCV4310	Training population	ICRISAT, Hyderabad	(ICC4973 × ICC14196) × ICCV92329	Kabuli
37	Pusa1003	Released variety	ICAR-IARI, New Delhi	Mutant of L532	Kabuli
38	CSG8962	Released variety	ICAR-CSSRI, Karnal	Selection from GPF7035	Desi
39	ICCV4303	Training population	ICRISAT, Hyderabad	(ICC4973 × ICC14196) × ICCV92329	Kabuli
40	ICCV2	Released variety	ICRISAT, Hyderabad	[(ICC5003 × ICC 4953) × ICC 583] × (ICC4973 × ICC7347)	Kabuli

Figure 1. Pot screening for drought stress tolerance in chickpea genotypes under glasshouse conditions.

2.2. Drought Stress Application and Management

For imposing drought stress, irrigation to pots was withheld until the soil FC reached 35 to 40%. A completely randomized design was used with three replications, and two water regimes consisting of a well-irrigated level of soil water and severe drought stress equivalent to 35–40% FC were applied to each genotype. Another factor involved in the experimental design was time of drought stress. Precisely, the vegetative (35 days after sowing, between germination and flowering) and flowering (130 days after sowing, beginning from flowering) stages were selected to apply the drought stress treatments on individual replicates. The drought stress was imposed at 35 days after sowing. Plants were maintained well and watered repeatedly before being subjected to stress as per the improvised protocol where the drought stress comprised of three treatments, viz., control, i.e., no stress; cutoff irrigation at vegetative stage; cutoff irrigation at start of flowering stage [21]. Irrigation was performed regularly in control plants at all stages of growth. Thereafter, plants were watered with tap water about once a week depending on treatment at −2 bar soil water potential. The pots were kept weed free by hand weeding. Data on following parameters were recorded. Each treatment had 120 replicates for recording observations.

2.2.1. Plant Height

Plant height of three plants selected at random was recorded per replication. The height was measured with a meter scale from the level of ground to the plant shoot tip.

2.2.2. Relative Water Content

Three healthy leaves from three different plants per replication were taken for measuring the RWC. Then, 400 mg leaf samples were transferred to petriplates containing distilled water at room temperature. After an incubation of 4 h, their turgid weights were recorded. Oven drying of the leaves was performed for 72 h at 60 °C, and then the plant dry weight was recorded, avoiding any kind of retention of water from the atmosphere. RWC was calculated using the following formula [22]:

$$\text{RWC} = (\text{Fresh weight} - \text{Dry weight}/\text{Turgid weight} - \text{Dry weight}) * 100$$

2.2.3. Membrane Stability Index

Next, 400 mg fresh leaf sample was taken for calculation of membrane stability index (MSI) and added to test tubes containing 10 mL of distilled water. The test tubes were kept in a water bath maintained at two different temperatures 45 °C and 100 °C for 30 min and 10 min, respectively. Conductivities (C1) and (C2) were then noted using a portable conductivity meter. The MSI was calculated using the formula given by [23], which is as follows:

$$\text{MSI} = 1 - (\text{C1}/\text{C2}) * 100$$

2.2.4. Chlorophyll Index

Konica Minolta SPAD 502 Plus chlorophyll meter was used for measuring the chlorophyll index (CI). Three plants per replication were selected and readings were taken in the afternoon around 12:00 p.m.

2.2.5. Protein Content (Leaf)

For estimating protein content (leaf), crushing of leaves was conducted in 50 mM phosphate buffer with pH 7.8. The supernatant obtained by centrifugation at 14,000 rpm for 10 min was used for protein estimation [24]. Phosphate buffer and Bradford reagent were added to this supernatant, and vortexing was performed. It was then left undisturbed for 5 min at room temperature for color development. Absorbance of the samples was recorded on Beckman DU® 640 spectrophotometer at 595 nm.

2.2.6. Days to Flowering and Days to Maturity

At the time of maturity, the number of second-order branches arising from the main shoot was recorded. Three plants from each replication were selected. Number of days from sowing to the date when half the numbers of plants in a pot have at least one flower opened was recorded as days to 50% flowering (DF). Number of days to maturity (DM) was also recorded from sowing date to the date when 80% of the pods of a plant turn brown or brownish yellow.

2.2.7. Yield Traits

The weight of the above-ground part of the plants including the pods was measured on an electronic balance. Weights of three randomly selected plants per replication were recorded at the time of harvesting, averaged and expressed as biomass per plant. One hundred seeds were randomly counted per replication from the seed lot, and their weights were recorded on electronic balance (100 SW). All the seed-bearing pods of a plant were counted at the time of harvesting. Total number of pods from three plants per replication were counted, averaged and recorded as filled pods per plant (FPP). Five filled pods were selected at random, and the number of seeds per pod was noted and averaged (SPP). Harvested seeds were weighed on an electronic balance for yield. Weight of the seeds of 10 plants selected randomly was recorded, averaged and expressed as plant yield (PY).

2.3. Data Analysis

The drought related traits, viz., plant height, MSI, RWC, CI, protein content, secondary branches, days to 50% flowering, and maturity and yield traits, viz., biomass, 100 seed weight, filled pods per plant, seeds per pod, plant yield, were recorded for all 40 genotypes at vegetative and reproductive stages under stressed conditions and irrigated conditions (control). Mean, range and coefficient of variation were calculated for each parameter using Windostat software v9.1. The standard errors of the mean were presented in the figures as error bars. Analysis of variance (ANOVA) was used to evaluate differences between genotypes, water treatment and their interactions [25]. The Tukey's Studentized Range (HSD) test at $p = 0.05$ was employed to test the differences among the treatment means for the measured parameters at vegetative and reproductive stage after imposing drought stress. The mean performance of all the genotypes sown under stressed conditions was expressed in the form of drought susceptibility index (DSI), Pearson's coefficient of correlation was calculated for plant yield with its component traits and DSI index to discern the traits contributing to plant yield using XLSTAT software to identify genotypes with superior physiological traits imparting stress tolerance and yield under stress. Principal component analysis was also conducted to better understand the associations among the traits in plants grown under water-stressed and irrigated conditions, and biplots depicting the chickpea genotypes as points and traits as vectors were generated using XLSTAT software. The 10 most drought-tolerant genotypes were identified based on their agronomic performance under stressed conditions at different stages of growth.

3. Results

3.1. Physiological Changes under Drought Stress

During both the experimental years, and across the vegetative and reproductive stages, water-stress-related traits, viz., PH, RWC%, MSI, CI, protein content(leaf) and DTF, and yield traits were measured. Genotypes and the interaction effect of stress and genotypes significantly ($p < 0.01$) affected all the physiological and yield traits under study at both stages of growth (Table 2). Drought stress induced a gradual decrease in plant height, relative water content %, chlorophyll index, DTM, secondary branches and protein content (leaf) as compared to irrigated plants during the stress period. The magnitude of decline was more significant ($p \leq 0.05$) during the reproductive stage than the vegetative stage in all the cultivars. Plant height and MSI showed no significant difference, regardless of the growth stage at which stress was imposed (Table 3A,B).

Table 2. ANOVA for different morpho-physiological traits studied in chickpea genotypes at vegetative and reproductive stage.

	Vegetative Stage			Reproductive Stage		
Source of Variation	***Df***	**Stressed Conditions**	**Control Conditions**	***Df***	**Stressed Conditions**	**Control Conditions**
Genotypes	39	271.68 *	506.51 *	39	397.36 *	581.92 *
Columns	5	97,621.19 *	81,684.56 *	11	110,107.07 *	165,032.75 *
Interactions	195	179.39 *	440.80 *	429	269.63 *	343.79 *
Error	480	6.91	3.99	960	7.3	4.77
Total	719			1439		

* Significant at 1%.

3.1.1. Drought Stress at Vegetative Stage

The vegetative phase regulates the phenotypic expression of the plant in total and prepares the crop plant for the subsequent reproductive phase. The plant height and days to flowering (DTF) constitute the vegetative phase and specific traits (RWC%, MSI, leaf protein and CI). On an average basis, the per cent reductions due to drought stress for plant height, days to flowering, RWC%, MSI and CI were 12.10, 7.00, 29.99, 5.12 and 29.99, respectively (Table 4). The genotypes ICCV1309 (34.33 cm) ICCV3311 (33.33 cm), ICC4958 (33 cm) and CSG8962 (33 cm) under irrigated conditions and ICC4958 (31.33 cm), ICC3403 (31 cm) and ICCV3311 (30.66 cm) under vegetative stress recorded the maximum plant heights. The genotype ICC1882 (125) recorded the maximum number of days to flowering, followed by Pusa-1003 (111.33) under irrigated condition and the genotypes BGD-72 (110) and ICC1882 (110) under drought-stress conditions (Table 3B). The genotype ICC4958 maintained the maximum RWC (%) under drought-stress (78.88) and irrigated (84.38) conditions, followed by genotypes ICCV10313 under irrigated (83.64) condition and genotype ICCV10 under drought-stress (75.97) condition. The highest MSI was recorded in the genotypes ICC4958 (78.70), ICCV97309 (78.33) and ICCV3311 (76.38) under drought stress (74.75, 74.11, 73.37) and irrigated condition (78.70, 78.33, 76.38), respectively. The genotypes ICCV3103 (63.20) and ICCV4303 (62.20) recorded the maximum chlorophyll indices under irrigated conditions, while under drought-stress conditions, genotypes ICC4958 (58.03) and ICCV7301 (56.93) recorded the highest chlorophyll indices (Table 3A). A significant decrease in DTF, RWC%, MSI, protein content and CI (Table 3A,B) occurred at vegetative stage.

Table 3. A: Means [±standard error (SE)] of plant height, membrane stability index, relative water content, chlorophyll index and protein content (leaf) at vegetative and reproductive stages under irrigated and stressed conditions. B: Means [±standard error (SE)] of days to flowering, days to maturity and secondary branches at vegetative and reproductive stages under irrigated and stressed conditions. C: Mean values of Biomass, 100seed weight (100SW), Filled pods per plant (FPP), Seeds per pod (SPP) and Plant yield (PY) of chickpea genotypes at reproductive stage.

A																					
		PH				MSI				RWC%				CI				Protein Content			
	GS	Drought		Control		Drought		Control		Drought		Control		Drought		Control		Drought		Control	
		Avg	SE	Avg	SE	Avg	SE	Avg	SE	Avg	SE	Avg	SE	Avg	SE	Avg	SE	Avg	SE	Avg	SE
ICC1882	Veg	23.67	1.02	27.33	0.34	39.87	0.44	47.44	0.10	49.18	0.24	61.99	0.14	50.60	1.06	51.05	0.48	23.43	0.14	27.76	0.40
	Flw	25.33	1.61	30.33	1.12	57.34	0.85	60.29	1.15	52.76a	0.84	56.33a	1.15	36.15a	0.64	48.95a	0.26	13.32a	0.25	14.67a	0.05
ICC4958	Veg	31.33	0.47	33.00	0.45	76.15	0.62	78.67	0.14	80.45	0.37	82.03	0.25	55.05	0.24	61.75	0.22	31.47	0.00	33.51	0.11
	Flw	36.67	2.44	40.00	2.36	73.16	0.37	76.45	0.52	76.05b	0.46	84.88b	0.93	52.45b	0.12	58.30b	0.38	23.06b	0.13	25.60b	0.31
PUSA1103	Veg	29.00	0.59	31.00	0.22	61.69	0.18	68.26	0.19	69.09	0.24	72.56	0.15	46.30	0.43	54.55	0.41	24.67	0.15	27.56	0.61
	Flw	32.00	1.63	34.67	0.86	73.10	0.48	75.29	0.64	69.07c	0.27	71.07c	0.24	50.15c	0.05	53.90c	0.24	17.01c	0.08	17.53c	0.08
BGD72	Veg	28.67	0.72	30.00	0.98	69.12	0.38	70.62	0.11	71.77	0.54	72.48	0.13	52.00	0.59	53.05	0.46	27.79	0.26	28.84	0.59
	Flw	30.33	1.25	33.00	1.93	70.86	0.38	71.28	0.34	69.13c	0.33	71.54c	0.24	50.95c	0.46	53.40c	0.36	19.94d	0.38	19.52d	0.17
P-1003	Veg	30.33	0.34	29.33	0.56	47.02	0.24	51.50	0.07	41.01	0.19	50.54	0.07	41.25	0.35	49.40	0.26	25.75	0.76	26.14	0.36
	Flw	27.33	0.57	29.67	0.69	47.33	0.64	53.92	0.91	41.67d	1.24	56.85a	0.59	41.75d	0.39	47.50d	0.56	15.38e	0.07	15.79e	0.15
CSG8962	Veg	29.33	0.69	33.00	1.19	70.07	0.26	71.25	0.25	70.63	0.16	80.45	0.14	56.20	0.18	54.05	0.57	32.10	0.41	34.37	0.17
	Flw	31.67	1.51	33.67	1.46	69.88	0.12	71.01	0.24	70.52c	0.29	75.04d	0.82	50.95c	1.14	54.85e	0.26	18.59h	0.27	20.97f	0.12
C-235	Veg	26.67	1.16	29.67	1.28	44.00	0.32	58.90	0.68	60.27	0.13	62.64	0.08	48.10	0.43	49.50	0.43	28.92	0.56	29.85	0.29
	Flw	26.33	1.07	30.33	1.12	54.10	0.46	62.78	0.51	55.28e	0.78	50.02e	1.41	40.75e	1.59	44.30f	0.15	17.86c	0.17	16.46g	0.17
ICCV3310	Veg	31.33	0.34	36.00	0.98	64.83	0.18	67.82	0.28	62.40	0.45	62.99	0.12	40.55	1.06	53.95	0.35	28.60	0.78	32.01	0.12
	Flw	33.67	1.25	36.33	1.12	63.51	0.58	67.03	0.72	56.45f	0.58	67.12f	0.83	46.40f	0.22	51.45g	0.57	15.04e	0.22	16.54g	0.20
ICCV3311	Veg	30.67	0.34	33.33	0.79	73.11	0.16	77.05	0.21	65.83	0.24	72.30	0.09	40.20	0.57	52.55	1.93	27.71	0.15	29.63	0.17
	Flw	33.33	0.26	35.33	1.07	74.63	1.45	75.00	0.65	70.19c	0.26	80.67g	1.00	44.50g	0.24	53.45c	0.78	18.09f	0.10	19.47d	0.21
ICCV3403	Veg	31.00	0.22	32.33	0.56	43.98	0.38	44.67	0.15	66.56	0.48	69.01	0.24	37.85	1.05	47.05	1.20	30.63	0.89	30.75	0.08
	Flw	30.67	1.37	33.33	1.90	45.88	1.40	47.14	0.48	50.77g	1.16	56.59a	0.96	49.35h	0.14	44.75f	0.84	15.79e	0.02	16.54g	0.08
ICCV3404	Veg	30.67	0.47	30.33	1.36	64.31	0.36	65.89	0.19	45.01	0.48	45.14	0.17	23.90	1.57	52.85	2.35	27.70	0.29	29.28	0.17
	Flw	31.67	0.69	33.33	2.10	64.40	0.80	67.65	1.94	52.55a	1.41	59.02h	0.73	46.15f	0.41	47.30d	1.06	15.77e	0.11	16.89g	0.13

Table 3. *Cont.*

A																					
		PH				**MSI**				**RWC%**				**CI**				**Protein Content**			
	GS	**Drought**		**Control**		**Drought**		**Control**		**Drought**		**Control**		**Drought**		**Control**		**Drought**		**Control**	
ICCV7301	Veg	30.00	0.22	32.00	0.45	66.33	0.40	66.87	0.27	60.34	0.23	63.08	0.15	56.60	0.34	57.95	0.29	32.06	0.80	29.75	0.11
	Flw	29.67	0.13	30.00	0.45	63.54	0.39	65.40	0.68	66.82h	0.91	64.18i	0.71	45.70i	2.01	55.90h	0.20	15.42e	0.09	18.02h	0.14
ICCV4303	Veg	21.67	0.47	22.67	1.13	56.48	0.59	56.76	0.23	66.67	0.22	69.77	0.14	29.20	2.31	62.05	0.29	30.26	0.97	31.59	0.21
	Flw	21.67	0.47	33.67	3.07	58.73	0.73	61.92	0.35	58.20i	1.98	65.50i	0.74	44.8g	2.19	56.10i	0.20	16.46h	0.17	18.75h	0.24
ICCV4310	Veg	30.33	0.34	31.00	0.22	56.27	0.28	59.59	0.16	67.10	0.35	67.87	0.16	53.30	0.39	57.40	0.29	29.60	1.01	30.61	0.21
	Flw	32.67	1.25	33.00	0.82	60.08	0.65	61.61	0.61	62.17j	1.05	61.87j	0.69	52.85b	0.30	51.50g	0.56	16.98h	0.13	18.59h	0.18
ICCV5312	Veg	30.67	0.27	31.67	0.47	70.89	0.80	73.60	0.14	66.18	0.61	69.58	0.16	45.40	0.80	59.75	0.26	32.02	1.16	32.05	0.50
	Flw	34.00	1.20	34.33	0.57	68.67	1.28	72.31	0.61	65.77k	0.72	69.40k	0.31	54.55j	0.39	56.60i	0.47	16.63h	0.20	17.86c	0.01
ICCV9312	Veg	30.00	0.22	30.00	0.22	52.14	0.43	55.88	0.23	68.59	0.41	70.21	0.18	54.45	0.39	45.60	0.89	27.81	0.23	29.57	0.11
	Flw	30.67	0.47	32.33	1.12	52.03	0.91	57.14	0.57	51.0g	1.01	66.98f	0.46	40.60e	2.35	51.75g	0.50	16.89h	0.23	17.84c	0.20
ICCV9313	Veg	32.33	0.34	33.33	0.72	59.84	0.17	65.78	0.15	60.42	0.39	64.95	0.12	44.30	0.84	55.15	0.18	26.67	0.16	29.75	0.16
	Flw	33.33	0.47	35.00	0.68	58.13	0.57	66.52	0.85	56.86l	0.93	60l	0.92	44.30g	0.83	51.85g	0.87	16.48h	0.29	17.86c	0.23
ICCV9314	Veg	27.00	1.17	29.33	0.47	54.13	0.28	69.30	0.30	72.41	0.19	73.28	0.26	33.50	2.03	44.55	0.53	26.46	0.07	28.41	0.21
	Flw	30.33	2.15	32.67	1.51	60.08	0.91	70.07	0.36	62.67j	0.81	58.82h	0.81	41.60d	1.04	48.45a	0.35	16.46h	0.06	17.84c	0.24
ICCV10313	Veg	26.33	69.00	28.33	0.85	63.57	0.21	70.95	0.21	76.50	0.37	84.72	0.22	51.51	0.29	54.30	0.33	21.24	0.04	28.41	0.13
	Flw	31.00	0.23	34.67	2.10	63.33	0.79	69.54	0.18	70.06c	0.51	72.14c	0.57	50.85c	0.19	54.45e	0.35	18.19f	0.29	19.21d	0.25
ICCV10	Veg	24.67	1.24	32.33	0.34	70.59	0.33	72.59	0.17	77.62	0.38	82.73	0.10	52.20	0.21	52.60	0.73	31.27	0.15	31.09	0.28
	Flw	31.33	1.29	34.33	0.57	75.31	0.61	78.38	0.76	70.93c	0.14	78.34m	0.34	50.65c	0.14	53.90c	0.47	17.29c	0.20	20.71f	0.34
ICCV2	Veg	30.00	0.22	30.00	0.81	44.04	0.66	48.26	0.49	55.64	0.40	68.00	0.30	46.95	0.72	56.55	0.21	26.90	0.70	30.15	0.48
	Flw	29.33	0.35	30.67	1.02	45.81	0.62	48.17	0.80	52.28a	0.76	58.19h	0.68	37.2k	0.63	46.00j	0.45	14.67g	0.18	15.93e	0.17
ICCV92337	Veg	27.67	0.56	28.33	0.67	65.94	0.59	67.65	0.08	64.04	0.62	65.07	0.25	44.15	0.78	47.05	0.18	29.85	0.22	30.53	0.09
	Flw	31.33	1.61	32.33	1.70	61.71	0.38	69.47	0.50	60.52m	0.85	61.50l	0.58	42.7l	2.64	46.50j	0.33	16.85h	0.25	18.09h	0.23
ICCV8310	Veg	32.33	0.56	30.00	0.22	52.07	0.24	56.29	0.21	68.22	0.89	72.35	0.17	46.60	0.59	49.50	0.56	24.83	0.17	30.08	0.20
	Flw	31.67	0.80	33.33	1.51	60.00	1.12	62.03	0.78	63.24n	1.09	64.03i	0.91	40.80e	1.04	45.40k	0.36	18.24f	0.25	18.57h	0.29
ICCV97309	Veg	22.33	0.56	28.00	0.59	77.12	0.60	78.09	0.13	65.97	0.69	68.36	0.15	41.95	1.08	52.30	0.46	26.08	0.31	30.42	0.33
	Flw	33.33	1.02	36.33	2.27	72.22	0.82	76.10	0.70	70c	0.23	74.00d	0.92	45.90i	1.31	52.15l	0.48	19.52d	0.09	20.42f	0.32

Table 3. *Cont.*

		A																			
		PH				**MSI**				**RWC%**				**CI**				**Protein Content**			
	GS	**Drought**		**Control**		**Drought**		**Control**		**Drought**		**Control**		**Drought**		**Control**		**Drought**		**Control**	
ICCV1309	Veg	29.00	0.22	34.33	1.02	65.15	0.60	64.21	0.32	50.00	0.27	52.15	0.16	55.05	0.90	55.30	0.32	24.65	0.11	29.89	0.17
	Flw	31.33	0.52	34.00	1.04	59.90	0.66	61.44	0.41	53.02a	1.04	60.55l	0.68	44.25g	1.55	46.00j	1.24	15.36e	0.11	17.84c	0.23
ICCV10304	Veg	24.33	0.69	32.33	0.56	68.96	0.62	70.80	0.14	61.92	0.26	62.63	0.16	37.15	1.84	49.75	1.17	28.16	0.31	30.10	0.09
	Flw	30.33	0.35	32.00	0.68	68.93	0.60	70.44	0.42	65.93k	11.24	56.58a	0.82	37.35k	0.66	43.90k	0.88	16.83h	0.03	17.86c	0.12
ICCV10307	Veg	25.33	0.56	32.67	0.34	60.82	0.20	65.02	0.28	70.65	0.30	65.02	0.25	40.50	1.10	67.10	1.39	26.92	0.12	30.68	0.13
	Flw	30.33	0.57	33.33	0.47	67.53	1.02	68.85	0.59	61.82m	1.02	65.33i	1.02	40.75e	1.09	44.70m	0.74	16.54h	0.12	17.84c	0.10
ICCV10306	Veg	23.00	0.81	34.00	0.59	59.82	0.28	67.35	0.30	68.04	0.93	69.67	0.05	52.60	1.38	54.75	0.86	27.41	0.12	31.28	0.24
	Flw	29.00	0.82	35.67	0.73	55.42	1.08	64.44	0.63	62.90n	0.57	69.67m	0.34	48.00m	0.67	50.20n	0.63	16.35h	0.14	17.84c	0.20
ICCV10316	Veg	25.00	0.67	33.33	0.34	55.73	0.21	60.50	0.35	63.47	0.46	65.13	0.24	47.00	0.30	55.40	0.65	27.09	0.21	29.51	0.30
	Flw	29.00	0.82	35.00	0.68	62.50	0.62	65.65	0.35	66.66k	1.06	68.00m	0.91	48.90m	0.40	51.95g	0.69	16.83h	0.34	17.86c	0.21
ICCV00109	Veg	22.67	0.47	30.33	0.34	55.17	0.56	61.76	0.16	60.26	0.26	64.46	0.29	53.30	1.25	54.85	1.31	27.88	0.35	29.46	0.10
	Flw	28.00	0.68	31.33	0.73	60.04	1.04	63.33	0.65	58.59	1.41	60.87l	0.61	44.45g	1.25	49.60o	1.38	16.52h	0.24	17.84c	0.21
ICCV3103	Veg	23.33	0.34	29.00	0.22	61.61	0.31	66.84	0.17	40.67	0.26	70.82	0.13	57.20	0.46	63.05	0.31	29.88	0.14	30.53	0.07
	Flw	25.00	0.99	29.67	0.47	64.13	0.23	65.05	0.91	48.22	0.80	60.49l	0.62	47.50n	0.56	48.50a	1.69	16.41h	0.16	17.86c	0.18
ICCV9307	Veg	28.00	0.45	30.67	0.34	71.14	0.28	73.04	0.26	61.75	0.32	69.43	0.18	53.95	0.45	54.35	1.48	26.75	0.14	29.82	0.35
	Flw	30.67	0.26	32.67	0.47	70.99	0.34	72.78	0.37	58.31i	0.79	68.78m	0.46	50.45c	0.55	53.55c	0.55	18.13f	0.46	18.55h	0.08
ICCV95423	Veg	28.00	0.39	32.33	0.47	60.33	0.27	60.81	0.39	62.33	0.23	64.65	0.21	53.40	0.67	48.50	0.28	23.32	0.14	25.24	0.30
	Flw	29.33	0.13	32.00	0.60	65.65	0.81	66.00	0.78	63.55n	0.91	66.21	0.55	43.10o	1.15	46.40j	0.22	15.79e	0.07	17.86c	0.15
ICCV97404	Veg	15.67	1.16	28.33	0.34	63.84	0.44	67.02	0.33	52.91	0.53	56.50	0.13	46.20	0.50	46.30	0.16	29.57	0.19	29.42	0.21
	Flw	25.00	0.45	30.00	0.23	60.36	0.53	62.75	0.52	53.96a	0.91	59.19l	0.61	42.00l	0.45	45.70k	0.52	15.77e	0.14	16.81g	0.07
ICCV0301	Veg	26.67	0.34	31.33	0.72	54.29	0.49	58.50	0.40	57.64	0.87	60.32	0.15	49.75	0.28	50.35	0.38	31.34	1.07	32.04	0.27
	Flw	27.33	0.57	31.67	0.65	55.00	0.82	56.11	0.67	56.55f	0.81	63.22n	0.97	46.75f	0.39	49.35o	0.14	15.42e	0.20	16.94g	0.22
ICCV0302	Veg	25.33	0.56	23.00	0.81	51.96	0.21	56.25	0.24	60.00	0.45	63.73	0.09	54.60	0.18	55.15	1.17	29.86	0.99	29.88	0.05
	Flw	26.00	0.82	25.67	0.92	52.38	0.57	57.14	0.36	55.63e	1.52	62.76n	0.58	41.50d	0.33	47.15d	0.64	14.62g	0.06	16.56g	0.11
ICCV1301	Veg	25.00	0.59	29.00	0.22	61.67	0.21	68.12	0.24	54.78	0.61	56.16	0.10	50.00	0.05	55.95	0.31	28.04	0.83	30.39	0.20
	Flw	26.00	0.23	29.67	0.13	66.85	0.80	69.23	0.82	54.72e	1.71	60.38l	1.00	44.10g	1.38	45.70k	2.01	15.04e	0.14	16.79g	0.09

Table 3. *Cont.*

A																					
		PH				MSI				RWC%				CI				Protein Content			
	GS	Drought		Control		Drought		Control		Drought		Control		Drought		Control		Drought		Control	
L-550	Veg	18.67	0.52	26.67	0.56	55.78	0.45	61.76	0.22	62.61	0.31	64.46	0.17	46.70	0.52	45.95	1.45	28.18	0.93	29.66	0.22
	Flw	24.67	0.57	27.00	0.68	52.63	0.57	57.45	0.99	57.25f	1.27	63.15n	0.62	42.70l	0.38	47.25d	1.64	16.28h	0.16	16.76g	0.08
ICCV5308	Veg	17.00	0.81	28.33	0.34	54.55	0.48	63.04	0.39	64.81	0.42	68.00	0.16	35.00	2.36	52.10	0.42	25.35	0.60	33.02	0.60
	Flw	20.67	0.69	29.33	0.26	57.38	0.64	60.00	1.24	60.91m	0.92	67.66f	0.57	39.40p	0.09	47.50d	1.01	15.82e	0.11	16.19g	0.17
ICCV5313	Veg	26.67	0.47	30.33	0.34	75.31	0.67	77.13	0.14	65.28	0.48	71.49	0.21	50.75	0.19	52.30	0.99	26.84	0.27	31.28	0.11
	Flw	30.00	0.45	30.67	0.26	72.41	0.86	73.91	1.01	61.12m	1.10	73.46d	0.51	51.40q	0.31	54.55e	0.39	18.52f	0.18	18.70h	0.19

B													
		Days to Flowering				Days to Maturity				SB			
		Drought		Control		Drought		Control		Drought		Control	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
ICC1882	Veg	125.00a	0.47	110.00a	0.69								
	Flw					92.67a	0.13	128.00a	0.22	0.67a	0.13	1.67a	0.13
ICC4958	Veg	110.00b	0.47	109.00a	0.79								
	Flw					81.00b	0.45	124.67b	0.13	3.00b	0.00	3.67b	0.13
PUSA1103	Veg	109.00c	0.79	107.00a	0.72								
	Flw					87.00c	0.81	126.00c	0.22	2.67c	0.13	3.00c	0.22
BGD72	Veg	111.00b	0.56	110.00a	0.59								
	Flw					94.33a	1.16	125.33d	0.13	2.67c	0.13	3.33c	0.13
P-1003	Veg	111.33b	0.59	106.66a	0.47								
	Flw					101.00e	0.59	128.67a	0.13	1.00d	0.22	2.00d	0.22
CSG8962	Veg	100.00d	0.59	96.00b	0.81								
	Flw					84.00b	0.81	125.67d	0.13	2.33c	0.13	2.67d	0.13
C-235	Veg	73.00e	0.22	76.00c	0.45								
	Flw					100.00d	0.59	128.00a	0.22	1.00d	0.22	1.67a	0.13
ICCV3310	Veg	44.00f	0.59	79.00c	0.72								
	Flw					98.00d	0.59	129.33e	0.13	1.33d	0.26	2.00d	0.22

Table 3. *Cont.*

		B											
		Days to Flowering				**Days to Maturity**				**SB**			
		Drought		**Control**		**Drought**		**Control**		**Drought**		**Control**	
		Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
ICCV3311	Veg	45.00f	0.59	79.00c	0.56								
	Flw					90.00a	0.45	126.33c	0.13	2.00c	0.22	2.67d	0.13
ICCV3403	Veg	59.00g	0.69	79.00c	1.24								
	Flw					99.00d	0.22	128.00a	0.22	1.67d	0.26	2.00d	0.22
ICCV3404	Veg	62.00h	1.03	76.00c	0.22								
	Flw					101.33e	0.72	128.33a	0.26	1.33d	0.13	2.33d	0.26
ICCV7301	Veg	64.00h	0.56	88.00d	0.69								
	Flw					97.00d	0.98	125.00d	0.22	1.67d	0.26	2.00d	0.00
ICCV4303	Veg	49.00i	0.34	79.00c	0.22								
	Flw					95.67d	0.91	128.00a	0.22	1.67d	0.26	2.00d	0.22
ICCV4310	Veg	46.33i	0.52	71.00g	0.72								
	Flw					101.33e	0.47	123.00e	0.13	1.67d	0.13	2.33d	0.13
ICCV5312	Veg	46.50i	0.56	75.00g	0.34								
	Flw					100.67e	0.47	128.00a	0.22	2.00c	0.22	3.33c	0.13
ICCV9312	Veg	52.00j	0.47	73.00g	0.47								
	Flw					97.67d	0.72	126.00c	0.13	1.33d	0.13	1.67a	0.26
ICCV9313	Veg	49.00i	0.34	82.00e	0.34								
	Flw					93.00a	0.59	129.67e	0.22	1.00d	0.22	1.33a	0.26
ICCV9314	Veg	47.00i	0.59	80.00e	0.34								
	Flw					97.67d	0.56	130.33f	0.34	1.00d	0.22	2.00d	0.00
ICCV10313	Veg	48.00i	0.34	78.00c	0.56								
	Flw					91.00a	0.81	125.67d	0.34	2.00c	0.22	2.67d	0.13
ICCV10	Veg	104.00d	0.47	90.00d	0.45								
	Flw					91.00a	0.39	126.33c	0.13	2.67c	0.13	3.00c	0.00

Table 3. *Cont.*

B													
		Days to Flowering				**Days to Maturity**				**SB**			
		Drought		**Control**		**Drought**		**Control**		**Drought**		**Control**	
		Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
ICCV2	Veg	43.00f	0.45	73.00g	0.81								
	Flw					101.67e	0.85	127.00f	0.47	0.67a	0.13	1.00a	0.22
ICCV92337	Veg	74.00e	0.34	71.00g	0.45								
	Flw					98.33d	0.47	128.00a	0.39	1.00d	0.22	1.67a	0.13
ICCV8310	Veg	43.00f	0.22	71.00g	0.94								
	Flw					99.00d	0.22	122.67g	0.34	1.33d	0.13	1.33a	0.34
ICCV97309	Veg	68.00k	0.34	64.00f	0.56								
	Flw					91.00a	0.59	124.67b	0.34	2.33c	0.13	3.00c	0.22
ICCV1309	Veg	42.33f	0.56	74.00e	0.79								
	Flw					97.33d	0.69	126.67c	0.26	1.33d	0.13	1.33d	0.26
ICCV10304	Veg	46.00i	0.81	75.00g	0.34								
	Flw					98.67d	0.34	125.00d	0.22	1.00d	0.22	2.00d	0.22
ICCV10307	Veg	44.00f	0.81	71.00g	0.72								
	Flw					99.00d	0.22	125.00d	0.22	1.33d	0.13	1.67d	0.13
ICCV10306	Veg	41.00f	0.56	73.00g	0.34								
	Flw					95.33d	0.85	126.00c	0.22	1.33d	0.13	2.00d	0.00
ICCV10316	Veg	58.00g	0.67	81.00e	0.45								
	Flw					91.00a	0.81	126.67c	0.52	1.67d	0.13	2.00d	0.22
ICCV00109	Veg	75.50l	0.22	91.00h	0.85								
	Flw					99.67d	0.47	126.00c	0.22	1.33d	0.13	1.00a	0.22
ICCV3103	Veg	102.00d	0.79	92.00h	0.34								
	Flw					97.33d	0.56	127.33f	0.47	1.33d	0.34	0.67e	0.26
ICCV9307	Veg	51.00j	0.13	79.00c	0.47								
	Flw					95.67d	0.69	129.33e	0.34	2.67c	0.13	2.67d	0.13

Table 3. *Cont.*

B													
		Days to Flowering				**Days to Maturity**				**SB**			
		Drought		**Control**		**Drought**		**Control**		**Drought**		**Control**	
		Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
ICCV95423	Veg	107.00b	0.56	93.00h	0.56								
	Flw					99.67d	0.47	127.00f	0.39	1.33d	0.26	1.33a	0.13
ICCV97404	Veg	107.00b	0.47	64.00f	0.45								
	Flw					98.00d	0.59	125.00d	0.22	1.00d	0.22	1.33a	0.13
ICCV0301	Veg	43.00f	0.91	70.00g	0.56								
	Flw					99.00d	0.90	124.00b	0.22	0.67a	0.13	0.67e	0.13
ICCV0302	Veg	43.00f	0.81	75.00g	0.72								
	Flw					99.33d	1.02	128.00a	0.22	0.67a	0.13	0.67e	0.26
ICCV1301	Veg	46.00i	0.47	70.00g	0.45								
	Flw					101.33e	0.34	127.00	0.22	0.67a	0.13	1.00a	0.22
L-550	Veg	108.00b	0.39	107.00a	0.45								
	Flw					85.33c	0.56	127.33	0.34	1.00d	0.22	1.33a	0.26
ICCV5308	Veg	41.00b	0.72	71.00g	0.47								
	Flw					101.00e	0.59	127.00	0.22	0.67a	0.13	1.33a	0.13
ICCV5313	Veg	45.00i	0.22	68.00g	0.59								
	Flw					88.33c	0.34	128.00	0.39	1.67d	0.13	2.00d	0.22

C																				
Yield Traits																				
	Irrigated Conditions										**Drought Stressed Conditions**									
	Biomass (gms)		**100 SW (gms)**		**FPP**		**SPP**		**PY (gms)**		**Biomass (gms)**		**100 SW (gms)**		**FPP**		**SPP**		**PY (gms)**	
Genotypes	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**
ICC1882	689.48a	0.55	17.65a	0.53	26.00a	0.00	1.32a	0.00	216.77	0.12	612.99a	1.51	14.91	0.04	23.66a	0.00	1.05a	0.00	164.73a	0.16
ICC4958	730.66b	0.54	28.72b	0.53	25.66a	0.00	1.17a	0.00	185.23	0.12	672.13a	1.51	25.18	0.04	22.36a	0.00	1.12a	0.00	177.40a	0.16
Pusa1103	518.03c	0.55	21.97c	0.53	28.33b	0.00	0.88b	0.00	248.27	0.12	426.82b	1.54	17.87	0.04	25.33b	0.00	0.81b	0.00	226.97b	0.17

Table 3. *Cont.*

C																				
Yield Traits																				
	Irrigated Conditions										**Drought Stressed Conditions**									
	Biomass (gms)		**100 SW (gms)**		**FPP**		**SPP**		**PY (gms)**		**Biomass (gms)**		**100 SW (gms)**		**FPP**		**SPP**		**PY (gms)**	
Genotypes	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**
BGD72	588.55d	0.57	16.39d	0.52	31.00c	0.00	1.00a	0.00	461.43	0.12	591.53c	1.57	14.13	0.04	24.66b	0.00	0.87b	0.00	401.43c	0.15
Pusa1003	420.63d	0.58	16.58d	0.51	18.33d	0.01	0.35c	0.00	144.73	0.12	120.83d	1.61	13.63	0.04	13.00c	0.01	0.28c	0.00	62.50d	0.15
CSG8962	694.78a	0.60	11.19e	0.51	34.33e	0.00	0.97d	0.00	241.40	0.13	374.27e	1.66	10.53	0.04d	31.00d	0.01	0.78d	0.00	214.30b	0.15
C235	320.87a	0.62	14.22f	0.51	35.67e	0.00	0.40c	0.00	143.70	0.13	108.67d	0.53	10.80	0.04	28.66e	0.00	0.35e	0.00	47.60d	0.15
ICCV3310	463.10d	0.63	33.17g	0.49	22.66f	0.00	0.34c	0.00	120.59	0.13	56.43f	0.54	28.00	0.04	18.66f	0.00	0.31e	0.00	45.84d	0.15
ICCV3311	520.14c	0.64	30.59h	0.45	32.00g	0.00	0.16e	0.00	114.52	0.13	155.40d	0.55	22.90	0.04	27.00g	0.00	0.13f	0.00	95.87d	0.16
ICCV3403	472.29d	0.66	30.94h	0.45	23.33h	0.00	0.18e	0.00	145.80	0.13	53.67f	0.56	25.04	0.04	16.66h	0.00	0.17f	0.00	116.74a	0.16
ICCV3404	463.07d	0.68	38.71i	0.45	39.33i	0.00	0.16e	0.00	168.25	0.14	121.30d	0.57	30.46	0.04	32.33d	0.00	0.14f	0.00	120.72a	0.16
ICCV7301	363.88e	0.70	37.30j	0.45	19.00j	0.00	0.27f	0.00	155.70	0.14	121.30d	0.59	24.55	0.04	14.00d	0.00	0.14f	0.00	74.65d	0.16
ICCV4303	539.35c	0.72	35.96k	0.44	24.00k	0.00	0.38c	0.00	130.05	0.14	40.53f	0.61	30.96	0.04	14.00d	0.00	0.32e	0.00	78.26d	0.16
ICCV4310	284.78f	0.73	33.61g	0.44	32.33g	0.00	0.37c	0.00	128.42	0.14	101.30d	0.62	25.85	0.04	22.00a	0.01	0.34e	0.00	58.03d	0.17
ICCV5312	467.56d	0.74	35.72k	0.44	32.00g	0.00	0.18e	0.00	50.43	0.14	73.73f	0.63	30.16	0.05	28.00e	0.00	0.20f	0.00	41.73d	0.17
ICCV9312	380.00e	0.75	37.29j	0.44	19.66j	0.01	0.36c	0.00	125.41	0.15	227.37g	0.64	30.66	0.05	15.33d	0.01	0.27c	0.00	63.81d	0.17
ICCV9313	461.07d	0.76	39.24l	0.43	37.33l	0.00	0.24f	0.00	71.61	0.15	304.43e	0.66	31.91	0.05	43.00h	0.00	0.22c	0.00	61.90d	0.17
ICCV9314	354.60e	0.78	36.45m	0.41	62.33m	0.00	0.22f	0.00	183.34	0.15	122.63d	0.69	30.45	0.05	56.33i	0.00	0.18f	0.00	168.85d	0.17
ICCV10313	699.37a	0.80	37.56j	0.41	37.00l	0.00	0.23f	0.00	365.70	0.15	368.67e	0.72	31.96	0.05	30.33d	0.00	0.21c	0.00	253.41b	0.18
ICCV10	361.40e	0.82	19.61n	0.40	64.33n	0.00	0.35c	0.00	161.90	0.16	212.07g	0.72	16.15	0.05	55.50j	0.01	0.30e	0.00	134.77a	0.18
ICCV2	703.19b	0.86	21.92c	0.36	49.83o	0.00	0.35c	0.00	167.59	0.17	311.50e	0.76	17.53	0.05	44.33h	0.01	0.34e	0.00	132.14a	0.18
ICCV92337	422.85d	0.89	30.93h	0.36	47.33p	0.00	0.19e	0.00	85.28	0.18	164.93d	0.80	25.87	0.05	42.5h	0.01	0.17f	0.00	75.99d	0.19
ICCV8310	356.75e	0.94	30.22h	0.36	60.33q	0.00	0.27f	0.00	88.54	0.18	268.10g	0.81	22.99	0.05	59.16k	0.00	0.24c	0.00	51.87d	0.19
ICCV97309	687.49a	0.97	24.66o	0.36	34.00l	0.00	0.27f	0.00	146.44	0.19	310.37e	0.73	20.25	0.06	30.66d	0.00	0.23c	0.00	136.99a	0.20
ICCV1309	854.00f	1.02	30.97h	0.32	29.66b	0.00	0.32c	0.00	150.36	0.20	79.37f	0.75	28.17	0.06	22.66a	0.00	0.29c	0.00	73.76d	0.21
ICCV10304	382.70e	1.01	22.68p	0.30	26.00a	0.00	0.29f	0.00	78.86	0.21	173.07d	0.77	17.51	0.06	22.00a	0.01	0.24c	0.00	66.93d	0.22

Table 3. *Cont.*

C																				
Yield Traits																				
	Irrigated Conditions										Drought Stressed Conditions									
	Biomass (gms)		100 SW (gms)		FPP		SPP		PY (gms)		Biomass (gms)		100 SW (gms)		FPP		SPP		PY (gms)	
Genotypes	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**	**Avg**	**SE**
ICCV10307	456.63d	0.94	35.24k	0.30	77.33r	0.00	0.21f	0.00	81.10	0.18	304.83e	0.81	30.43	0.06	59.00k	0.01	0.17f	0.00	62.54d	0.23
ICCV10306	398.42e	1.01	35.53k	0.28	21.00f	0.00	0.36c	0.00	104.67	0.18	153.27d	0.86	28.87	0.07	20.33l	0.00	0.34e	0.00	75.00d	0.24
ICCV10316	447.18d	1.05	41.76q	0.28	37.33l	0.00	0.16e	0.00	138.47	0.19	410.40b	0.89	34.46	0.07	31.33d	0.00	0.12f	0.00	74.83d	0.26
ICCV00109	474.56d	1.07	20.87r	0.28	18.66j	0.00	0.33c	0.00	153.94	0.19	282.10g	0.94	17.55	0.07	17.33f	0.00	0.29c	0.00	54.35d	0.28
ICCV3103	311.67e	1.17	25.43s	0.28	35.33e	0.00	0.32c	0.00	106.88	0.18	198.43d	1.02	19.16	0.08	33.33d	0.00	0.28c	0.00	59.96d	0.27
ICCV9307	408.30d	1.25	38.95t	0.27	25.66a	0.00	0.16e	0.00	117.61	0.18	165.93d	1.09	33.84	0.08	16.00m	0.00	0.14f	0.00	54.51d	0.26
ICCV95423	391.07e	1.34	27.37u	0.27	21.67f	0.00	0.44g	0.00	417.28	0.19	212.27g	1.16	23.14	0.08	23.00a	0.00	0.41g	0.00	156.54a	0.29
ICCV97404	655.73a	1.34	25.46s	0.27	35.66e	0.01	0.62h	0.00	237.00	0.22	320.30e	1.30	18.73	0.09	37.33n	0.00	0.52h	0.00	159.55a	0.33
ICCV0301	568.00c	1.13	17.96a	0.27	31.33g	0.00	0.31c	0.00	120.93	0.18	130.57d	1.48	13.22	0.11	24.67o	0.00	0.27c	0.00	49.01d	0.38
ICCV0302	413.11d	0.88	31.17v	0.25	38.00s	0.00	0.26f	0.00	121.03	0.21	141.63d	1.75	24.67	0.11	35.00p	0.00	0.24c	0.00	58.29d	0.37
ICCV1301	349.85e	1.05	26.54w	0.20	46.00t	0.00	0.19e	0.00	123.51	0.16	205.27g	2.09	21.13	0.06	43.33h	0.00	0.19f	0.00	119.07a	0.44
L550	695.48a	0.95	17.73a	0.20	50.33u	0.00	1.31a	0.00	162.17	0.19	619.32a	2.66	15.91	0.07	46.16q	0.00	1.19a	0.01	73.99d	0.28
ICCV5308	135.88g	1.30	37.67j	0.20	40.00i	0.00	0.44g	0.00	275.79	0.23	73.60f	1.67	29.98	0.09	34.67d	0.00	0.42g	0.00	246.78b	0.23
ICCV5313	416.07d	1.53	33.72g	0.02	40.00i	0.00	0.35c	0.00	191.71	0.30	90.67f	2.86	29.76	0.06	37.33n	0.00	0.32e	0.00	115.41a	0.37

Means followed by different letters within a column are significantly different from each other according to Tukey's Studentized Range (HSD) test at $p < 0.05$; Flw: Reproductive stage; SE, standard error; Avg: Mean values; Veg: Vegetative stage; Different alphabets show significant difference ($p < 0.05$).

Table 4. Per cent reduction in different traits in chickpea genotypes.

Traits	Vegetative			Reproductive		
	Control	Stress	% Decrease	Control	Stress	% Decrease
Plant height (cm)	30.48	26.79	12.10	32.56	29.55	9.23
Membrane stability index	64.98	61.66	5.12	65.31	62.03	5.02
Relative water content	66.82	46.78	29.99	65.82	62.21	5.48
Chlorophyll index (SPAD units)	53.38	46.99	11.97	50.01	45.36	9.30
Protein content	29.98	26.55	11.44	17.36	16.19	6.72
Days to flowering (DF)	70.25	65.33	7.00			
Days to maturity (DM)				119.21	103.99	12.87
Biomass				46.38	32.91	29.04
100 seed weight				28.74	25.29	12.00
Filled pods per plant (FPP)				35	30	14.28
Seeds per plant (SPP)				1.08	1.03	4.34
Plant Yield (gms)				16.55	11.05	33.23

3.1.2. Drought Stress at Reproductive Stage

Drought stress at flowering stage significantly reduced PY for all the cultivars (Table 3C). As shown in Table 4, the yield components of the number of filled pods per plant, biomass and plant yield (PY) significantly reduced by 29.36%, 29.04% and 33.23%, respectively, when compared with the irrigated plants (Table 4). The total biomass ranged from 13.58 to 73.06 g in irrigated conditions, whereas under stressed conditions, the range was from 10.86 to 67.21 g per plant with a reduction of 29.04% as a result of drought stress. The mean 100 SW in irrigated conditions ranged from 11.19 to 41.76 g per plant, while in the stressed conditions, the range was 10.19 to 37.46 per plant, and yields under stress varied from 4.2 g in irrigated condition in ICCV5312 to 46.1 g in BGD-72. At the start of the water stress, the number of seeds produced per pod varied among the 40 genotypes ($p < 0.05$), from 0.13 in ICCV3311 to 1.12 in ICC4958 (Table 3C). The total number of seeds produced per plant varied with the genotype ($p < 0.05$, Table 3C) and water treatment ($p < 0.05$, Table 3C). In total, irrigated plants produced 16.68 seeds per pod, and the drought-stress treatment reduced these numbers by 0.7% in ICCV10316 to 7% in L-550 ($p < 0.05$). Of the pods set before the drought stress was imposed, the number that developed into filled pods (12–62) per plant and seeds (0–2) per pod differed among genotypes in both the irrigated and drought-stress condition (Table 3C). Furthermore, there were significant genotype × water treatment interactions for the number of filled pods ($p < 0.05$) and seeds per pod ($p < 0.05$) at the reproductive stress. The number of filled pods per plant under drought stress varied from 12 in ICCV3311 to 62 in ICC4958, 15–25% of the 16 to 80 filled pods plant^{-1} in irrigated conditions (Table 3C). In irrigated conditions, 32% of the plants had more than 40 filled pods per plant compared with only 22% under drought stress, which contributed to a 32.3% reduction in average filled pods per plant over the 40 genotypes ($p < 0.05$). Similarly, drought stress decreased the number of seeds per pod to 0.16 in ICCV3311 to 1.32 in ICC1882, a reduction of 14–85% of the 0.13–1.12 seeds per pod in irrigated condition (Table 3C). Thus, the effects of drought stress on physiological changes might be appearing at reproductive stage signify that a flowering stage is sensitive to drought stress, and thus, it appears that in the selection of tolerant genotypes, it is better to take into consideration optimal performance under stress to increase the possibility of developing high yielding cultivars.

3.2. Screening of Genotypes Based on Drought Susceptibility Index (DSI)

The DSI index was assessed to identify the most tolerant genotypes [18]. This index ranged from 0.06 to 0.97, with an average value of 0.38. On the basis of DSI diagram (Figure 2), 22 genotypes had values less than the average value, whereas 18 genotypes, 2 varieties (P-1003 and C-235) and 1 breeding line (L-550) had DSIs greater than 0.38. Furthermore, eight kabuli genotypes (ICCV1301, ICCV97309, ICCV9314, ICCV5308, ICCV92337, ICCV9313 and ICCV10304, ICCV3311) and one desi genotype (ICCV10) showed similar values of DSI similar to the well-known drought tolerant breeding line ICC4958 (0.06). As a result, the following genotypes with the lowest DSIs (included in brackets) were identified as the most tolerant: ICCV1301(0.04), ICC4958(0.05), ICCV97309 (0.07), Pusa1103 (0.1), ICCV5308 (0.12), ICCV92337 (0.12), CSG8962 (0.13), BGD72 (0.15), ICCV9313 (0.15), ICCV10304 (0.17), ICCV3311 (0.19) and ICCV10 (0.19).

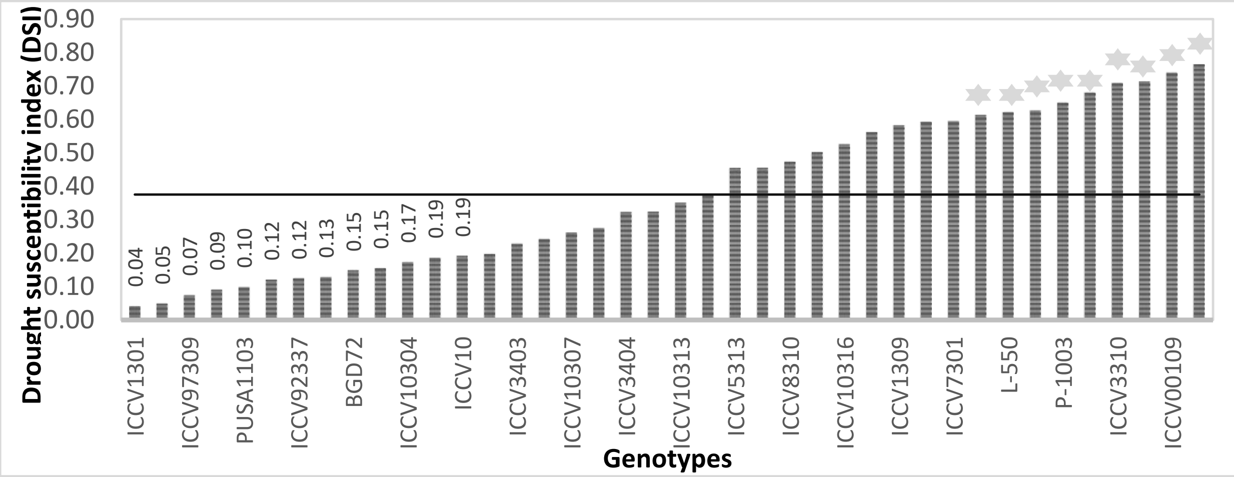

Figure 2. Drought susceptibility index (DSI) values for the forty genotypes. Black line indicates the median value. Lowest DSI values represent the most tolerant genotypes. Stars indicate the highest DSI values (from the left, L-550, ICCV4310, P-1003, ICCV0301, ICCV3310, ICCV95423, ICCV00109, C-235).

3.3. Association of Multiple Traits under Drought Stress

The correlations of chickpea yield and other physiological traits and DSI were compared under irrigated and under stress (at both the vegetative and reproductive stages) using Pearson coefficient analysis.

Among the 40 genotypes, seed yield was positively associated with the days to flowering, SB, MSI and RWC, protein content and biomass in both the irrigated and stress treatments ($p < 0.05$) at the vegetative and reproductive stages (Figure 3). However, significant positive correlation was observed with days to flowering (r = 0.207, $p < 0.05$; r = 0.134, $p < 0.05$) and RWC (r = 0.05, $p < 0.05$; r = 0.039, $p < 0.05$) at both the stages. Seed yield was negatively associated with plant height, 100SW (r = 0.057, $p < 0.05$; r = 0.065, $p < 0.05$) and DM (r = 0.035, $p < 0.05$; r = 0.106, $p < 0.05$) and DSI (r = 0.004, $p < 0.05$; r = 0.218, $p < 0.05$) at both stages under irrigated conditions and drought stress, except plant height. DSI was strongly positively associated with chlorophyll index at vegetative stage and days to maturity at reproductive stage ($p < 0.05$). However, DSI was negatively correlated with MSI (r = −0.354, $p < 0.05$; r = −0.29, $p < 0.05$; r = −0.195, $p < 0.05$; r = −0.348, $p < 0.05$), RWC (r = −0.376, $p < 0.05$; r = −0.303, $p < 0.05$; r = −0.284, $p < 0.05$; r = −0.371, $p < 0.05$) and protein content (r = −0.295, $p < 0.05$; r = −0.202, $p < 0.05$; r = −0.336, $p < 0.05$; r = −0.229, $p < 0.05$), biomass (r = −0.302, $p < 0.05$) and seed yield (r = −0.467, $p < 0.05$). No correlation was observed between plant height at vegetative stage and biomass at reproductive stage (r = 0.002, $p > 0.05$) (Figure 3).

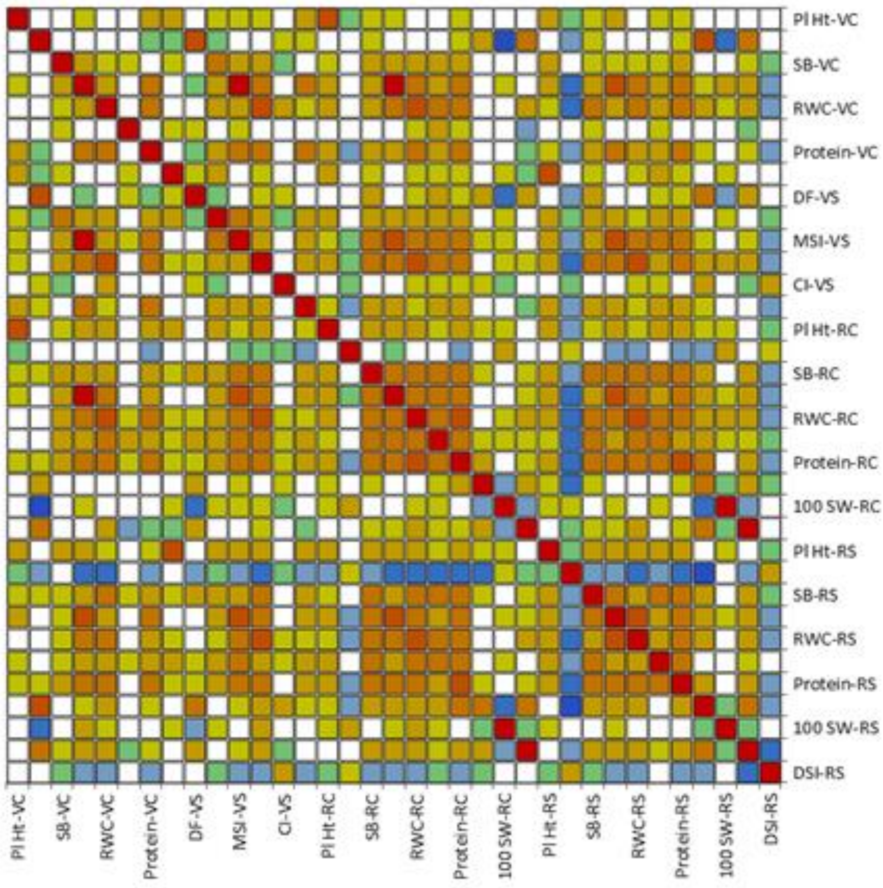

Figure 3. Pearson's coefficient of correlation amongst the traits measured under control (VC) and Scheme 100. SW, DSI indicate the plant height, days to maturity, secondary branches, membrane stability index, relative water content, chlorophyll index, protein content (leaf), 100 seed weight, drought susceptibility index, filled pods per plant, seeds per pod, respectively.

3.4. Principal Component Analysis

A principal component analysis was performed to dissect the associations amongst the morpho-physiological traits under stressed conditions. At vegetative stage, PC1 and PC2 together accounted for 44.14% of the total variation. PC1 contributed 26.46% of total variation and was positively correlated with plant height, RWC, MSI, protein (leaf) and SB. In addition, 17.68% of the total variation was explained by PC2 showing positive correlation with CI and DF (Figure 4A). At the reproductive stage, the first 2 PCs collectively explained 53.21% of the total variation. PC1 accounted for 37.96% of the total variation showing positive correlation with plant height, CI, SB, RWC, protein (leaf), MSI, PY and biomass. PC2, on the other hand, contributing 15.25% of the total variation, showed positive correlation with 100SW and DM and negative correlation with DSI (Figure 4B). No distinct grouping pattern was observed amongst the chickpea genotypes at both the stages. The 2D biplots also indicated that genotypes had a strong positive correlation with CI, RWC%, MSI, protein content PH, yield traits (Biomass, PY, 100SW) and a strong negative correlation with DSI and DTM. Therefore, these physiological traits can be used as suitable tools for screening the drought-tolerant genotypes.

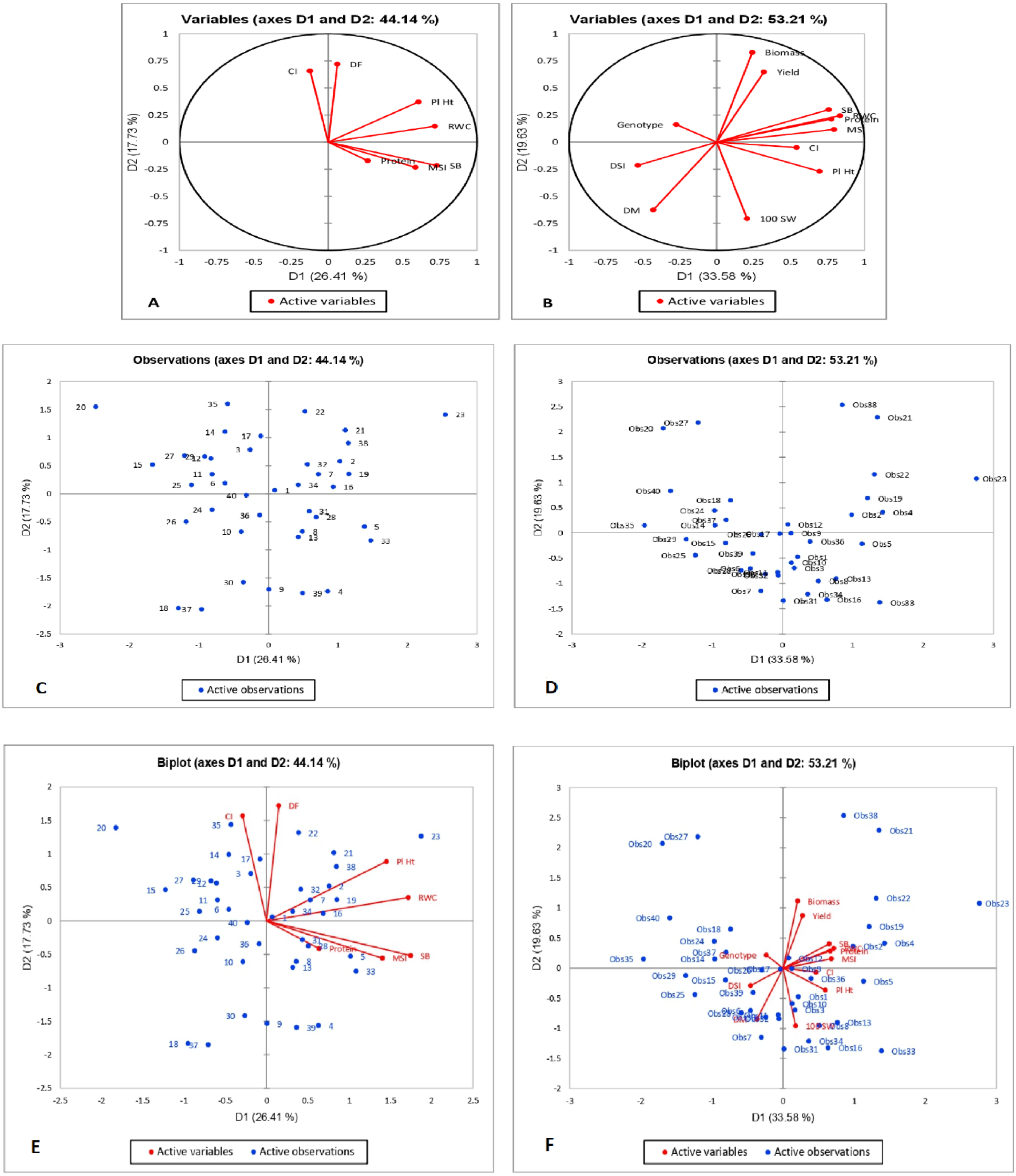

Figure 4. PCA biplots depicting relationships between the traits measured at vegetative stage (**A**), reproductive stage (**B**); Distribution of 40 chickpea genotypes based on principle component analysis

under stressed conditions at vegetative stage (**C**), reproductive stage (**D**); PCA-based biplots depicting performance of 10 most drought-tolerant chickpea genotypes under stressed conditions at vegetative stage (**E**) and reproductive stage (**F**), where Pl Ht, RWC, MSI, CI, DF, SB, 100 SW, DM, DSI indicate the plant height, relative water content, membrane stability index, chlorophyll index, days to flowering, secondary branches, 100 seed weight and days to maturity and drought susceptibility index, respectively. The pattern of distribution of the chickpea genotypes under stressed conditions is shown in (**C**,**D**).

3.5. Performance of Ten Most Tolerant Genotypes under Stressed Conditions

The PCA-based 2D biplots identified the most drought-tolerant genotypes, ICC4958 (23), BGD72 (21), Pusa1103 (22), CSG8962 (38), ICCV10 (19), ICCV97309 (4), ICCV03311 (5), ICCV03403 (10), ICCV05308 (34), ICCV10313 (2), with higher plant height, SB, RWC, MSI, CI, protein (leaf), biomass, FPP, SPP and PY and lower DM and DSI (Figure 4E,F). These genotypes maintained higher yield and yield traits under stress, establishing their tolerance to drought (Figure 5). The seed-filling stage began earlier in the genotypes identified with significantly reduced days to maturity under stressed conditions and can be used as sources of drought-stress tolerance in future breeding programs.

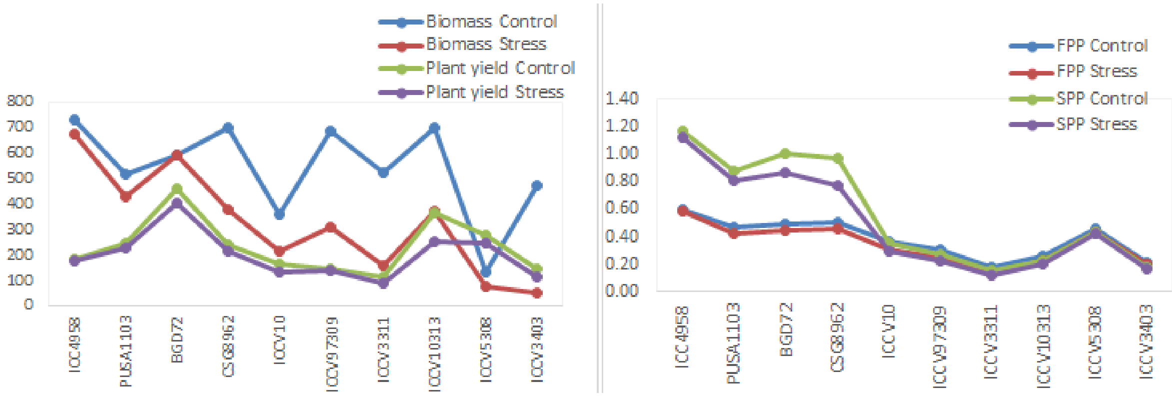

Figure 5. Effect of water stress on yield and yield traits of tolerant genotypes; FPP, filled pods per plant; SPP, seeds per pod.

4. Discussion

The narrow genetic variability in chickpea largely restricts chickpea improvement [5] and the repeated use of fewer numbers of elite lines with narrow genetic base in developing new breeding lines could have been one of the major reasons for this narrow diversity [3]. Thus, the study of agronomic performance of selected chickpeas was undertaken to identify genotypes improved drought tolerance and yield under stress. The effect of water stress on chickpea growth at different growth periods has been widely studies. Chickpea experiences water stress at different growth stages [26]. Some studies have showed that the most critical period to water stress of chickpea growth is early podding vegetative stage and water use efficiency for higher seed yield [27]. Other studies found that the reproductive stage is the most sensitive stage to water deficit [26,28,29]. Consistent with previous studies [21,27], our results confirmed that water stress at the reproductive stage had noteworthy effect on yield and yield-related traits (Table 3C), with reductions of 33.23% in PY, 29.04% in biomass and 14.28% in FPP, respectively (Table 4). Our results have shown that the most sensitive period to water stress of chickpea yield is reproductive stage, and controlled irrigation and drainage at vegetative stages might be the most critical period. Plants that were stressed during the vegetative stage but not later performed better than those that were stressed during the reproductive stage.

Water stress influences a variety of yield-governing metabolic processes in plants [30,31]. Although the impact of drought stress on plant physiology has been studied, research in chickpea is not extensive [32–35], and the basis of tolerance to drought that can explain part of the differences in seed yield under stressed conditions is not clear [36]. The analysis of variance for all the traits indicated a high significance under non-stressed as well as stressed conditions (Table 2). These variations could be credited to the differences in the genetic makeup of the selected genotypes. Many researchers have also stated the differential responses of the chickpea genotypes under different environments and at different growth stages [15]. The finding of this study will assist in selecting the genotypes based on their *per se* performance. The mean sum of squares was considerably high for all the traits studied in both non-stressed and stressed conditions, indicating sufficient variability in the materials.

Under stress, legumes exhibit a range of morpho-physiological and biochemical consequences [37]; thus, the estimation of drought-related traits is a precondition for chickpea breeders in selecting drought-tolerant genotypes. The selection of plants with the ability to extract water from the soil is an additional procedure to aid to genetic improvement to drought tolerance [38–43]. The performance of selected genotypes varied considerably under stressed and non-stressed environments with a decrease in most of the parameters under stressed conditions. The mean performance of 40 chickpea cultivars under optimal and stress conditions are given in Table 3A–C. Irrespective of the genotypes, the normal growing conditions had higher values, while those grown under moisture stress had reduced values for all the traits. In our study, we used the DSI as one of the drought stress tolerance indices based on seed yield, as it signifies the extent of reduction in performance of genotypes when exposed to drought stress as compared to a non-stressed environment. Conversely, it does not point towards the comparative susceptibility of different characters to drought stress. Our study indicated that DSI varied between the 40 genotypes, which is in agreement with numerous studies on different crops to differentiate the drought-tolerant and sensitive genotypes [21]. This index is recommended as the most reliable criterion for the identification of tolerant and sensitive genotypes at vegetative and post-vegetative stages [44]. This result was further supported by the results of Pearson's correlation coefficients, where DSI showed significant negative correlation with MSI, RWC, protein content, biomass and seed yield and significant positive correlation with CI and DM. Uninterrupted stress affects plant growth severely by inducing changes at the anatomical, physiological and biochemical levels. Similar changes were evident in the present study also. Impaired biological processes at cellular, molecular and organ level under drought stress conditions reduces biomass or biological yield, days to flowering and seed yield persistently.

The observed statistically significant associations between the same traits recorded under irrigated, drought stress at vegetative and reproductive stage signify presence of common genetic factors governing expression of those traits under the different water regimes. However, weak correlations between seed yield under irrigated condition and drought stress indicate presence of independent factors regulating yield performance under these conditions. This insignificant association of seed yield under the stress and optimal conditions in our study are consistent with the findings of many previous works [44]. The strong correlations between seed yield and the days to flowering, SB, MSI and RWC, protein content and biomass in both the irrigated and stress treatments ($p < 0.05$) at vegetative and reproductive stages (Figure 3) demonstrate their use as selection indices for selecting promising genotypes under drought stress. However, a negative correlation for plant height relative to seed yield suggests that its use as an indicator for determining drought tolerance requires further validation. The strong positive correlations between DSI with days to maturity and negative correlation with MSI ($r < -0.354$, $p < 0.05$; $r < -0.29$, $p < 0.05$; $r < -0.195$, $p < 0.05$; $r < -0.348$, $p < 0.05$), RWC ($r < -0.376$, $p < 0.05$; $r < -0.303$, $p < 0.05$; $r < -0.284$, $p < 0.05$; $r < -0.371$, $p < 0.05$), protein content ($r < -0.295$, $p < 0.05$; $r < -0.202$, $p < 0.05$; $r < -0.336$, $p < 0.05$; $r < -0.229$, $p < 0.05$), biomass ($r < -0.302$, $p < 0.05$) and seed yield ($r < -0.467$, $p < 0.05$) indicate that selection for earliness offers a promising strategy for the development of drought-tolerant chickpea cultivars. ICCV1301 (0.04), ICC4958 (0.05), ICCV97309 (0.07), Pusa1103 (0.1), ICCV5308 (0.12), ICCV92337 (0.12), CSG8962 (0.13), BGD72 (0.15), ICCV9313 (0.15), ICCV10304 (0.17), ICCV3311 (0.19) and ICCV10 (0.19) had the lowest DSI (Figure 2), and the lowest yield reductions (Table 3C) were identified as tolerant to drought. Water stress reduces the plant yields remarkably in grain legumes, and the reduction in pods per plant is probably the major reason for reduction in the yield of legume plants grown under drought conditions. The maximum plant yield was observed in BGD72 (401.43 g) with lower reductions in RWC, MSI, CI, secondary branches and biomass, whereas the minimum yield was observed in Pusa1003 (62.5 g) with very low RWC, MSI, CI, secondary branches and biomass and a high susceptibility index under stressed conditions. A drastic reduction was confirmed in seed yield in chickpea genotypes ranging from 2.97 to 5.73 percent in tolerant genotypes and 9.2 to 24.66 percent in susceptible genotypes [45]. Considerable decreases were also observed in plant yield and 100 seed weight in lentil and green pea under stressed conditions. ICC 4958 with profuse root system and yield stability has been well established as a donor parent for introgression of a stronger root system in elite varieties [46]. A significant reduction in yield traits under water stress contributed in decline in PY and a negative correlation was found between PY and DTM at flowering stage under stressed conditions, and other similar indicators, RWC%, MSI and CI, were shown to establish a similar trend [38–41]. The genotypes under water stress mature earlier with a shorter life cycle and had lower number of seeds and decreased seed weight. The findings of lower PY under drought stress during reproductive stage are in accordance with several reports. Previous studies, pre-flowering moisture stress shortened the days to flowering, but flowering stage stress shortened the seed-filling period [40].

Principal Component analysis showed a good contribution towards the performance of chickpea genotypes by demonstrating the correlations between the physiological traits (Figure 4A,B) and the distribution patterns of genotypes under stressed conditions at the vegetative and reproductive stages (Figure 4C,D). The first two PCs showed positive associations with all the physiological traits, viz., plant height, CI, SB, RWC, protein (leaf), MSI, 100SW, PY, biomass and DM. Therefore, these physiological traits can be used as effective selection indices for screening for drought tolerance. These biplots clearly suggested that tolerant genotypes, viz., ICC4958, BGD72, Pusa1103, CSG8962, ICCV10, ICCV97309, ICCV03311, ICCV09307, ICCV3403 ICCV05308 and ICCV10313, showed positive associations with all the traits and lower DSI and DM values (Figure 4E,F). The findings of the correlation studies were concordant to the PCA biplots, providing a new insight to our understanding of drought mechanisms and plant responses to drought stress in chickpea. ICC4958, BGD72, Pusa1103, CSG8962, ICCV10, ICCV97309, ICCV03311, ICCV3403, ICCV05308 and ICCV10313 were the drought-tolerant genotypes with higher trait values, lower DSI and DTM and high RWC and MSI values under stress conditions at both the growth stages and were thus recognized as the most tolerant (Table 3A–C, Figure 5). Negative and strong correlations of seed yield with the DSI index and DM established their use as the best non-invasive traits to screen for tolerant genotypes; therefore, genotypes with early maturity are more promising under arid conditions. In addition, drought stress at the flowering stage had a stronger influence on chickpea physiological traits and yield. Furthermore, it is also worth mentioning that different genotypes have different physiological mechanisms to combat drought stress, and the identified tolerant genotypes with water use efficiency and higher grain yield may provide ample opportunity to chickpea breeders to identify short-duration chickpea varieties for drought with high yield potential and merge them together in developing drought-resilient lines.

5. Conclusions

The effects of water stress on crop yield varies with the species, soil conditions, climatic conditions and the stage of imposing stress. Many regions of the world have experienced significant shifts in the pattern and amount of rainfall, thus raising concern of a growing water scarcity problem and increasing the frequency of crop failure. Our study emphasizes the need to prioritize the selection and development of drought-resilient chickpea cultivars adapted to the arid regions of the world that could assist breeders to minimize yield losses in chickpea under stress. Moreover, plants performed better in stress imposed during the vegetative stage than the reproductive stage, highlighting the importance of time of drought in determining crop productivity. These results revealed that the ability of a plant to maintain water use efficiency during drought is vital for determining final chickpea productivity and that the flowering stage is sensitive. The different water stress conditions were water stress during vegetative and flowering stages, and well-watered conditions served as the control. Water stress at the vegetative stage significantly reduced days to flowering in all cultivars. Water stress at the reproductive stage resulted in a significant reduction in plant yield and yield traits. ICC4958, BGD72, Pusa1103, CSG8962, ICCV10, ICCV97309, ICCV03311, ICCV3403, ICCV05308 and ICCV10313 were the drought0tolerant genotypes with higher trait values and lower DSI and DTM. Selection for early cultivars could be a major target for chickpea breeders for accelerating improvements against water stress.

Author Contributions: Data curation, M.R.; formal analysis, S.S., B.S.P. and R.K.V.; funding acquisition, C.B.; investigation, S.S.; methodology, S.S., C.B. and M.P.; project administration, C.B. and R.K.V.; resources, C.B., B.S.P. and R.K.V.; software, M.R.; supervision, C.B. and M.P.; validation, S.S.; visualization, C.B.; writing—original draft, S.S.; writing—review and editing, C.B., M.P., M.R. and R.K.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by ICAR, Government of India (21-51), and Department of Biotechnology, AISRF (24-557).

Data Availability Statement: Not applicable.

Acknowledgments: We duly acknowledge the support of Division of Genetics, Indian Agricultural Research Institute, New Delhi, that provided facilities to carry out phenotyping and data analysis.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sachdeva, S.; Dawar, S.; Rani, U.; Patil, B.S.; Soren, K.R.; Singh, S.; Sanwal, S.K.; Chauhan, S.K.; Bharadwaj, C. Identification of SSR markers linked to Botrytis grey mould resistance in chickpea (*Cicer arietinum* L.). *Phytopathol. Mediterr.* **2019**, *58*, 283–292.
2. Varshney, R.K.; Song, C.; Saxena, R.K.; Azam, S.; Yu, S.; Sharpe, A.G.; Cannon, S.; Baek, J.; Rosen, B.D.; Tar'an, B.; et al. Draft genome sequence of chickpea (*Cicer arietinum* L.) provides a resource for trait improvement. *Nat. Biotechnol.* **2013**, *31*, 240–246. [CrossRef] [PubMed]
3. Bharadwaj, C.; Chauhan, S.K.; Rajguru, G.; Srivastava, R.; Tara Satyavathi, C.; Yadav, S.; Hasan Rizvi, A.; Kumar, J.; Solanki, R.K. Diversity analysis of chickpea (*Cicer arietinum* L.) cultivars using STMS markers. *Indian J. Agric. Sci.* **2010**, *80*, 947.
4. FAOSTAT, F.A.O. Crops. Food and Agriculture Organization of the United Nations. 2012. Available online: https://www.fao.org/statistics/en/ (accessed on 10 November 2021).
5. Sachdeva, S.; Bharadwaj, C.; Singh, R.K.; Jain, P.K.; Patil, B.S.; Roorkiwal, M.; Varshney, R. Characterization of ASR gene and its role in drought tolerance in chickpea (*Cicer arietinum* L.). *PLoS ONE* **2020**, *15*, e0234550. [CrossRef] [PubMed]
6. Neeraj, K.; Bharadwaj, C.; Satyavathi, C.T.; Madan, P.; Tapan, K.; Tripti, S.; Supriya, S.; Jain, P.K.; Patil, B.S.; Soren, K.R. Morpho-Physiological characterization and grouping (SAHN) of chickpea genotypes for salinity tolerance. *Vegetos* **2017**, *30*, 116–123.
7. Tiwari, S.; Lata, C.; Chauhan, P.S.; Nautiyal, C.S. Pseudomonas putida attunes morphophysiological, biochemical and molecular responses in *Cicer arietinum* L. during drought stress and recovery. *Plant Physiol. Biochem.* **2016**, *99*, 108–117. [CrossRef]
8. Khoyerdi, F.F.; Shamshiri, M.H.; Estaji, A. Changes in some physiological and osmotic parameters of several pistachio genotypes under drought stress. *Sci. Hortic.* **2016**, *198*, 44–51. [CrossRef]
9. Deshmukh, R.; Sonah, H.; Patil, G.; Chen, W.; Prince, S.; Mutava, R.; Vuong, T.; Valliyodan, B.; Nguyen, H.T. Integrating omic approaches for abiotic stress tolerance in soybean. *Front. Plant Sci.* **2014**, *5*, 244. [CrossRef]
10. Mir, R.R.; Zaman-Allah, M.; Sreenivasulu, N.; Trethowan, R.; Varshney, R.K. Integrated genomics, physiology and breeding approaches for improving drought tolerance in crops. *Theor. Appl. Genet.* **2012**, *125*, 625–645. [CrossRef]
11. Jha, U.C.; Chaturvedi, S.K.; Bohra, A.; Basu, P.S.; Khan, M.S.; Barh, D. Abiotic stresses, constraints and improvement strategies in chickpea. *Plant Breed.* **2014**, *133*, 163–178. [CrossRef]
12. Pandey, V.; Shukla, A. Acclimation and tolerance strategies of rice under drought stress. *Rice Sci.* **2015**, *22*, 147–161. [CrossRef]
13. Maqbool, M.A.; Aslam, M.; Ali, H.; Shah, T.M.; Farid, B.; Zaman, Q.U. Drought tolerance indices based evaluation of chickpea advanced lines under different water treatments. *Res. Crops* **2015**, *16*, 336–344. [CrossRef]
14. Parameshwarappa, S.G.; Salimath, P.M.; Upadhyaya, H.D.; Patil, S.S.; Kajjidoni, S.T.; Patil, B.C. Characterization of drought tolerant accessions identified from the minicore of chickpea (*Cicer arietinum* L.). *Indian J. Genet. Plant Breed.* **2010**, *70*, 125–131.

15. Yaqoob, M.; Hollington, P.A.; Mahar, A.B.; Gurmani, Z.A. Yield performance and responses studies of chickpea (*Cicer arietinum* L.) genotypes under drought stress. *Emir. J. Food Agric.* **2013**, *25*, 117–123. [CrossRef]
16. Choukri, H.; Hejjaoui, K.; El-Baouchi, A.; Smouni, A.; Maalouf, F.; Thavarajah, D.; Kumar, S. Heat and Drought Stress Impact on Phenology, Grain Yield, and Nutritional Quality of Lentil (*Lens culinaris* Medikus). *Front. Nutr.* **2020**, *7*, 596307. [CrossRef] [PubMed]
17. Daryanto, S.; Wang, L.; Jacinthe, P.A. Global synthesis of drought effects on food legume production. *PLoS ONE* **2015**, *10*, e0127401. [CrossRef]
18. Lu, H.; Tabassum, A.; Zhou, G. Plant hydraulic conductivity determines photosynthesis in rice under PEG-induced drought stress. *Pak. J. Bot.* **2021**, *53*, 409–417.
19. Tomer, A.; Singh, S.K. Drought Stress Tolerance in Legume Crops. In *Agronomic Crops*; Springer: Singapore, 2020; pp. 149–155.
20. Ulemale, C.S.; Mate, S.N.; Deshmukh, D.V. Physiological indices for drought tolerance in chickpea (*Cicer arietinum* L.). *World J. Agric. Sci.* **2013**, *9*, 123–131.
21. Mafakheri, A.; Siosemardeh, A.F.; Bahramnejad, B.; Struik, P.C.; Sohrabi, Y. Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. *Aust. J. Crop Sci.* **2010**, *4*, 580–585.
22. Barrs, H.D.; Weatherley, P.E. A re-examination of the relative turgidity technique for estimating water deficits in leaves. *Aust. J. Biol. Sci.* **1962**, *15*, 413–428. [CrossRef]
23. Blum, A.; Ebercon, A. Cell membrane stability as a measure of drought and heat tolerance in wheat. *Crop Sci.* **1981**, *21*, 43–47. [CrossRef]
24. Hameed, A.; Shah, T.M.; Atta, B.M.; Iqbal, N.; Haq, M.A.; Ali, H. Comparative seed storage protein profiling of Kabuli chickpea genotypes. *Pak. J. Bot.* **2009**, *41*, 703–710.
25. Panse, V.G.; Sukhatme, P.V. Statistical methods for agricultural workers. In *Statistical Methods for Agricultural Workers*; Indian Council of Agricultural Research (ICAR): New Delhi, India, 1954.
26. Pang, J.; Turner, N.C.; Du, Y.L.; Colmer, T.D.; Siddique, K.H. Pattern of water use and seed yield under terminal drought in chickpea genotypes. *Front. Plant Sci.* **2017**, *8*, 1375. [CrossRef] [PubMed]
27. Rani, A.; Devi, P.; Jha, U.C.; Sharma, K.D.; Siddique, K.H.; Nayyar, H. Developing climate-resilient chickpea involving physiological and molecular approaches with a focus on temperature and drought stresses. *Front. Plant Sci.* **2020**, 1759. [CrossRef]
28. Ramamoorthy, P.; Lakshmanan, K.; Upadhyaya, H.D.; Vadez, V.; Varshney, R.K. Shoot traits and their relevance in terminal drought tolerance of chickpea (*Cicer arietinum* L.). *Field Crops Res.* **2016**, *197*, 10–27. [CrossRef]
29. Khatun, M.; Sarkar, S.; Era, F.M.; Islam, A.K.M.M.; Anwar, P.; Fahad, S.; Datta, R.; Islam, A.K.M.A. Drought Stress in Grain Legumes: Effects, Tolerance Mechanisms and Management. *Agronomy* **2021**, *11*, 2374. [CrossRef]
30. Pereira, J.W.L.; Silva, E.C.A.; Luz, L.N.; Nogueira, R.J.M.C.; Melo Filho, P.A.; Lima, L.M.; Santos, R.C. Cluster analysis to select peanut drought tolerance lines. *Aust. J. Crop Sci.* **2015**, *9*, 1095–1105.
31. Devasirvatham, V.; Tan, D.K.Y.; Gaur, P.M.; Raju, T.N.; Trethowan, R.M. High temperature tolerance in chickpea and its implications for plant improvement. *Crop Pasture Sci.* **2012**, *63*, 419–428. [CrossRef]
32. Golldack, D.; Li, C.; Mohan, H.; Probst, N. Tolerance to drought and salt stress in plants: Unraveling the signaling networks. *Front. Plant Sci.* **2014**, *5*, 151. [CrossRef]
33. Shavrukov, Y.; Kurishbayev, A.; Jatayev, S.; Shvidchenko, V.; Zotova, L.; Koekemoer, F.; Groot, S.D.; Kathleen Soole, K.; Langridge, P. Early flowering as a drought escape mechanism in plants: How can it aid wheat production? *Front. Plant Sci.* **2017**, *8*, 1950. [CrossRef]
34. Kamanga, R.M.; Mbega, E.; Ndakidemi, P. Drought tolerance mechanisms in plants: Physiological responses associated with water deficit stress in Solanum lycopersicum. *Adv. Crop Sci. Technol.* **2018**, *6*, 1–8. [CrossRef]
35. Bechtold, U. Plant life in extreme environments: How do you improve drought tolerance? *Front. Plant Sci.* **2018**, *9*, 543. [CrossRef] [PubMed]
36. Krishnamurthy, L.; Gaur, P.M.; Basu, P.S.; Chaturvedi, S.K.; Tripathi, S.; Vadez, V.; Rathore, A.; Varshney, R.K.; Gowda, C.L.L. Large genetic variation for heat tolerance in the reference collection of chickpea (*Cicer arietinum* L.) germplasm. *Plant Genet. Resour.* **2011**, *9*, 59–69. [CrossRef]
37. Leport, L.; Turner, N.C.; French, R.J.; Barr, M.D.; Duda, R.; Davies, S.L.; Tennant, D.; Siddique, K.H.M. Physiological responses of chickpea genotypes to terminal drought in a Mediterranean-type environment. *Eur. J. Agron.* **1999**, *11*, 279–291. [CrossRef]
38. Sachdeva, S.; Bharadwaj, C.; Sharma, V.; Patil, B.S.; Soren, K.R.; Roorkiwal, M.; Varshney, R.; Bhat, K.V. Molecular and phenotypic diversity among chickpea (*Cicer arietinum* L.) genotypes as a function of drought tolerance. *Crop Pasture Sci.* **2018**, *69*, 142–153. [CrossRef]
39. Fathi, A.; Tari, D.B. Effect of drought stress and its mechanism in plants. *Int. J. Life Sci.* **2016**, *10*, 1–6. [CrossRef]
40. Jiang, Y.; Huang, B. Protein alterations in tall fescue in response to drought stress and abscisic acid. *Crop Sci.* **2002**, *42*, 202–207. [CrossRef]
41. Maqbool, M.A.; Aslam, M.; Ali, H. Breeding for improved drought tolerance in Chickpea (*Cicer arietinum* L.). *Plant Breed.* **2017**, *136*, 300–318. [CrossRef]
42. Ye, H.; Roorkiwal, M.; Valliyodan, B.; Zhou, L.; Chen, P.; Varshney, R.K.; Nguyen, H.T. Genetic diversity of root system architecture in response to 2015drought stress in grain legumes. *J. Exp. Bot.* **2018**, *69*, 3267–3277. [CrossRef]

43. Ahmadi, J.; Pour-Aboughadareh, A.; Ourang, S.F.; Mehrabi, A.A.; Siddique, K.H. Wild relatives of wheat: Aegilops–Triticum accessions disclose differential antioxidative and physiological responses to water stress. *Acta Physiol. Plant.* **2018**, *40*, 1–14. [CrossRef]
44. Basheer-Salimia, R.; Aloweidat, M.Y.; Al-Salimiya, M.A.; Hamdan, Y.A.S.; Sayara, T.A.S. Comparative study of five legume species under drought conditions. *Legume Res.-Int. J.* **2021**, *44*, 712–717. [CrossRef]
45. Kumar, P.; Deshmukh, P.S.; Kushwaha, S.R.; Kumari, S. Effect of terminal drought on biomass production, its partitioning and yield of chickpea genotypes. *Ann. Agric. Res.* **2001**, *22*, 408–441.
46. Varshney, R.K.; Thudi, M.; Nayak, S.N.; Gaur, P.; Kashiwagi, J.; Krishnamurthy, L.; Jaganathan, D.; Koppolu, J.; Bohra, A.; Tripathi, S.; et al. Genetic dissection of drought tolerance in chickpea (*Cicer arietinum* L.). *Theor. Appl. Genet.* **2014**, *127*, 445–462. [CrossRef] [PubMed]