agronomy

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Water Relation, Gas Exchange Characteristics and Yield Performance of Selected Mungbean Genotypes under Low Soil Moisture Condition

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Abstract: Among the environmental constraints, the growth and yield of crops are seriously impaired by moisture stress. With this view, an experiment was conducted to observe genotypic differences in water relation, gas exchange characteristics and yield performance of mungbean under low soil moisture conditions. Experimental variables consisted of five drought tolerant genotypes (G88, G108, G141,varietiesG186), one susceptible genotype (G43) and two standard check variety (BU mug 5, Binnamoog-8) which assigned to two moisture regimes viz., water regime A ((80 to 90% field capacity (FC)) and water regime B (40 to 50% FC). Results showed that water saturation deficit, water uptake capacity and transpiration rate were the lowest in tolerant genotypes G88 followed by genotypes G141, while those were the highest in susceptible genotype G43 under low soil moisture conditions. Contrarily, the highest amount of relative water content and water retention capacity were found in tolerant genotypes G141, G108 and G88 and the lowest was recorded in susceptible genotype G43 under low soil moisture conditions. In the case of the photosynthetic rate and stomatal conductance, the tolerant genotype G141, G88 and G108 showed the higher values at moisture stress condition. The highest total chlorophyll content and proline content were also found in tolerant genotype G88 followed by G141 and G108, and the lowest was found in susceptible genotype G43 under moisture stress conditions. Irrespective of genotypes, moisture stress significantly decreased the yield attributes and yield of mungbean genotypes. However, the highest seed yield per plant (12.11 g) was found in tolerant genotype G88 under low soil moisture conditions because of its lowest reduction rate of yield attributes under moisture stress. Similar responses were also observed in tolerant genotypes G141 and G108. Therefore, the genotypes G88, G108 and G141 showed better performance in the case of water relation and gas exchange characteristics which might be contribute to higher yield of those genotypes.

Keywords: low soil moisture stress; water relation; gas exchange characteristics; mungbean; yield

Citation: Tamanna, T.; Islam, M.M.; Chaity, A.R.; Shams, S.-N.-U.; Rasel, M.A.; Haque, M.M.; Miah, M.G.; Alamri, S.; Murata, Y. Water Relation, Gas Exchange Characteristics and Yield Performance of Selected Mungbean Genotypes under Low Soil Moisture Condition. *Agronomy* **2023**, *13*, 1068. https://doi.org/10.3390/agronomy13041068

Academic Editor: Meisam Zargar

Received: 21 February 2023
Revised: 2 April 2023
Accepted: 3 April 2023
Published: 6 April 2023

1. Introduction

Mungbean (*Vigna radiata* L.) is a well-known pulse crop with an excellent taste and significant source of easily digestible plant protein (19.5 to 28.5%). It is cultivated across the Asian countries and also expanded to some parts of Africa, South America and Australia [1]. Mungbean seeds also contain 60–65% carbohydrates, 1–1.5% fat, 3.5–4.5% fibers and

4.5–5.5% ash [2]. Minerals and antioxidants such as flavonoids and phenolics are present in mungbean seeds [3]. It is a fast growing and short duration crop and helps in the effective utilization of summer fellows to enhance the cropping intensity and crop production [4]. Mungbean has the capability to improve the soil fertility through atmospheric nitrogen fixation by its strong root system and sustain crop productivity [5,6].

Mungbean is a renowned short duration legume crop. It can be grown both during kharif I (March to May) and kharif II (August to October) season, although most of the land is occupied with Aman rice during the kharif II season of Bangladesh. Therefore, the kharif I season may be a good option for growing mungbean especially in the drought-prone area of Bangladesh. However, the problem of the drought-prone area of Bangladesh during the kharif I season is that it encounters more low soil moisture conditions than other parts of the country. Similar soil conditions with low moisture content also prevail in char land which comprised nearly one million hectares. Different crops are widely grown in char lands with low productivity; therefore, there is a great opportunity to introduce new mungbean variety that is well adapted and better productive under low soil moisture conditions.

Climate change, influencing the regularity and level of hydrological fluctuations, is a major threat to agriculture particularly in developing nations, and causes various abiotic stresses for crops [1]. Drought-prone areas of the globe are expanding rapidly due to uneven and uncertain rainfall, shortage of water sources and other environmental changes. Low soil moisture is the most dominant multidimensional environmental stress condition which agitates the physiological, morphological, biochemical and molecular states of crops, restricts growth and crop productivity [7]. The leaf area, cell size and intercellular volume are lessened under moisture stress conditions [8]. Disrupted flow of water from xylem towards another cell, including lower turgor pressure due to water deficiency, responds in the form of poor cell development and diminished leaf area in crops [9]. These changes reduce the leaf size and decrease the number of stomata. Plants become impotent to uptake enough water through the root system under water deficit condition which results in reduced relative water content [10]. The reduced soil moisture causes low water content of leaves, diminished leaf water potential, as a result stomatal closure occurs due to loosening of turgor pressure of guard cells [11,12]. Photosynthesis, the vital phenomena of crops, are highly affected by the drought stress environment by reducing leaf area, leaf senescence, stomatal aperture and improper functioning of the photosynthetic machinery [1,13]. Furthermore, drought stress results in overproduction of reactive oxygen species (ROS), whose excessive accumulation damages cellular constituents such as chloroplast, homeostatic proteins, nucleic acids and cell membrane, and drastically reduce photosynthesis (1). Therefore, severe water stress may result in the arrest of photosynthesis, disturbance of metabolism and finally the death of the plant [12,14].

Plant productivity is diminished under low soil moisture conditions through the inhibition of growth and photosynthesis [15]. Leaf chlorophyll content is vital for photosynthesis [16]. Under water stress conditions, the chlorophyll content reduces which is thought as a representative indicator as a result of pigment photooxidation and chlorophyll degradation [17]. The duration and the intensity of moisture stress govern the reduction in chlorophyll content under water deficit conditions [1]. The depletion of canopy development and suppression of photosynthesis leading to less dry matter accumulation under low soil moisture which finally reduces the crop growth and yield [8]. Water deficiency at the flowering stage is the most serious and devastating impact to yield because it has a diverse effect on pollination and causes flower abortion of the mungbean [18].

Currently, a lack of mungbean variety adapted to low soil moisture conditions is restricting the expansion of mungbean in drought prone areas of Bangladesh as well as the globe. Under the adverse climatic situation of retreating water supplies for agriculture, there is an urgent need to find out drought tolerant varieties. Moreover, the anticipated global food demand also necessitates a significant increase in crop productivity on these less favorable environments. In this context, understanding physiology of mungbean under low soil moisture conditions will be useful in breeding programs for developing a drought

tolerant mungbean variety which is a prerequisite to explore the suitable one for drought prone ecosystem of the globe. Therefore, it is hypothesized that tolerant genotypes of mungbean may show desire water relations characteristics, gas exchange traits, chlorophyll content, porline content, higher grain yield under moisture stress conditions.

2. Materials and Methods

2.1. Experimental Variables and Treatments

On the basis of yield and yield contributing characters, experimental variables consisted of eight mungbean genotypes, of which five genotypes (G88, G108, G141, G164, G186) were tolerant to drought, one genotype (G43) was susceptible and two mungbean varieties BU mug 5 and Binamoog-8 were used as a check for the experiment. Eight mungbean genotypes and two water regimes viz., 80 to 90% field capacity (FC) and 40 to 50% FC were used as treatment variables. The experiment was conducted at the vinyl house of the Department of Agronomy, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh. The experiment was conducted in factorial completely randomized design (CRD) with five replications.

2.2. Preparation of Pot and Fertilizer Application

The soil of the experimental pot was collected from Codda of Gazipur district. The soil of the experimental pot was silty clay loam in texture, bulk density (g/cc) 1.36, particle density (g/cc) 2.61, soil pH 5.94, organic carbon (%) 0.98, total nitrogen (%) 0.093, available P (mg kg^{-1} soil) 18.86, exchangeable K (meq/100 g soil) 0.128, available S (mg kg^{-1} soil) 20.91, field capacity 30.55% vol/vol. Each pot of 24 cm (diameter) x 30 cm (height) in size was filled with 13 kg soil mixed with cow dung (1:0.25 ratio). Fertilizer at the rate of 20-17-18-10 kg ha^{-1} NPKS in the form of urea, triple super phosphate (TSP) and muriate of potash (MoP) and gypsum were incorporated in the soil as per the recommendation of [19]. Total amount of urea, triple super phosphate, muriate of potash and gypsum were applied at the time of final pot preparation.

2.3. Seed Sowing and Treatment Imposition

Initially, eight healthy mungbean seeds were sown maintaining uniform spacing in each pot. The seeds were surface sterilized with 0.2% $HgCl_2$ solution for 5 min and thoroughly rinsed with tap water. Light irrigation was given by using the water cane to ensure uniform germination of seeds after sowing. After seedling establishment, one healthy plant was kept in each pot for subsequent treatment imposition. Drought treatment was imposed at 21 days after sowing (DAS) and continued up to 45 DAS. The soil moisture condition was maintained at 80–90% (water regime A) and 40–50% (water regime B) of field capacity (FC). Water was applied to bring the soil moisture to the higher range of each treatment (50 and 90% FC). When the soil moisture came down to the lower levels (40 and 80% FC) of those treatments, respectively, then subsequent irrigation was given. Soil moisture status (%) (v/v) under different treatment involving ranges of FC was monitored at 4 days interval from 21 to 45 DAS (Figure 1). Irrigation water was applied by a measuring cylinder. A Soil moisture meter (Stevens, Field POGO, Portland, OR, USA) was used to assess the soil moisture.

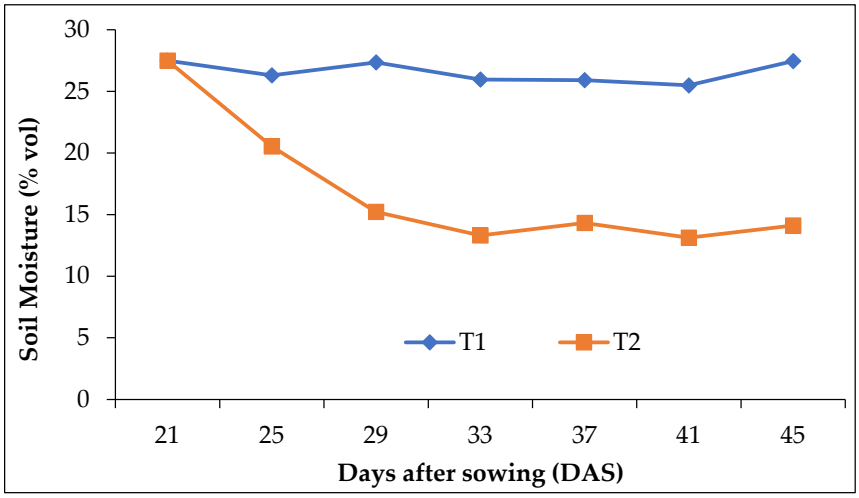

Figure 1. Soil moisture status (% vol) under different treatments at regular interval of four days from 21 to 45 DAS. (T1 = Soil moisture 24.44 to 27.50% at 80 to 90% FC, T2 = Soil moisture12.22 to 15.28% at 40 to 50% FC).

2.4. Collection of Data

We performed physiological analysis for consecutive two years. For physiological analysis, plant samples were collected after imposition of drought stress. Yield and yield contributing parameters were recorded after harvesting of the crop.

2.5. Estimation of Water Relation Parameters

Relative water content (RWC) was measured using fully expanded uppermost trifoliate leaves of each genotype under both control and water deficit condition at noon. Immediately after cutting at the base of the lamina, leaves were sealed within plastic bags and kept in an icebox then quickly transferred to the laboratory. The fresh weight of the leaves from each treatment was recorded just after removal from the polythene bag. Turgid weight (TW) obtained after soaking leaves in distilled water in beakers for 24 h at room temperature (about 20 °C) and under the low light conditions in the laboratory. After soaking, leaves were quickly and carefully blotted dried with tissue paper for determining turgid weight. The dry weight (DW) of the leaves was obtained after oven drying the leaf samples for 72 h at 70 °C. The RWC was calculated in following equation according to Barrs and Weatherley [20]:

$$\mathrm{RWC}(\%) = [\frac{\mathrm{FW} - \mathrm{DW}}{\mathrm{TW} - \mathrm{DW}}] \times 100$$

where FW = Fresh weight (mg), DW = Dry weight (mg), TW = Turgid weight (mg)

Water saturation deficit (WSD), water retention capacity (WRC) and water uptake capacity (WUC) were calculated as follows according to Sangakkara et al. [21].

$$\mathrm{WSD} = \frac{\mathrm{TW} - \mathrm{FW}}{\mathrm{TW} - \mathrm{DW}} \times 100$$

$$\mathrm{WRC} = \frac{\mathrm{TW}}{\mathrm{DW}}$$

$$\mathrm{WUC} = \frac{(\mathrm{TW} - \mathrm{FW})}{\mathrm{DW}}$$

where FW = Fresh weight (mg), DW = Dry weight (mg), TW = Turgid weight (mg).

2.6. Gas Exchange Characteristics

Gas exchange measurements such photosynthetic rate (Pn), stomata conductance (Gs), transpiration rate (Tr), photosynthetic water use efficiency were recorded. Fully expanded uppermost trifoliate leaves of each genotype of all the treatments were used in gas exchange measurements. Li-COR, 6400 portable photosynthetic system (Li-COR, Lincon, NE, USA) was used at an atmospheric CO_2 concentration of 360 µmol air mol^{-1} (360 ppm). All measurements were taken in a sunny day between 11:00 and 13:00 when photosynthetically active radiation (PAR) intensity was between 1100 and 1200 µmol m^{-2} s^{-1}. Photosynthetic water use efficiency was calculated as the ratio between photosynthetic rate and transpiration rate.

2.7. Estimation of Total Chlorophyll Content

The total chlorophyll content of third trifoliate fresh leaves was determined on fresh weight basis extracting with 80% acetone by using double beam spectrophotometer according to Fadeels [22].

2.8. Proline Determination

Proline content was measured as described previously by Bates et al. [23]. Plant materials (0.5 g fresh leaf sample) were homogenized in 5 mL of 6% aqueous sulfosalicylic acid and the homogenate was centrifuged for 20 min at 4000 rpm. Two ml of supernatant was taken in Pyrex test tube with 2 mL acid ninhydrin and 2 mL of glacial acetic acid and covered tightly with aluminum foil. Then, the test tubes were heated at 100 °C for 60 min and the reaction terminated in an ice bath for 15 min. The reaction mixture was added with 4 mL toluene, mixed vigorously for 15–20 s. At room temperature for 10 min, the toluene layer was separated and the absorbance was measured at 520 nm with a spectrophotometer (Shimadzu, UV-1201). A series of standard with pure proline (0, 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 µg/mL distilled water) was run in a similar way and a standard curve was prepared.

2.9. Yield Attributes and Yield

After harvesting, data of yield and yield attributes such as plant height, branch per plant, pods per plant, pod length, seeds per pod, thousand-seed weight and seed yield per plant were recorded. The seed weight per plant was adjusted at 12% moisture content. All measurements were obtained from five independent replications of all the genotypes.

2.10. Analysis of the Data

Data were statistically analyzed using an analysis of variance technique with the help of statistical analysis package program statistics 10 (https://statistix.informer.com accessed on 10 November 2022). Means were compared by a least significant difference (LSD) test with a 5% level of significance. Coefficient of variation (CV) was calculated using the following equation: standard deviation/mean. Higher values of CV indicate that the standard deviation is relatively large compared to the mean.

3. Results

3.1. Water Status of Mungbean

3.1.1. Relative Water Content

In the present study, moisture stress significantly decreased relative water content in mungbean plants regardless of genotype (Table 1). Mungbean genotypes showed similar trends during both years. Under water regime A, genotypes G141 (87.29%), G108, BU mug 5, Binamoog-8 and G88 showed better performance. Under water regime B, genotypes G141, G108 and G88 showed better performance during both years, whereas the lowest RWC was found in genotype G43 (60.41% and 61.33% during 1st year and 2nd year, respectively) which was statistically dissimilar with other genotypes. Reduction rate of RWC is another indication of plants for adaptation under stress condition. Mungbean

genotypes showed similar trends for reduction in RWC during both years. However, during the 1st year, the reduction in RWC was the lowest in genotype G88 (4.87%) followed by genotype G141 (5.36%) and during the 2nd year, the reduction in RWC was the lowest in genotype G141 (6.19%) followed by genotype G108 (6.55%), G88 (6.92%) and the highest reduction was observed in genotype G43 (29.10% and 26.68% during the 1st year and 2nd year, respectively). The result showed that genotype G141 was found to be more tolerant to drought stress than the other genotypes. Better water relations in G141 and G108 under drought conditions obviously contributed to the maintenance of better plant growth than other mungbean genotypes.

Table 1. Interaction effects of different mungbean genotypes and two irrigation treatments on relative water content, water saturation deficit, water retention capacity and water uptake capacity of mungbean genotypes.

Treatments	Genotypes	Relative Water Content (%)		Water Saturation Deficit (%)		Water Retention Capacity		Water Uptake Capacity	
		First Year	Second Year	First Year	Second Year	First Year	Second Year	First Year	Second Year
Water regime A	G43	85.21 b	83.65 d	6.09 gh	6.45 ghi	4.61 a	4.56 bcde	0.30 ij	0.30 f
	G88	84.33 c	85.26 c	6.21 gh	6.17 i	4.59 ab	4.70 a	0.31 i	0.31 f
	G108	85.61 b	86.62 ab	6.55 g	6.69 gh	4.61 a	4.63 abcd	0.31 i	0.31 f
	G141	87.29 a	86.62 ab	6.39 g	6.44 ghi	4.63 a	4.55 cde	0.31 i	0.31 f
	G164	85.36 b	85.66 bc	6.41 g	6.76 g	4.61 a	4.66 ab	0.30 ij	0.32 f
	G186	84.69 bc	86.23 bc	6.05 gh	6.52 ghi	4.57 ab	4.56 bcde	0.31 i	0.29 f
	BU mug 5	86.05 ab	85.61 bc	6.56 g	6.31 hi	4.61 a	4.52 de	0.32 i	0.32 f
	Binamoog-8	85.61 b	87.52 a	6.41 g	6.35 ghi	4.55 b	4.65 abc	0.30 ij	0.31 f
Water regime B	G43	60.41 h	61.33 h	23.41 a	24.59 a	3.48 f	3.59 i	0.968 a	0.989 a
	G88	80.22 e	79.36 f	12.51 f	13.76 f	4.36 c	4.51 e	0.501 h	0.526 e
	G108	80.62 e	80.95 e	14.22 e	15.84 c	4.32 c	4.38 f	0.562 e	0.559 d
	G141	82.61 d	81.26 e	14.02 e	14.40 e	4.36 c	4.34 fg	0.549 f	0.558 d
	G164	78.41 f	79.35 f	15.11 c	15.63 c	4.17 de	4.26 gh	0.638 bc	0.639 b
	G186	77.36 g	75.32 g	15.99 b	16.71 b	4.13 e	4.16 h	0.629 b	0.621 b
	BU mug 5	77.69 g	76.12 g	14.81 cd	15.12 d	4.30 cd	4.29 fg	0.579 d	0.590 c
	Binamoog-8	80.28 e	81.76 e	14.69 cd	14.37 e	4.23 d	4.39 f	0.541 g	0.549 de
	CV(%)	4.36	1.91	5.16	2.53	4.82	1.76	3.81	4.47
	SE	0.8153	0.5266	0.5381	0.2036	0.0714	0.0552	0.0151	0.0148

Mean values in the same column with different letters are significantly different at a 5% level of significance. Averages data are shown with mean values of five independent replicates (n = 5). SE, standard error. Water regime A: 80 to 90% FC, Water regime B: 40 to 50% FC.

3.1.2. Water Saturation Deficit

Water saturation deficit (WSD) presents an inverse trend of RWC, and it indicates the degree of water deficiency in plants. Low moisture stress increased the WSD in all genotypes compared to the control during both years (Table 1). Under water regime A, the highest WSD was found in the BU mug 5 (6.56%) in the 1st year, while in genotype G164 (6.76%) in the second year.

While under water regime B, the highest WSD was observed in the genotype G43 (23.41% and 24.59% during 1st year and 2nd year, respectively) which was statistically unlike other genotypes and the lowest was recorded in genotype G88 (12.51% and 13.76% during 1st year and 2nd year, respectively) followed by genotype G141 (14.02% and 14.40% during 1st year and 2nd year, respectively). Relative value of WSD was the lowest in genotype G88 (201.45% and 223.01% during 1st year and 2nd year, respectively) followed by genotype G141 (219.41% and 223.80% during 1st year and 2nd year, respectively) and the highest was in genotype G43 (384.41% and 381.24% during 1st year and 2nd year, respectively). The genotype G43 was found to suffer more under drought stress, while the genotype G88 and genotype G141 maintained better water relations and contributed to higher plant growth compared to other genotypes.

3.1.3. Water Retention Capacity

The turgid weight and dry weight ratio illustrate the water retention capacity (WRC) of plants that are determined by the cell structures. In the present study, low moisture stress significantly decreased the WRC in all mungbean genotypes (Table 1). Under water regime A, genotypes G88, G108 and G141 showed the higher WRC during both years. Under water regime B, the highest WRC was also found in the genotype G88 (4.36 and 4.51 during 1st year and 2nd year, respectively) which was statistically similar with genotype G141 and genotype G108 and the lowest WRC was observed in genotype G43 (3.48 and 3.59 during 1st year and 2nd year, respectively). Reduction of WRC was the lowest in genotype G88 (5.01% and 4.02% during 1st year and 2nd year, respectively) followed by genotype G141 (5.83% and 4.49% during 1st year and 2nd year, respectively) and it was the highest in genotype G43 (24.51% and 21.27% during 1st year and 2nd year, respectively) which indicated that under drought stress, genotype G88 and G141 maintained higher plant growth than other genotypes.

3.1.4. Water Uptake Capacity

Water uptake capacity (WUC) measures the ability of plants to absorb water per unit dry weight in relation to turgid weight. A higher WUC signifies a plant is exposed to a greater degree of moisture stress, as the plant would absorb a greater quantity of water to reach turgid weight. Irrespective of genotypes, low moisture stress resulted in an increase in WUC compared to that of control during both years (Table 1). Under water regime A, all genotypes showed statistically identical results during both years, while under water regime B, the highest WUC was recorded in genotype G43 (0.968 and 0.989 during the 1st year and 2nd year, respectively) which was statistically dissimilar with all the genotypes and the lowest WUC was found in genotype G88 (0.501 and 0.526 during the 1st year and 2nd year, respectively). The lowest relative value of WUC was found in genotype G88 (162.71% and 170.79% during the 1st year and 2nd year, respectively) followed by genotype G141 (179.00% and 181.94% during the 1st year and 2nd year, respectively) and the highest was in genotype G43 (333.79% and 324.90% during the 1st year and 2nd year, respectively). The result showed that drought tolerant genotypes (G88 and G141) have less WUC as compared with drought sensitive genotype G43 under moisture stress conditions.

3.2. Gas Exchange Characteristics

3.2.1. Photosynthetic Rate

Photosynthesis (Pn) is very sensitive to drought stress as it directly influences the photosynthetic capacity of crops. In this experiment, moisture stress significantly decreased the Pn in all mungbean genotypes during both year (Table 2). Under water regime A, genotypes G141, G88 and G108 showed higher Pn rate during both year. Under water regime B, the highest rate of Pn was found in the genotype G141 (14.99 μmol m^{-2} s^{-1} and 15.62 μmol m^{-2} s^{-1} during the 1st year and 2nd year, respectively) which was statistically different with other genotypes and the lowest rate of Pn was found in genotype G43 (6.23 μmol m^{-2} s^{-1} and 5.13 μmol m^{-2} s^{-1} during the 1st year and 2nd year, respectively). Photosynthesis and transpiration rates might decrease due to reduced stomatal conductance under drought stress. The lowest reduction of Pn was found in genotype G88 (10.23) followed by genotype G141 (11.35%) during 1st year and in genotype G141 (11.00%) followed by genotype G88 (17.90%) during 2nd year. However, the highest reduction was found in genotype G43 (61.24% and 68.10% during 1st year and 2nd year, respectively). This result suggested that genotype G141 and G88 are more tolerant to drought than other genotypes as they showed the lowest reduction in photosynthetic rate.

Table 2. Interaction effects of different mungbean genotypes and two irrigation treatments on photosynthetic rate, stomatal conductance, transpiration rate, photosynthetic water use efficiency and total chlorophyll content of mungbean genotypes.

		Photosynthetic Rate (μmol m^{-2} s^{-1})		Stomatal Conductance (mmol m^{-2} s^{-1})		Transpiration Rate (mmol m^{-2} s^{-1})		Photosynthetic Water Use Efficiency (Pn/Tr)		Total Chlorophyll Content (mg g^{-1})	
Treatments	**Genotypes**	**First Year**	**Second Year**	**First Year**	**Second Year**	**First Year**	**Second Year**	**First Year**	**Second Year**	**First Year**	**Second Year**
Water regime A	G43	16.24 e	16.08 e	0.285 a	0.286 a	4.48 bc	4.65 bc	3.63 g	3.46 ef	3.44 c	3.37 d
	G88	16.61 b	16.87 b	0.285 a	0.285 a	4.52 ab	4.71 ab	3.67 g	3.58 e	3.52 a	3.63 a
	G108	16.55 bc	16.78 bc	0.286 a	0.287 a	4.49 abc	4.60 c	3.69 g	3.65 e	3.41 c	3.44 c
	G141	16.91 a	17.55 a	0.286 a	0.283 ab	4.50 ab	4.67 bc	3.76 g	3.76 e	3.47 b	3.51 b
	G164	15.88 g	16.39 d	0.281 ab	0.270 cd	4.56 a	4.70 ab	3.48 gh	3.49 ef	3.51 a	3.63 a
	G186	16.42 d	16.66 c	0.283 ab	0.287 a	4.61 a	4.83 a	3.56 g	3.45 ef	3.42 c	3.35 d
	BU mug 5	16.53 c	16.29 d	0.275 b	0.277 bc	4.63 a	4.69 b	3.57 g	3.47 ef	3.42 c	3.37 d
	Binamoog-8	16.11 f	15.99 e	0.268 c	0.267 d	4.59 a	4.61 c	3.51 gh	3.47 ef	3.47 b	3.54 b
Water regime B	G43	6.23 o	5.13 l	0.176 i	0.182 i	0.87 g	0.85 g	7.16 f	6.04 cd	1.62 h	1.47 k
	G88	14.91 i	13.85 g	0.215 de	0.219 ef	1.61 d	1.60 d	9.26 a	9.69 a	3.21 d	3.29 e
	G108	13.26 j	12.78 h	0.206 f	0.214 f	1.48 f	1.52 de	8.96 b	8.41 ab	3.04 ef	3.09 h
	G141	14.99 h	15.62 f	0.221 d	0.225 e	1.62 d	1.61 d	9.25 a	9.70 a	3.16 de	3.22 f
	G164	11.34 n	10.51 k	0.201 fg	0.190 h	1.53 ef	1.54 de	7.41 e	6.41 c	2.96 fg	2.99 i
	G186	11.51 m	10.79 j	0.191 gh	0.189 h	1.58 de	1.55 de	7.28 ef	6.17 bc	2.91 g	2.86 j
	BU mug 5	12.36 k	11.87 i	0.206 f	0.212 f	1.49 ef	1.53 de	8.30 c	7.76 b	2.99 f	2.99 i
	Binamoog-8	12.11 l	11.94 i	0.197 g	0.200 g	1.57 de	1.61 de	7.71 d	7.42 b	3.06 e	3.15 g
	CV(%)	3.29	1.77	5.26	2.03	4.81	1.60	4.37	2.63	3.91	1.62
	SE	0.0631	0.0776	0.00416	0.00339	0.117	0.266	0.231	0.536	0.068	0.140

Mean values in the same column with different letters are significantly different at 5% level of significance. Averages data are shown with mean values of five independent replicates (n = 5). SE, standard error. Water regime A: 80 to 90% FC, Water regime B: 40 to 50% FC.

3.2.2. Stomatal Conductance

Stomatal conductance (Gs) specifies the degree of exchange of CO_2 and water vapor between ambient and inner leaf. It is measured from the transpiration rate and difference in vapor pressure between air and leaf. The decrease in soil moisture significantly reduced the stomatal conductance of leaves in all mungbean genotypes during both year (Table 2). Under water regime A, genotypes G43, G88 G108 and G141 showed higher stomatal conductance during both year. However, under water regime B, the highest stomatal conductance was found in genotype G141 (0.221 mmol m^{-2} s^{-1} and 0.225 mmol m^{-2} s^{-1} during 1st year and 2nd year, respectively) which was statistically identical with genotype G88 (0.215 mmol m^{-2} s^{-1} and 0.219 mmol m^{-2} s^{-1} during 1st year and 2nd year, respectively) and the lowest stomatal conductance was found in genotype G43 (0.176 mmol m^{-2} s^{-1} and 0.182 mmol m^{-2} s^{-1} during 1st year and 2nd year, respectively). Reduction of stomatal conductance of mungbean genotypes differed significantly, where the lowest was recorded in genotype G141 (22.73% and 20.39% during 1st year and 2nd year, respectively) followed by genotype G88 (24.54% and 23.17% during 1st year and 2nd year, respectively) and the highest was in genotype G43 (38.25 and 36.51% during 1st year and 2nd year, respectively). The results indicated that the genotype G141 and G88 are more promising genotype for surviving under drought condition as they showed lower reduction in stomatal conductance under drought stress condition.

3.2.3. Transpiration Rate

Transpiration not only helps to maintain leaf temperature but also drives water and nutrient uptake and CO_2 influx. In the present study, decrease in soil moisture significantly decreased the transpiration rate (Tr) of leaves of all mungbean genotypes (Table 2). Under water regime A, genotypes G186, G164, G108, G88 and G141 showed higher Tr rate during both year. On the other hand, under water regime B, the highest Tr was observed in genotype G141 (1.62 mmol m^{-2} s^{-1} and 1.61 mmol m^{-2} s^{-1} during 1st year and 2nd year,

respectively) which was statistically similar with genotype G88 ((1.61 mmol m^{-2} s^{-1} and 1.60 mmol m^{-2} s^{-1} during 1st year and 2nd year, respectively) and the lowest Tr was found in genotype G43 (0.87 mmol m^{-2} s^{-1} and 0.85 mmol m^{-2} s^{-1} during 1st year and 2nd year, respectively). However, tolerant genotype maintain the regular size of stomata, hence the Tr was higher in tolerant genotypes than the susceptable genotype. Results of reduction percentage of Tr varied from 63.77 to 81.72, where the lowest reduction was recorded in genotype G141 (64.00% and 65.52% during 1st year and 2nd year, respectively) followed by genotype G88 and the highest reduction was recorded in genotype G43 (80.58% and 81.72% during 1st year and 2nd year, respectively). Comparing all genotypes, genotype G88 and G141 were found more tolerant to drought stress than the other genotypes and genotype G43 was found more susceptible.

3.2.4. Photosynthetic Water Use Efficiency

The decreased in soil moisture significantly increased the photosynthetic water use efficiency of leaves of all mungbean genotypes (Table 2). Under water regime A, genotypes G141, G108 and G88 showed higher photosynthetic water use and the lowest was found in G186 during both year. Under water regime B, the highest photosynthetic water use efficiency was found in genotype G88 (9.26 and 9.69 during 1st year and 2nd year, respectively) followed by G141 (9.25 and 9.70 during 1st year and 2nd year, respectively) and lowest was found in G43 (7.16 and 6.04 during 1st year and 2nd year, respectively). Water use efficiency is an important aspect for physiological regulation of drought tolerance.

3.3. Chlorophyll Contents

Reduction in soil moisture significantly decreased the total chlorophyll contents of leaves of all mungbean genotypes (Table 2). Under water regime A, the highest total chlorophyll content was found in genotype G88 (3.52 mg g^{-1} and 3.63 mg g^{-1} during 1st year and 2nd year, respectively) which was statistically alike with genotype G164 (3.51 mg g^{-1} and 3.63 mg g^{-1} during 1st year and 2nd year, respectively). Under water regime B, the highest total chlorophyll content was found in genotype G88 (3.21 mg g^{-1} and 3.29 mg g^{-1} during 1st year and 2nd year, respectively) which was statistically unlike with other genotypes and the lowest was found in genotype G43 (1.62 mg g^{-1} and 1.47 mg g^{-1} during 1st year and 2nd year, respectively). Reduction rate of chlorophyll content varied from 8.81% to 52.91% during 1st year and 8.23% to 56.42% during 2nd year, where the lowest reduction was recorded in genotype G88 (8.81% and 9.26% during 1st year and 2nd year, respectively) followed by G141 (8.93% and 8.23% during 1st year and 2nd year, respectively) and the highest reduction was found in genotype G43 (52.91% and 56.42% during 1st year and 2nd year, respectively). Like other parameters, the genotypes G88 and G141 are supposed to be more tolerant under drought stress as indicated by lower chlorophyll damage. On the other hand, the genotype G43 was found to suffer more from drought stress than the other mungbean genotypes.

3.4. Proline Content

In this study, proline content of different mungbean genotypes was significantly increased due to low soil moisture stress compared to control condition (Figure 2A). Under water regime A, proline content was the highest in genotype G43 (2.13 μg g^{-1} FW) followed by genotype G108 (2.07 μg g^{-1} FW) and the lowest proline content was found in genotype G164 (1.91 μg g^{-1} FW). Under water regime B, the highest proline content was found in genotype G88 (6.43 μg g^{-1} FW) followed by genotypes G141 (6.23 μg g^{-1} FW) and G108 (6.03 μg g^{-1} FW) and the lowest was found in genotype G43 (3.85 μg g^{-1} FW). Percent increase over control is another important indicator of low moisture stress tolerance as indicated in Figure 2B. The highest percent increase over the control was found also in genotype G88 (233%) followed by genotype G141 (195%) and the lowest was found in genotype G43 (81%).

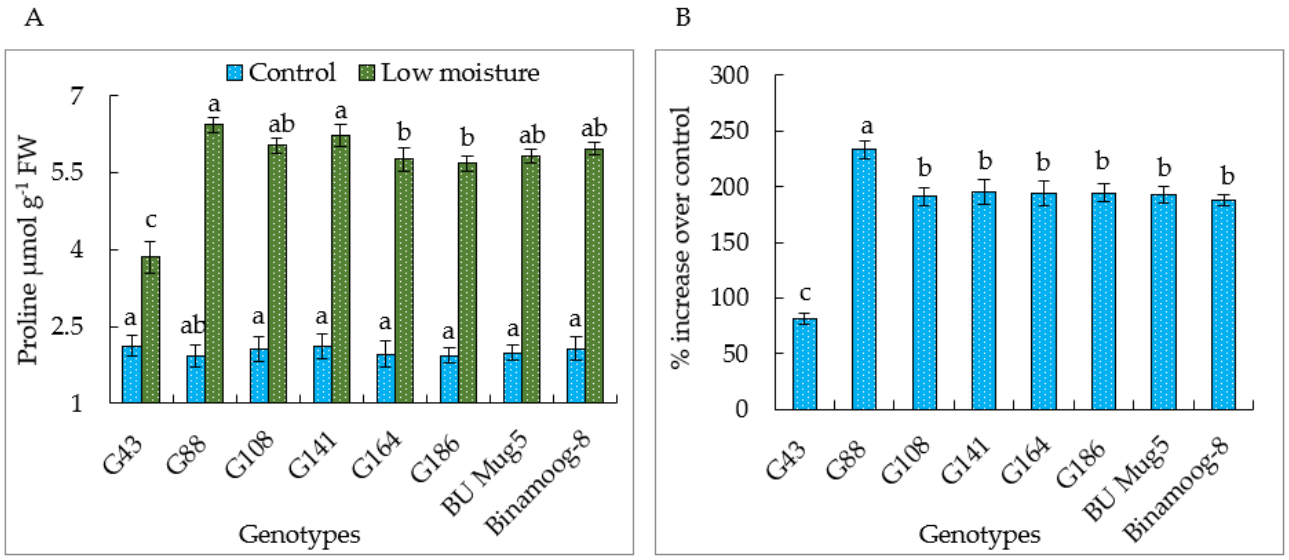

Figure 2. Proline content (**A**) and (%) increase over control (**B**) in leaf of mungbean genotypes under low soil moisture conditions. The vertical bar indicates an average of five independent replicates (n = 5). Error bars represent standard error. Different letters indicate significant differences at $p \leq 0.05$.

3.5. Yield Attributes and Yield

3.5.1. Plant Height

Plant height of different mungbean genotypes were significantly affected by low soil moisture stress (Table 3). Higher plant height in the control condition might be due to the better functional role of water in the plant body. Contrarily, reduction in plant height under water stress might be due to inhibition of cell enlargement. Under water regime A, the highest plant height was observed in genotype G141 (76.19 cm) which was statistically superior to all other genotypes and the lowest plant height (51.29 cm) was found in Binamooog-8 which was statistically alike with G186 (52.50 cm). Under water regime B, the highest plant height was found in genotype G141 (68.96 cm) and the shortest in genotype G43 (35.29 cm). However, minimum reduction (6.17%) in plant height was observed in genotype G88 and maximum reduction (33.23%) was found in genotype G43. Other genotypes showed moderate reduction in plant height due to moisture stress. Figure 3 shows the relationship between water use efficiency with plant height. Under 40 to 50% FC, the maximum positive relationship was found in genotype G141 followed by G164 and G88.

3.5.2. Number of Branches per Plant

The number of branches per plant was also significantly reduced due to low moisture stress and consequently reduced total plant growth (Table 3). Under water regime A, the highest number of branches per plant was found in genotype G108 (3.13) and the lowest was found in genotype G43 (2.25). Under water regime B, the highest number of branches per plant was found in genotype G108 (2.71) which was statistically similar with genotypes G88, G141 and G186 and the lowest was found in genotype G43 (1.75).

In the case of branch per plant, different genotypes showed different reduction rate. However, the lowest reduction was found in genotype G88 (5.45%) followed by genotype G141 (6.06%) and the highest reduction was recorded in genotype G43 (22.22%). These results indicated that genotype G88 and G141 maintained better plant growth, while genotype G43 showed susceptibility to low soil moisture conditions.

Table 3. Interaction effects of different mungbean genotypes and two irrigation treatments on plant height, branch per plant, pods per plant, pod length, seeds per pod, thousand seed weight and seed yield per plant of mungbean genotypes.

Treatments	Genotypes	Plant Height (cm)	No. of Branches Plant^{-1}	No. of Pods Plant^{-1}	Pod Length (cm)	No. of Seeds Pod^{-1}	1000-Seeds Weight (g)	Seed Yield Plant^{-1} (g)
Water regime A	G43	52.85 fg	2.25 c	16.65 g	7.51 abc	6.93 cd	45.80 c	12.05 d
	G88	58.45 de	2.75 b	22.63 bc	7.87 a	7.20 c	40.25 d	14.48 a
	G108	61.08 cd	3.13 a	21.88 cd	7.88 a	6.93 cd	51.37 a	13.32 b
	G141	76.19 a	2.75 b	28.88 a	7.48 abcd	6.90 cd	37.79 ef	13.06 b
	G164	69.08 b	2.67 b	23.25 b	7.25 cdef	8.86 a	37.43 f	12.81 b
	G186	52.50 fg	3.00 a	16.75 fg	7.04 efg	6.98 cd	48.92 b	12.72 bc
	BU mug 5	57.64 de	2.68 b	18.00 e	7.73 ab	6.13 ef	50.69 ab	14.17 a
	Binamoog-8	51.29 fg	2.68 b	21.00 d	7.38 bcde	7.20 c	46.23 c	13.05 b
Water regime B	G43	35.29 j	1.75 d	13.13 i	5.99 h	5.28 h	40.76 d	6.18 g
	G88	54.84 ef	2.60 b	21.30 d	7.63 abc	6.80 cd	39.86 de	12.11 cd
	G108	53.61 f	2.71 b	18.75 e	7.62 abc	6.51de	49.82 ab	11.11 e
	G141	68.96 b	2.58 b	28.50 a	6.97 fg	6.55 de	37.42 f	11.86 d
	G164	63.09 c	2.18 c	18.88 e	6.95 fg	7.35 b	37.05 f	10.29 f
	G186	49.24 gh	2.58 b	15.75 gh	6.63 g	6.51 de	45.44 c	10.06 f
	BU mug 5	45.98 hi	2.18 c	15.18 h	7.07 def	5.72 fgh	49.62 ab	9.81 f
	Binamoog-8	44.55 i	2.19 c	17.88 ef	6.89 fg	6.47 de	44.75 c	10.39 f
CV(%)		3.99	4.62	3.57	3.40	4.80	3.20	3.36
SE		1.187	0.0678	0.4103	0.1422	0.1847	0.8128	0.2268

Mean values in the same column with different letters are significantly different at 5% level of significance. Averages data are shown with mean values of five independent replicates (n = 5). SE, standard error. Water regime A: 80 to 90% FC, Water regime B: 40 to 50% FC.

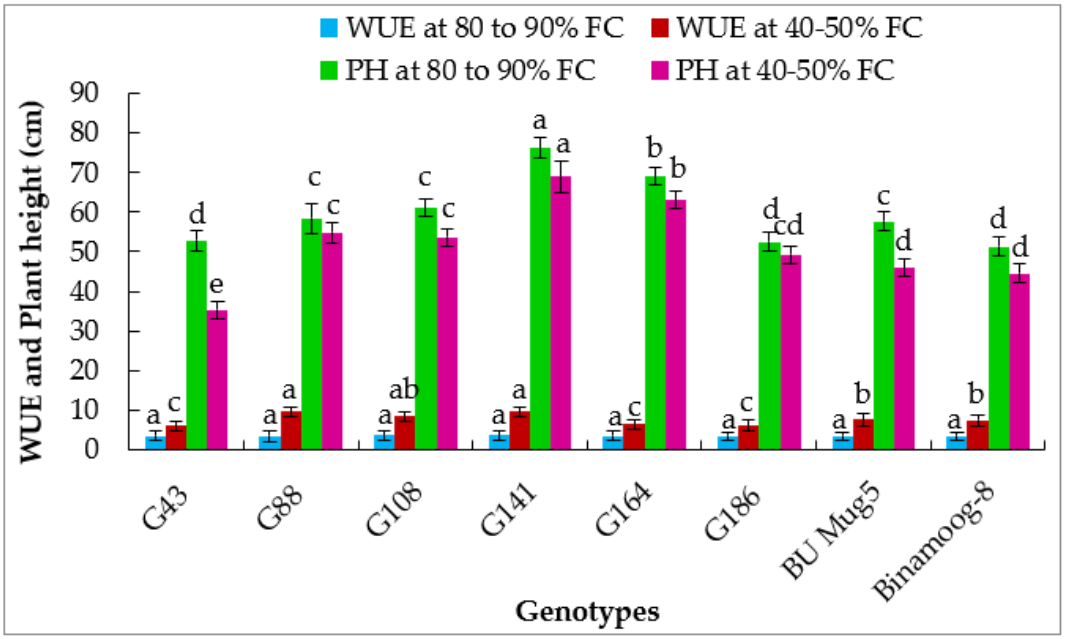

Figure 3. Relationship between water use efficiency and plant height of different mungbean genotypes. The vertical bar indicates an average of five independent replicates (n = 5). Error bars represent standard error. Different letters indicate significant differences at $p \leq 0.05$.

3.5.3. Number of Pods per Plant

In the present study, water stress significantly reduced the number of pods per plant in all genotypes (Table 3). Under water regime A, the highest number of pods per plant was found in genotype G141 (28.88) followed by genotype G164 (23.25) and genotype G88 (22.63) and the lowest number of pods per plant was observed in genotype G43 (16.65) which was statistically identical with genotype G186 (16.75). Under water regime

B, the highest number of pods per plant was found in genotype G141 (28.50) followed by genotype G88 (21.30) and the lowest number of pods per plant was found in genotype G43 (13.13). Figure 4 illustrated that the lowest reduction in pods number per plant was found in genotype G141 (1.30%) followed by genotype G88 (5.86%) and the highest reduction was found in genotype G43 (21.67%). Therefore, genotype G88 and G141 maintained better plant growth and number of pods per plant than the other genotypes under low moisture stress.

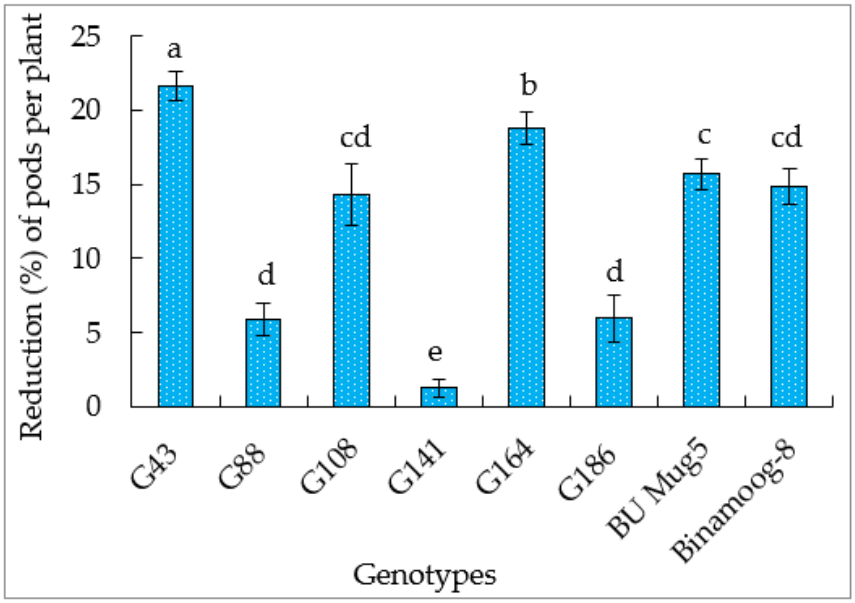

Figure 4. Reduction (%) in pods per plant of mungbean genotypes under low soil moisture condition. The vertical bar indicates an average of five independent replicates (n = 5). Error bars represent standard error. Different letters indicate significant differences at $p \leq 0.05$.

3.5.4. Pod Length

Drought stress caused severe reduction in plant growth as indicated in pod length where pod length of mungbean genotypes reduced due to drought stress (Table 3). Under water regime A, the highest pod length was found in genotype G108 (7.88 cm) which was statistically similar with genotype G88 (7.87 cm) and BU mug 5 (7.73 cm) and the lowest pod length was recorded in genotype G186 (7.04 cm). Under water regime B, the highest pod length was observed in genotype G88 (7.63 cm) which was statistically similar with genotype G108 (7.62 cm), and the lowest pod length was found in genotype G43 (5.99 cm). However, the lowest reduction was found in genotype G88 (3.05%), and the highest reduction (20.28%) was observed in genotype G43. Pod length reduction under drought stress might be due to lower photosynthetic capacity which results in lower dry matter accumulation and pod length.

3.5.5. Number of Seeds per Pod

Drought stress has detrimental effects on the number of seeds per pod of mungbean genotypes. There were genotypic differences in the number of seeds per pod under both control and low moisture stress condition (Table 3). Under water regime A, the highest number of seeds per pod was found in genotype G164 (8.86). However, under water regime B, the highest number of seeds per pod was also found in G164 (7.35), which was statistically different from others genotypes and the lowest number of seeds per pod was found in G43 (5.28). Under low moisture stress, the genotype G88 also showed better in number of seeds per pod. The reduction in seeds per pod due to low moisture stress was significantly different among the mungbean genotypes (Figure 5). The lowest reduction

was recorded in genotype G141 (5.07%) followed by genotype G88 (5.61%) and the highest reduction was found in genotype G43 (23.85%) followed by G164 (17.02%).

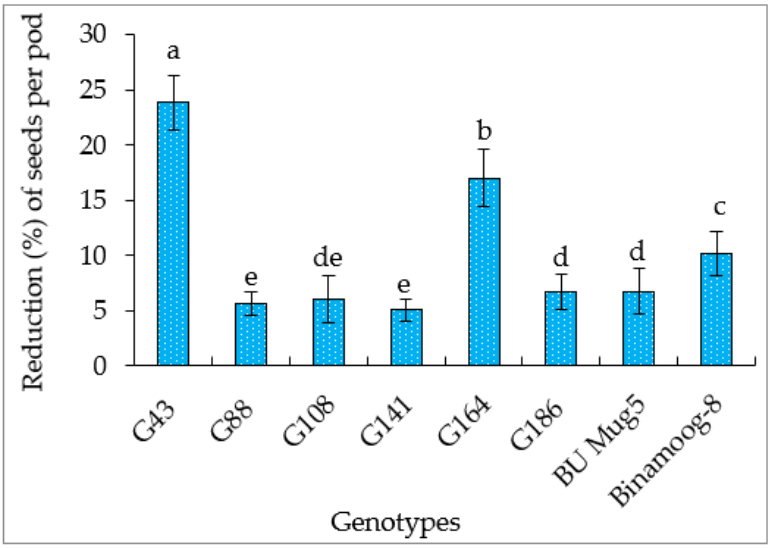

Figure 5. Reduction (%) of seeds per pod of mungbean genotypes under low soil moisture condition. The vertical bar indicates an average of five independent replicates (n = 5). Error bars represent standard error. Different letters indicate significant differences at $p \leq 0.05$.

3.5.6. Thousand Seed Weight

Thousand seed weight is an important yield attribute to determine yield of mungbean, where its reduction was significant under low soil moisture stress (Table 3). Under water regime A, the highest 1000-seed weight was found in genotype G108 (51.37 g), and the lowest 1000-seed weight was found in genotype G164 (37.43 g). Under water regime B, the highest 1000-seed weight was found in genotype G108 (49.82 g) which was statistically identical with genotype BU mug 5 (49.62 g) and the lowest 1000-seed weight was found in genotype G164 (37.05 g). The lowest reduction in 1000-seed weight was found in genotype G88 (0.96%) followed by genotype G141 (0.98%) and the highest reduction (11.08%) was found in genotype G43.

3.5.7. Seed Yield

Seed yield of mungbean genotypes differed significantly both under control and low soil moisture stress conditions (Table 3). Under water regime A, the highest seed yield per plant was recorded in genotype G88 (14.48 g) and the lowest seed yield per plant was recorded in genotype G43 (12.05 g). Under water regime B, the highest seed yield per plant was recorded also in genotype G88 (12.11 g) which was statistically similar with genotype G141 (11.86 g) and the lowest seed yield per plant was found in genotype G43 (6.18 g). Further, different genotypes showed different degrees in seed yield reduction under low soil moisture stress condition. However, the lowest seed yield reduction was recorded in genotype G141 (9.19%) followed by genotype G88 (16.35%) and the highest reduction was observed in genotype G43 (48.67%). Figure 6 shows the relationship between photosynthetic water use efficiency with seed yield. Under 40 to 50% FC, the highest WUE and seed yield was found in genotype G88 followed by G108 and G141.

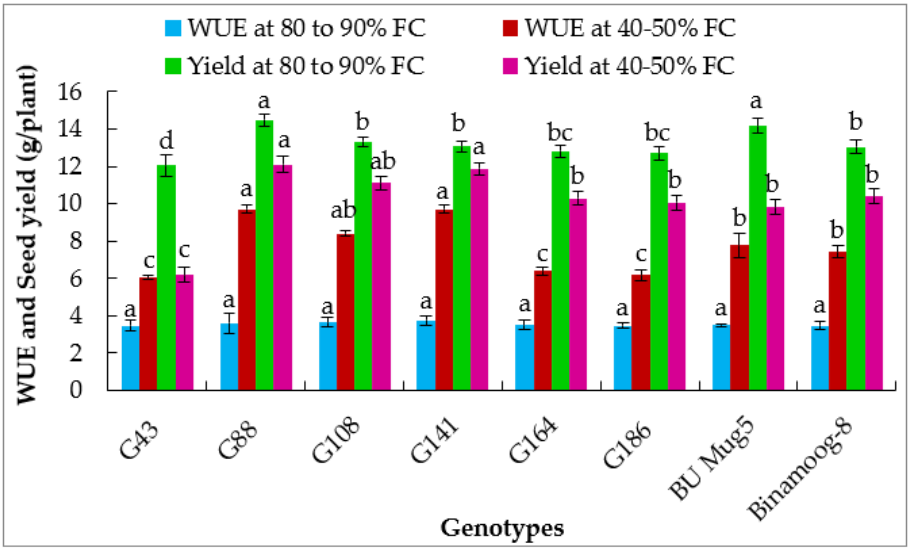

Figure 6. Relationship between water use efficiency and seed yield of different mungbean genotypes. The vertical bar indicates an average of five independent replicates (n = 5). Error bars represent standard error. Different letters indicate significant differences at $p \leq 0.05$.

4. Discussion

Drought stress is one of the major constraints for pulse crops, and it seriously affects their production. Drought-induced several morphological and physiological alterations including decrease of plant growth, tissue water content, cell wall degradation, reduce stomatal conductance, disrupts photosynthetic pigments and decline leaf gas exchange. Consequently, water stress hinders plant growth, development and decreases crop productivity. Water relations characteristics are the perfect indicator of plant hydrological state which denotes the physiological effects of cellular water deficiency and leaf metabolism [24]. In the present study, water stress significantly affected the water relations characteristics of mungbean plants regardless of genotype (Table 1). Our results also supported by Islam et al. [25] where exposure of plants to drought stress substantially decrease the leaf water potential, relative water content (RWC) and transpiration rate, with a concomitant increase in leaf temperature. When plants are subjected to drought, leaves exhibit large reductions in relative water content and water potential. RWC is an important attribute of water relations in the plants and considered as the best integrated measurement of plant water status, which represents the variations in water potential and turgor potential of the plants [26]. Water stress is one amongst the several factors that negatively affects the RWC, turgor pressure and transpiration in crops [27]. Water relations characteristics are also affected by the interaction of severity, duration of the drought event and species [8,28]. Table 1 also indicated that tolerant genotypes G141 and G108 showed better water relations than the susceptible genotypes. Similar results also reported by Bangar et al. [8] that a decrease in relative water content of sensitive mungbean genotypes were more than tolerant genotypes under drought stress condition. Tolerant mungbean genotypes had higher potential for surface water extraction under drought stress. Islam et al. [25] reported that water relations characteristics are well associated with stress strength and decreased under drought condition. It was observed that, under moisture stress, the free water content, water potential, and osmotic potential decreased but bound water content and water saturation deficit increased [29]. Under shortage of water, greater damage in cell structures occurs which reduces the water retention capacity of field crops [24,30]. Different varieties showed significant variation in water relations characteristics might be due to differences in their ability for absorption and transpiration loss of water through stomata.

Regardless of genotypes, water stress significantly reduced photosynthetic rate (Pn), stomatal conductance (gs) and transpiration rate (Tr) of mungbean (Table 2). However, genotype G141 and genotype G88 showed higher Pn, gs and Tr. Photosynthesis is one of

the key metabolic processes that determine the crop growth and yield, and it is affected by water stress. Water stress changes the standard pace of photosynthesis as well as the gas exchange characteristics in plants (Table 2 [31]). Reductions in leaf area (size and number) and stomatal closure impaired the activities of carboxylation enzymes and ATP synthesis, and destruction of photosynthetic apparatus are the key factors for lowering photosynthetic rate under drought stress [32]. Environment of limited moisture condition induces stomatal closure, reduces carbon dioxide influx to leaves and drives extra electrons for formation of reactive oxygen species and reduce photosynthesis [33,34]. Several factors such as stomatal closure, decline of turgor pressure, reduction in leaf gas exchange and decrease in CO_2 assimilation are involved in the decline of photosynthesis [26,31]. Higher stomatal conductance in plants (Table 2) is known to increase CO_2 diffusion into leaves thereby enhancing photosynthetic rates. Higher net CO_2 assimilation rates results in higher biomass and higher crop yields (Tables 2 and 3, [35,36]). Moisture stress reduces the capture and use of light, impairs Rubisco activity, pigments and photosynthetic machinery, which are the reasons for photosynthesis diminutions [33,37]. Under water stress condition, transpiration rate decreases in susceptible genotypes which are closely related to the amount of dry matter production of crops (Tables 2 and 3). Under drought stress osmotic balance is disrupted which disturbs the fluidity of cell membrane leading towards more electrolyte leakage owing to cell membrane damage. These all factors are responsible for causing reduction in Pn, Gs and Tr [1,38,39]. Drought tolerant genotypes have the potential of higher water use efficiency under drought stress conditions than the susceptible cultivars and produce higher dry matter by the mechanism of low water consumption and low transpiration rate [1].

Chlorophyll content reflects the intensity and ability of photosynthesis and thereby affecting the growth of plants. Water stress has adverse effects on chlorophyll content because of the damage of mesophyll chloroplasts, lower chlorophyll synthesis and higher chlorophyll breakdown [40]. Moisture stress decreased the total chlorophyll contents of leaves of all mungbean genotypes (Table 2). Reduction in chlorophyll content due to drought also reported by Kusvuran et al. [41] in common bean, Mafakheri [42] in chickpea and Meena et al. [36] in mungbean. Decrease in total chlorophyll content under drought stress because of lower light harvesting capacity. Reactive oxygen species under drought stress damage the chloroplasts and results in lower chlorophyll content [42]. In the current research, the injurious impact of moisture stress on relative water content and chlorophyll concentrations in mungbean might be due to the reduction in water flow. Reduction in water flow enhances disorder of thylakoid, dehydration of protoplasm, oxidative damage of chloroplasts, reduces photo-assimilation level, induces stomatal closure, and decreases CO_2 concentration in the mesophyll cells [43].

Plant accumulates osmolytic cytosolutes to minimize the physiological damage under stress [1,44]. Proline is one of the familiar osmoprotectants and proline accumulation is the most important physiological index for the plant's response to drought stress [1,8,44]. The proline content of different mungbean genotypes was significantly increased due to moisture stress compared to control conditions, which may be due to the key role of proline in osmotic regulation under water stress conditions. However, significantly higher proline accumulation was observed in genotypes G88 and G141 than other genotypes (Figure 2A). It implies that those genotypes provided better recovery during water stress conditions. Because proline acts as an osmolyte and protects the plant against low water potential by maintaining osmotic regulation of different organs in plant [45,46]. Contribution of proline to osmotic adjustment is considered as a mechanism to maintain water relations and postpone dehydration under osmotic stress (Table 1). Proline protected plants against water stress by stabilizing the mitochondrial electron transport complex II, membranes and proteins [47,48] and enzymes such as ribulose-bisphosphate carboxylase/oxygenase (RuBisCO; [49]). Moreover, proline also plays a major role as an electron receptor and may promote damage repair ability in the plant by scavenging ROS, and by increasing antioxidant enzyme activity during drought stress [50,51].

Yield reduction occurred under low soil moisture stress because plants were adversely affected as seen by the reduced number of branches per plant, number of pods per plant, number of seeds per pod and 1000-seed weight (Table 3). Plant height of different mungbean genotypes significantly reduced might be due to inhibition of cell division that decreases plant height under drought condition. Similar results were also found by Uddin et al. [52], who showed that water stress reduced plant height of mungbean. It is known that water is the fundamental input for photosynthesis and thus produces photosynthetic products which are required for crop growth. On the other hand, plant height was reduced in drought stress due to reducing transpiration rate for their survival and having low relative water content of the cells (Tables 1–3). Drought stress hampers the formation of generative organ and it brings plant early maturity that badly affects the number of pods as well as yield of crops. However, in well-watered condition, plants growth and maturation periods will be higher and it takes long time for pod formation [53]. More fertilization and optimum seed development contributed to a greater number of seeds per pod. Flower abortion and drying of stigma occurred due to water stress at the flowering stage which reduce the germination of pollen grain in stigma and reduce fertilization capability and eventually causes poor seed development and a fewer number of seeds in a pod [36]. Stomatal closure is an earlier response of moisture stress which leads to the decline of CO_2 uptake that impair photosynthesis and overall reduction in plant growth such as dry matter accumulation, pod length, seed size and 1000-seed weight [1]. Among the plant characters, the effect of water stress was severe on reproductive attributes which correlates well with previous studies [36,54,55]. This is probably due to the water absorption capacity being low because of shortage of soil water consequently seed yield was decreased [11,52]. Moreover, photosynthetic activity decreases due to reduction in chlorophyll content and leaf area under drought stress which results in reduced seed yield (Table 2; [8]). There was genotypic variation in drought tolerance and this variation might be due to the varying nature, as different traits are governed by a large number of genes [56,57]. Yield is a complex character, which depends on different morpho-physiological characteristics. However, morpho-physiological characteristics of crops are governed by different stress including drought, thereby drought stress reduces the crop yield. A number of previous studies reported similar variations under variable environmental stress conditions [11,32,58,59].

5. Conclusions

Food production of the globe is severely affected by different abiotic stresses. Drought stress is considered as severe one among the abiotic stress which reduces crop production. Here, we studied the impacts of low soil moisture on different morpho-physiological characteristics and yield of mungbean genotypes. Drought stress significantly affects the water relation, gas exchange characteristics, chlorophyll content, proline content and yield of different mungbean genotypes. However, genotypes G88, G108 and G141 showed considerable tolerance to drought with significantly lesser reduction exhibited for water relation, gas exchange traits, chlorophyll content, proline content and grain yield under stress treatments. Based on the above results, genotypes G88, G108 and G141 might be considered as potential for developing drought tolerant mungbean variety. These tolerant genotypes also might be used as 'donors' in the mungbean improvement programs for developing drought tolerant mungbean varieties with higher yield.

Author Contributions: Conceptualization, M.M.I., M.M.H. and T.T.; methodology, M.M.I., M.M.H., M.A.R. and T.T.; validation, M.M.I. and A.R.C.; formal analysis, T.T., A.R.C. and S.-N.-U.S.; investigation, T.T., A.R.C., S.-N.-U.S. and M.A.R.; data curation, M.M.I., T.T., A.R.C. and S.-N.-U.S.; writing—original draft preparation, T.T., A.R.C., M.M.I., S.-N.-U.S., M.A.R., M.G.M., S.A. and Y.M.; writing—review and editing, M.M.H., M.G.M., S.A. and Y.M.; visualization, M.M.I. and T.T.; supervision, M.M.I. and M.G.M.; project administration, M.M.I. and M.M.H.; funding acquisition, S.A. and M.M.I. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the Researchers Supporting Project number (RSP2023R194), King Saud University, Riyadh, Saudi Arabia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data are contained within the article.

Acknowledgments: Authors would like to extend their sincere appreciation to the Researchers Supporting Project number (RSP2023R194), King Saud University, Riyadh, Saudi Arabia.

Conflicts of Interest: The authors declare that they have no conflict of interest.

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