Phyton-
International Journal of
Experimental Botany

Tech Science Press

DOI: 10.32604/phyton.2023.025138

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ARTICLE

Drought Tolerance in Mung Bean is Associated with the Genotypic Divergence, Regulation of Proline, Photosynthetic Pigment and Water Relation

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Received: 23 June 2022 Accepted: 07 October 2022

ABSTRACT

Drought is one of the critical conditions for the growth and productivity of many crops including mung bean (*Vigna radiata* L. Wilczek). Screening of genotypes for variations is one of the suitable strategies for evaluating crop adaptability and global food security. In this context, the study investigated the physiological and biochemical responses of four drought tolerant (BARI Mung-8, BMX-08010-2, BMX-010015, BMX-08009-7), and four drought sensitive (BARI Mung-1, BARI Mung-3, BU Mung-4, BMX-05001) mung bean genotypes under well-watered (WW) and water deficit (WD) conditions. The WW treatment maintained sufficient soil moisture (22% ± 0.5%, i.e., 30% deficit of available water) by regularly supplying water. Whereas, the WD treatment was maintained throughout the growing period, and water was applied when the wilting symptom appeared. The drought tolerant (DT) genotypes BARI Mung-8, BMX-08010-2, BMX-010015, BMX-08009-7 showed a high level of proline accumulation (2.52–5.99 mg g^{-1} FW), photosynthetic pigment (total chlorophyll 2.96–3.27 mg g^{-1} FW at flowering stage, and 1.62–2.38 mg g^{-1} FW at pod developing stage), plant water relation attributes including relative water content (RWC) (82%–84%), water retention capacity (WRC) (12–14) as well as lower water saturation deficit (WSD) (19%–23%), and water uptake capacity (WUC) (2.58–2.89) under WD condition, which provided consequently higher relative seed yield. These indicate that the tolerant genotypes gained better physio-biochemical attributes and adaptability in response to drought conditions. Furthermore, the genotype BMX-08010-2 showed superiority in terms of those physio-biochemical traits, susceptibility index (SSI) and stress tolerance index (STI) to other genotypes. Based on the physiological and biochemical responses, the BMX-08010-2 was found to be a suitable genotype for sustaining yield under drought stress, and subsequently, it could be recommended for crop improvement through hybridization programs. In addition, the identified traits can be used as markers to identify tolerant genotypes for drought-prone areas.

KEYWORDS

Mung bean; drought; proline; chlorophyll; water status; stress tolerance

1 Introduction

Drought stress is an important constraint that limits growth, development, yield, and productivity in plants globally [1–4]. It has been recognized as one of the limiting factors for successful crop production in dry land [5], which induces a series of physiological and molecular alterations. In physiological processes, like plant photosynthesis, stomatal conductivity, and transpiration are reduced due to drought-induced reduction of CO_2 accumulation in leaves [1,2].

Mung bean [*Vigna radiata* (L.) Wilczek; Fabaceae], an important pulse crop is a vital source of the daily human diet in South Asian countries [6,7]. It is a good source of digestible dietary protein [7], and radically contributes to the soil by fixing environmental N_2 [8]. Mung bean is generally cultivated during the dry season (March–May), while the scarcity of water or unavailable soil moisture is a common incidence in Bangladesh. Nonetheless, it has been reported that the growth, development and yield of mung bean are severely affected by water deficit stress at the early, late vegetative and flowering stages, whereas the grain yield is found to be reduced by 25%, 39% and 59%, respectively [9]. In addition, the response of plants to drought depends on the intensity and duration of stress as well as the plant species. Thus, it is necessary to screen out drought tolerant mung bean genotypes for sustaining potential yield under drought condition.

Drought tolerance can be evaluated through bio-physiological parameters, such as metabolic compatible solutes (e.g., proline, soluble sugar), chlorophyll content, and plant water relations under drought condition [10,11]. The accumulation of proline is highly responsive in various plant species under water deficit condition [12–14]. Mung bean plants show higher accumulation of free proline and sugar under drought in field experiments [15]. Soil moisture has also been reported to affect plant water potential, and chlorophyll content which is the most important factor for grain development [16]. Moisture stress enhances changes in the internal environment within the crops, consequently affecting the physiological and biochemical processes of crop plants [17]. The shortage of water, i.e., drought, during the crop growing period inhibits the chlorophyll a (Chl a) & chlorophyll b (Chl b) synthesis, and decreases the quantity of Chl a & Chl b binding proteins, ultimately reducing the light-harvesting pigment protein which is linked with photosystem II [18]. Moreover, under this condition, the concentration of solutes in the soil increases, which reduces the access of the roots, thereby decreasing water reception by the roots, and consequently declining the leaf water potential [19].

Drought stress can be mitigated through different management practices, like supplemental irrigation, water conservation practices, i.e., mulching, use of plant growth regulators (PGRs), and a diversified farming system [20,21]. However, they have cost involvement and are sometimes quite impossible for the socio-economic conditions of the farmers. So, the absolute alleviation of drought is not possible. The best option is, thus, to select drought resistance cultivar(s) for sustainable crop production in the moisture deficit stress. Therefore, this study was conducted to explore physiological and biochemical traits that are associated with the drought tolerance of mung bean.

2 Materials and Methods

2.1 Experimental Site and Test Material

A trial was conducted at the research field of the Agronomy Department, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh (The geographical location of the area constitutes 25°38′ N latitude and 88°41′ E longitude, with an elevation of 38.20 m above sea level) during the Kharif (summer) season under the rain-out shelter, which belongs to the Old Himalayan Piedmont Plain that is designated as Agro-Ecological Zone-1. The rain-out shelter was constructed by using a transparent polythene sheet. Four drought tolerant and four drought susceptible mung bean genotypes were used in this study, which were chosen under a laboratory screening based on their germination indices, seedling growth characteristics and their relative performance with PEG induced water deficit stress [22]. The tested seeds were collected from Pulses Research Centre, Bangladesh Agricultural Research Institute (BARI), and Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Bangladesh. The pedigree and distinction of all genotypes of mung bean under the study are presented in Table 1.

Table 1: Pedigree and distinction of the studied experimental materials

Sl. No.	Genotypes	Distinction	Pedigree
1	BARI Mung-8	ST	Selection from local landrace (LM-101)
2	BMX-08010-2	ST	BARI Mung-6 × BMX-9902-2
3	BMX-010015	ST	NM-94 × BARI Mung -3
4	BMX-08009-7	ST	BARI Mung-6 × BAU Mung-2
5	BARI Mung-1	SS	Advance line of Mung 7706 (India)
6	BARI Mung-3	SS	Sonamung (Local) × BARI Mung-2 (BMX-842243)
7	BU Mung-4	SS	GK7 (AVRDC, Taiwan)
8	BMX-05001	SS	BARI Mung-5 × BARI Mung-6

Note: Where, ST = Stress tolerant; SS = Stress susceptible.

2.2 Experimental Design and Treatments

The study was conducted with two factors consisting of eight mung bean genotypes (four drought susceptible and four tolerant ones) (as described in Table 1), and two moisture conditions (well-watered and water deficit stress). Total 16 treatments were arranged in a Completely Randomized Design (CRD) with four replications.

2.3 Pot Preparation and Seed Sowing

The plastic pots of size 23 cm diameter (inside) and 23 cm height with a 17 cm base (8 L volume) were used in the present study. Each plastic pot was prepared with 10 kg well-pulverized air-dried soil including compost (1/4th of the soil mass). The soil was collected from the research field of the Agronomy Department (HSTU), Dinajpur, Bangladesh. It was of sandy loam type with 25.8% field capacity, 1.49 g/cc bulk density, and 11.6% permanent wilting point. The physical and chemical properties of the experimental soil have been mentioned in Table 2. The pots were supplied with fertilizers as 0.103, 0.088, 0.093, 0.046 and 0.007 g of urea, triple superphosphate, and boric acid corresponding to 20-17-18-10-2 kg Nitrogen (N), Phosphorus (P), Potassium (K), Sulphur (S) and Boron (B) per hectare, respectively [23]. Twenty seeds were sown in each pot after sterilizing with 0.1% mercuric chloride solution for 2 min [24–26], and subsequently washing with tap water. The seeding depth was maintained at 3 cm. After emergence and establishment, five homogenous and healthy seedlings were kept in each pot to grow up to maturity.

Table 2: The initial soil physical and chemical properties of experimental soil

Items	Soil texture (sandy loamy)			pH	OM (%)	N (%)	P ($\mu g\ g^{-1}$)	K ($meq100^{-1}$ g soil)	S ($\mu g\ g^{-1}$)	Zn ($\mu g\ g^{-1}$)	B ($\mu g\ g^{-1}$)
Initial soil	Sand (57.64%)	Silt (32.0%)	Clay (10.36%)	6.2	0.68	0.03	11.53	0.26	17.53	0.15	0.88
Critical level	–	–	–	–	–	0.12	10.00	0.12	10.00	0.60	0.20

Note: Where, OM = Organic matter; N = Nitrogen; P = Phosphorus; K = Potassium; S = Sulphar; Zn = Zinc; B = Boron.

2.4 Water Management

Primarily water was applied in all pots comprising of both treatments of well-watered (WW) and water deficit (WD) just after sowing of seeds, and subsequently water was applied at 5 days after sowing (DAS) for proper germination and seedling establishment. From 10 DAS, the WW treatment pots maintained the most favorable moisture for optimum plant growth and development throughout the growing period providing irrigation, which remained around 20% of the moisture content (MC) (Fig. 1a). As it, soil moisture was maintained at 22% ± 0.5%, i.e., 30% deficit of available water. The WD treatment pots were maintained at moisture deficit condition throughout the growing period, and irrigation was applied when the appearance of wilting symptom was shown (Fig. 1b). At wilting symptoms, the MC has prevailed about 50% of field capacity. However, water was applied in both treatments by frequent observation of soil MC through digital soil moisture metter (Model PMS-714), and water was applied up to the field capacity (FC) level in each watering. The net amount of water (d) required per irrigation was calculated according to [27] as follows:

$$\mathrm{d} = \frac{\mathrm{FC} - \mathrm{MC}}{100} \times p \times D \quad (1)$$

where, FC = Field capacity of the soil (%)

MC = Moisture content of the soil at the time of irrigation (%)

p = Bulk density of the soil ($g\ cm^{-3}$)

D = Root zone depth (cm)

2.5 Crop Management and Harvest

Weeding was done as and when necessary to keep the pot reasonably weeds-free throughout the growing period. The plants were protected from flower thrips by spraying with Imidachloprid (Imitaf 20 SL) @ 0.5 ml $litre^{-1}$ of water at the flowering and the pod developing stage. For controlling pod borer, Lambda-Cyhalothrin (Karate 2.5 EC/Reeva 2.5 EC) @ 1 ml $litre^{-1}$ of water was applied two times maintaining 7 days intervals from pod developing stage. Harvesting was done when the pods of mung bean genotypes had turned blackish-brown in color, and dried to such a point that they were about to shatter. The matured pods were collected thrice manually. After harvesting, the samples were sun-dried for three days, and then threshing was carried out. The threshed seeds were cleaned, sun-dried, and weighed per plant (g).

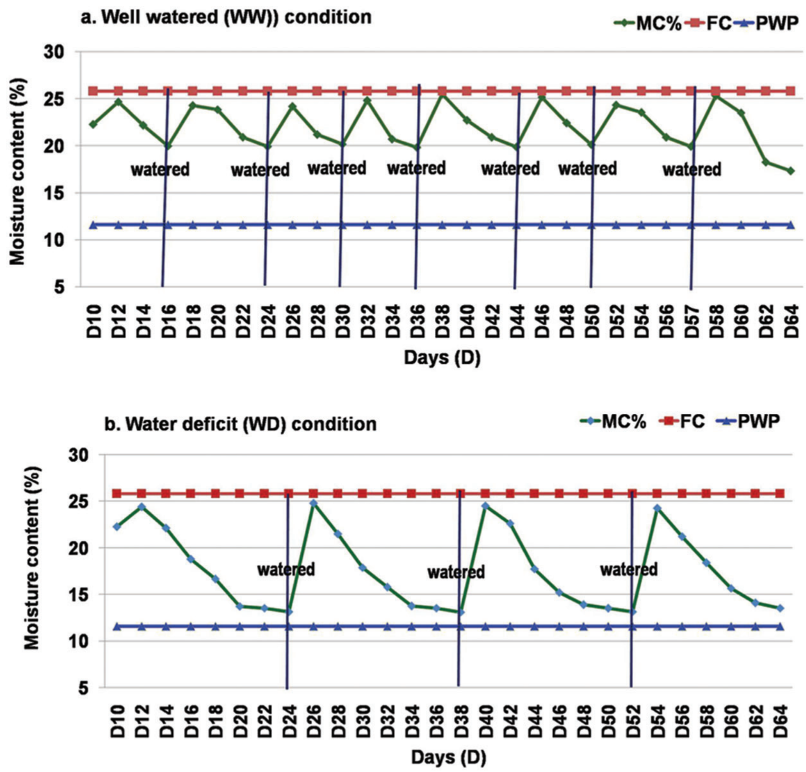

Figure 1: Changes of soil moisture content under WW and WD conditions. MC = Moisture content; FC = Field capacity; PWP = Permanent wilting point

2.6 Measurement of Physiological Traits

2.6.1 Proline Content

Fresh third trifoliate leaf samples from all genotypes of mung bean in each replication were used for assessments of proline content to minimize the error of results. It was collected from 0.5 g fresh weight (FW) of leaf samples that were homogenized with 3% sulfosalicylic acid, and acid ninhydrin reagent method was used to estimate the proline content [28]. The optical density of the solutions (sample and standard solution) was estimated through an Ultra Violet (UV)-visible spectrophotometer (Model T60 UV, Japan) at 520 nm wave length. The proline content was calculated from a standard curve, and stated as mg proline g^{-1} FW.

2.6.2 Chlorophyll Content

For getting uniform results in each treatment, the third trifoliate leaf was used to determine the chlorophyll content by the method described by Witham et al. [29]. Exactly 0.1 g of fresh leaf tissues of mung bean leaf were taken in a test tube containing 10 mL of 80% acetone. The sample was then shaken overnight by using an electric horizontal shaker. For measuring chlorophyll a (Chl a), chlorophyll b (Chl b) and total chlorophyll content, the optical density or absorbance of the supernatant were recorded through an UV-visible spectrophotometer at 663 and 645 nm wavelength. The concentration of Chl a, Chl b and total chlorophyll were measured using the following formula:

$$\text{Chlorophyll a}\left(\text{mg g}^{-1}\text{leaf}\right) = [12.7(\text{D663}) - 2.69(\text{D645})] \times \text{V}/(1000 \times \text{W}) \quad (2)$$

$$\text{Chlorophyll b}\left(\text{mg g}^{-1}\text{leaf}\right) = [22.9(\text{D645}) - 4.68(\text{D663})] \times \text{V}/(1000 \times \text{W}) \tag{3}$$

$$\text{Total chlorophyll}\left(\text{mg g}^{-1}\text{leaf}\right) = [20.2(\text{D645}) + 8.02(\text{D663})] \times \text{V}/(1000 \times \text{W}) \tag{4}$$

where, D = Absorbance reading of the chlorophyll extract at the specific wavelength

V = Final volume of the 80% acetone-chlorophyll extract

W = Fresh weight in gram of the tissue extracted

Chlorophyll stability index (CSI) was estimated according the formulae given by [30]

$$\text{CSI} = \frac{\text{Chlorophyll content in stressed leaves}}{\text{Chlorophyll content in control leaves}} \tag{5}$$

2.6.3 Plant Water Relations

The terminal leaflets of the fully expanded leaves for each treatment were collected during noon time. Immediately, the FW of the collected leaves was measured. The leaf samples were soaked in distilled water and kept in dark condition for 24 h at ambient room temperature for 24 h. The leaf samples were weighed after removing excess water from the leaf surface through gently wiping them with a paper towel, which is called turgid weight (TW). The dry weights (DW) of the leaf samples were taken after drying the samples in the oven at 80°C for 72 h. The estimated fresh, turgid and dry weights of the leaves were used to calculate relative water content [31], water saturation deficit [32], water retention capacity [33], and water uptake capacity [34]. The formula of all the parameters was presented below:

$$\text{Relative Water Content (RWC)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100 \tag{6}$$

$$\text{Water Saturation Deficit (WSD)} = 100 - \text{RWC} \tag{7}$$

$$\text{Water Retention Capacity (WRC)} = \frac{\text{Turgid weight}}{\text{Dry weight}} \tag{8}$$

$$\text{Water Uptake Capacity (WUC)} = \frac{\text{Turgid weight} - \text{Fresh weight}}{\text{Dry weight}} \tag{9}$$

2.6.4 Xylem Exudation Rate

The xylem exudation rate (XER) was measured at 5 cm above the stem base of the plant at 7:00 am. For measuring XER, clean cotton dry weight was taken. The stem was made a slanting cut with a sharp knife, and the weighted cotton was placed on the cut surface. The oozing sap was collected from the stem after one hour at normal temperature. To prevent evaporation, the cotton was covered with a cellophane bag. Thereafter, cotton with sap weight was taken. The calculation of XER was done by the following formula:

$$\text{Exudation rate} = \frac{(\text{Weight of cotton} + \text{sap}) - (\text{Weight of cotton})}{\text{Time (h)}} \tag{10}$$

2.7 Drought Tolerance Indices

Drought tolerance indices like relative performance [35], stress susceptibility index [36], tolerance [37], and stress tolerance index [38] were measured based on the values obtained under water deficit and control conditions. The formulas of tolerance indices have been given in below:

$$\text{Relative performance} = \frac{\text{Values of a plant character under water deficit condition}}{\text{Values of that character under well water condition}} \quad (11)$$

$$\text{Stress susceptibility index (SSI)} = \frac{1 - \frac{Y}{Y_P}}{1 - \frac{X}{X_P}} \quad (12)$$

where, Y = mean grain yield of a genotype under a stress environment; Yp = mean yield of the same genotype under a stress-free environment; X = mean Y of all genotypes; Xp = mean Yp of all genotypes.

$$\text{Tolerance (TOL)} = (\text{Yp} - \text{Ys}) \quad (13)$$

$$\text{Stress tolerance index (STI)} = (\text{Yp} \times \text{Ys})/(\text{Yp})^2 \quad (14)$$

where,

Yp = The yield of a particular genotype under control condition,

Ys = The yield of a particular genotype under stress condition.

2.8 Statistical Analysis

The data were compiled and subjected to statistical analysis with the help of a computer-based statistical program using the 'R' platform [39] following the basic procedure outlined by [40]. Correlation analysis was performed using the 'Agricolae' package [41]. The mean separation test was done with the least significant difference (LSD) test at $p = 0.05$.

3 Results

From variance analysis, it was revealed that the studied genotypes (at different stress levels) and stress levels (at different genotypes) were significant for all the studied variables (Supplementary Tables 1 and 2). The interaction effects (genotypes x stress levels) were also significant for all the measured variables (Tables 3–5; Figs. 2, 4 and 5).

3.1 Proline Accumulation

There was a distinct variation observed in proline accumulation under WD and WW (control) conditions. The studied genotypes exhibited different magnitudes of proline accumulation both under WW and WD conditions (Fig. 2). The proline accumulation increased in all the tested genotypes with WD condition than those of WW condition. This is due to the diminishing in the internal water status of the plant, which could be evident from the reduction in leaf water potential. Alternatively, the effect was recorded with sufficient moisture ensured by WW at all stages. However, the genotype BMX-08010-2 showed a significantly superior response to both WW and WD conditions for giving the highest proline accumulation. While the least value of proline accumulation was recorded in BARI Mung-1 genotype under the WW and WD stress conditions. In addition, BMX-08010-2 genotype gave about 1 fold higher proline accumulation than BMX-08009-7; 2 fold higher than BARI Mung-8 and BMX-01015; 4 fold higher than BARI Mung-3, BU Mung-4, BMX-05001 and 5 fold higher than BARI Mung-1 genotypes under WD condition. This means that the genotype BMX-08010-2 is more capable to sustain under WD condition than the other genotypes.

Table 3: Chlorophyll content (mg g^{-1} FW) at flowering stage (45 DAS) of mung bean genotypes under well-watered (control) and water deficit conditions

Genotypes	Chlorophyll a			Chlorophyll b			Chlorophyll a/b ratio		Total chlorophyll		
	WW condition	WD condition	% R over WW condition	WW condition	WD condition	% R over WW condition	WW condition	WD condition	WW condition	WD condition	% R over WW condition
BARI Mung-8	1.97abc	1.74ef	11.68	1.03c	0.84fg	18.45	1.91	2.07	3.00bc	2.57fgh	14.33
BMX-01015	1.96abc	1.63fg	16.84	1.00cd	0.80g	20.00	1.96	2.04	2.96bcd	2.44ghi	17.57
BMX-08010-2	2.09a	1.85cde	11.48	1.18a	0.99cde	16.10	1.77	1.87	3.27a	2.83cde	13.46
BMX-08009-7	2.02ab	1.77def	12.38	1.08b	0.88f	18.52	1.87	2.01	3.11ab	2.65efg	14.79
BARI Mung-1	1.63fg	1.14i	30.06	0.80g	0.52j	35.00	2.04	2.19	2.43hi	1.67l	31.28
BARI Mung-3	1.90b-e	1.35h	28.95	0.96de	0.66i	31.25	1.98	2.05	2.86cde	2.01k	29.72
BU Mung-4	1.93a-d	1.45h	24.87	0.96de	0.69hi	28.13	2.01	2.10	2.89cd	2.15jk	25.61
BMX-05001	1.82cde	1.51gh	17.03	0.95e	0.73h	23.16	1.92	2.07	2.77def	2.24ij	19.13
LSD (5%)	0.17			0.05			–		**0.21**		
CV (%)	5.50			3.21			–		**4.68**		
LS	*			*			–		*		

Note: Where, LS = level of significance; *significant at $P = 0.05$; DAS = days after sowing; R = reduction

Table 4: Relative water content (RWC), water saturation deficit (WSD), water uptake capacity (WUC) and water retention capacity (WRC) at flowering stage (45 DAS) of mung bean genotypes under control and water deficit conditions

Genotypes	RWC (%)			WSD (%)			WUC			WRC		
	WW condition	WD condition	% Decrease over WW condition	WW condition	WD condition	% Increase over WW condition	WW condition	WD condition	% Increase over WW condition	WW condition	WD condition	% Decrease over WW condition
BARI Mung-8	81.74ab	77.41c	5.30	18.26de	22.59c	23.71	2.24f	2.89d	29.02	13.79cde	12.37ghi	10.34
BMX-01015	81.61ab	77.77c	4.71	18.39de	22.23c	20.88	2.21f	2.77de	25.34	13.45def	12.03hi	10.56
BMX-08010-2	84.16a	81.37ab	3.32	15.84e	18.63de	17.61	2.13f	2.58def	21.13	15.01ab	13.72cde	8.59
BMX-08009-7	82.85a	79.18bc	4.43	17.15e	20.82cd	21.40	2.22f	2.77de	24.77	14.53bc	13.17efg	9.36
BARI Mung-1	78.58bc	64.04e	18.50	21.42cd	35.96a	67.88	2.56def	4.73a	84.77	14.18bcd	10.12j	28.61
BARI Mung-3	81.04ab	72.10d	11.03	18.96de	27.90b	47.15	2.35ef	3.61bc	53.62	14.05b-e	11.41i	18.79
BU Mung-4	82.92a	72.12d	13.02	17.08e	27.88b	63.23	2.40ef	4.06b	69.17	15.61a	13.12efg	15.95
BMX-05001	81.65ab	76.62c	6.16	18.35de	23.38c	27.41	2.45def	3.42c	39.59	15.63a	12.64fgh	19.13
LSD (5%)	3.19			3.19			0.47			0.98		
CV (%)	2.35			8.56			9.66			4.21		
LS	***			***			***			**		

Note: Where, LS = level of significance; **significant at $P = 0.01$; ***significant at $P = 0.001$; DAS = days after sowing

Table 5: Yield contributing traits of mungbean genotypes at harvest under well water (control) and water deficit conditions

Genotypes	Number of pods plant^{-1}			Pod length (cm)			Number of seeds pod^{-1}			100-seed weight (g)		
	WW condition	WD condition	Relative value	WW condition	WD condition	Relative value	WW condition	WD condition	Relative value	WW condition	WD condition	Relative value
BARI Mung-8	7.77a	5.25def	0.68	4.82e	3.68g	0.76	5.94b	3.97efg	0.67	2.70g	2.24h	0.83
BMX-01015	5.67cd	4.20gh	0.74	5.49abc	4.30f	0.78	6.82a	5.10c	0.75	3.82cd	3.19ef	0.84
BMX-08010-2	6.53b	4.97ef	0.76	5.76a	4.66e	0.81	6.26ab	5.24c	0.84	3.71cd	3.30ef	0.89
BMX-08009-7	4.73fg	3.55ij	0.75	4.72e	3.76g	0.80	4.20def	3.48gh	0.83	4.04c	3.52de	0.87
BARI Mung-1	7.25a	3.67hij	0.51	5.30cd	3.63g	0.68	6.08b	3.73fg	0.61	3.45de	2.23h	0.65
BARI Mung-3	7.53a	4.13ghi	0.55	5.44bc	4.13f	0.76	4.41de	2.89hi	0.66	3.98c	3.05fg	0.77
BU Mung-4	6.30bc	3.60hij	0.57	5.60ab	4.24f	0.76	4.77cd	3.46gh	0.73	4.08c	3.16ef	0.77
BMX-05001	5.40de	3.17j	0.59	5.12d	3.75g	0.73	3.99efg	2.63i	0.66	5.83a	4.67b	0.80
LSD (5%)	0.65			0.27			0.66	–		0.37		
CV (%)	7.15			3.33			8.41	–		6.02		
LS	***			*			*	–		*		

Note: Where, LS = level of significance; *significant at $P = 0.05$; ***significant at $P = 0.001$.

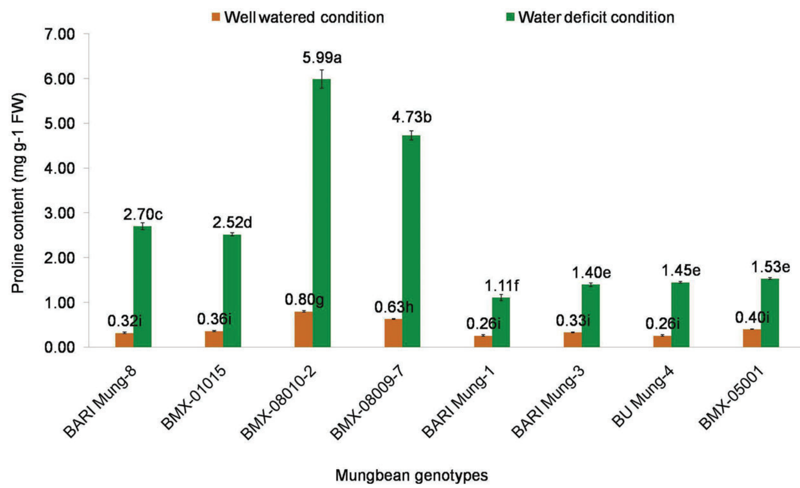

Figure 2: Proline content (mg g^{-1} FW) at flowering stage (45 days after sowing) of selected mung bean genotypes under water deficit and well-watered (control) conditions

3.2 Leaf Chlorophyll Content

The results revealed that all the mung bean genotypes exhibited a substantial variation in the leaf chlorophyll content under WD and WW conditions (Table 3). However, it seemed that Chl a content reduced to 11.48%–30.06% over control (WW) at flowering stages. Among the genotypes, the BMX-08010-2 contained the maximum Chl a content both in control and WD conditions. This genotype also showed the minimum reduction of Chl a content (11.48%) under WD condition over WW. The variety BARI Mung-1 showed the minimum Chl a content under WW and WD condition with the highest reductions of 30.06% over control.

Similarly, Chl b content in different genotypes decreased at WD condition. The data displayed a significant effect among the tested mung bean genotypes under stress condition in terms of Chl b content. However, numerically the highest Chl b content was obtained in BMX-08010-2 under WD condition, whereas the minimum value was recorded in BARI Mung-1 (Table 3). The genotype BMX-08010-2 grown under WW condition produced the highest Chl b, and BARI Mung-1 showed the lowest values. On the other side, the lowest diminishing in Chl b (16.10%) was recorded in BMX-08010-2 under WD condition, while the highest reduction (35.00%) was documented in BARI Mung-1. Moreover, it was also noticed that a higher reduction of the Chl b content over the Chl a was recorded under WD condition.

The chlorophyll a/b ratio showed a considerable dissimilarity among the genotypes of both WW and WD conditions (Table 3). The mung bean genotype BARI Mung-1 showed the highest chlorophyll a/b ratio under control condition. The genotype BMX-08010-2 exhibited the lowest values of chlorophyll a/b ratio. However, a similar observation was also found under WD condition. The increment of chlorophyll a/b ratio with WD stress might be imposed to lower deterioration of Chl a than Chl b under such stress.

The drought stress (DS) reduced higher total chlorophyll content among the entire genotypes. The total chlorophyll content ranged from 2.43 to 3.27 mg g^{-1} FW under WW, and from 1.67 to 2.83 mg g^{-1} FW under WD conditions (Table 3). However, the highest reduction (31.28%) with minimum total chlorophyll content under control and WD condition was documented in the genotype BARI Mung-1 which was followed by BARI Mung-3. In contrast, the genotype BMX-08010-2 showed the lowest reduction (13.46%) due to WD stress showing the highest amount of total chlorophyll content. A reduction of total chlorophyll content under WD condition implies a lowered capability for light absorption. The genotype BMX-08010-2 produced the highest values of Chl a, Chl b as well as total chlorophyll under WD condition than other tested genotypes indicating much capability to uptake water under WD condition which is directly related to producing higher yield (Table 3).

The chlorophyll stability index showed the disparity values among the mung bean genotypes (Fig. 3). However, the genotype BMX-08010-2 showed the highest CSI values (0.87). On the other hand, BARI Mung-1 gave the least value (0.69) under such stage. Furthermore, the BMX-08010-2 genotype gave about 2% higher CSI than BARI Mung-8 and BMX-08009-7, concomitantly 5%, 26%, 23%, 17% and 9% higher than BMX-01015, BARI Mung-1 BARI Mung-3, BU Mung-4, and BMX-05001 genotypes, respectively. This indicates the BMX-08010-2 showed minimum chlorophyll degradation under WD condition than the other genotypes.

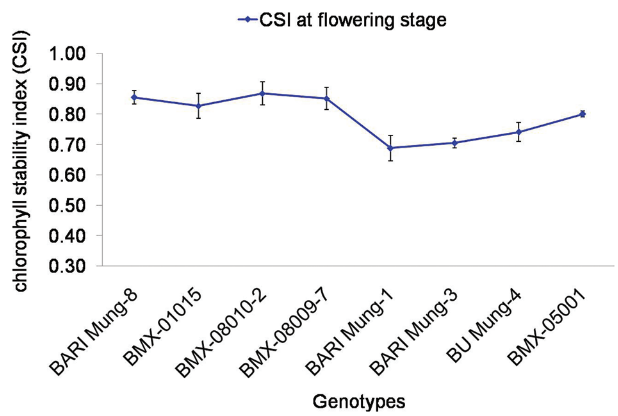

Figure 3: Chlorophyll stability index under two growth stages of selected mung bean genotypes under water deficit and well-watered conditions (Error bars symbolize standard error (±) which fit within the line symbol if not displayed)

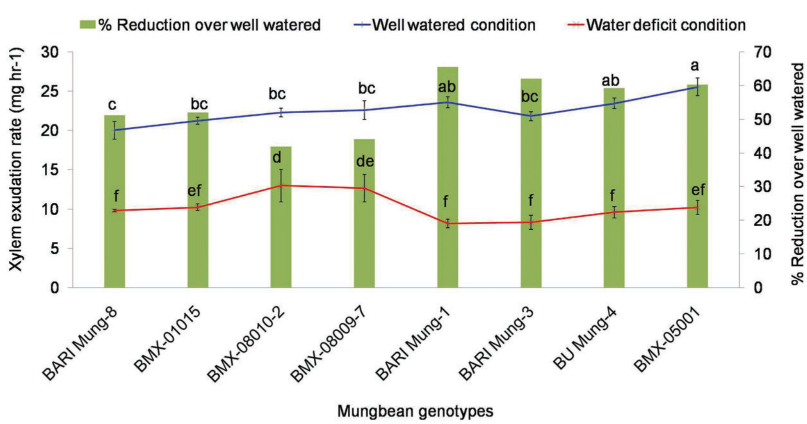

Figure 4: Xylem exudation rate (45 DAS) of selected mung bean genotypes under well-watered (control) and water deficit conditions

3.3 Plant Water Relation

Owing to genetic variation, the dissimilar results of RWC were obtained, and the RWC in the leaves of mung bean genotypes was reduced meaningfully by the WD stress (Table 4). The RWC varied from 78.58% to 84.16%, and 64.04% to 81.37% under WW and WD conditions, respectively. The highest RWC was found in the BMX-0801-2 genotype both under WW and WD conditions, whereas the lowest RWC was observed in

BARI Mung-1 in the same conditions. In case of reduction percentages over control, the BMX-0801-2 showed the minimum reduction (3.32%) of RWC, whereas the maximum reduction (18.50%) was observed in BARI Mung-1. Significantly higher RWC with lower reduction in the genotype BMX-0801-2 at a specific condition of water stress pointed out that it had superior tolerance to drought than BARI Mung-1, and also indicated that the genotype maintained higher amount of water in plant cell.

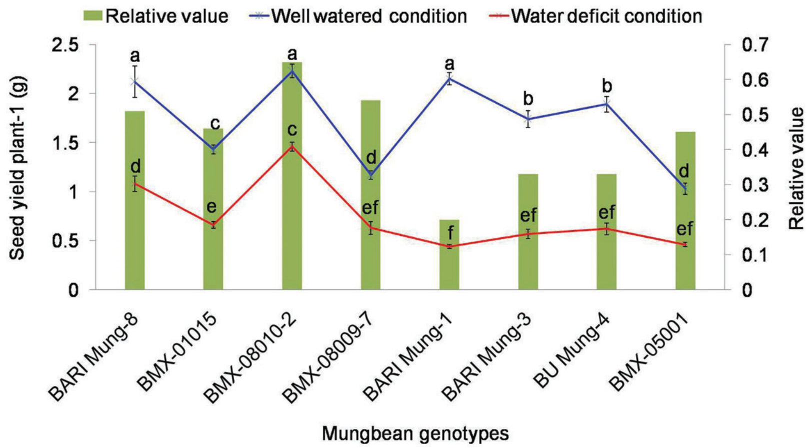

Figure 5: Seed yield (g plant^{-1}) of mung bean genotypes under well water (control) and water deficit conditions

A considerable variation of WSD in the leaves of mung bean genotypes under WD condition was found in this study. The values of WSD ranged from 15.84% to 21.42% under WW, and from 18.63% to 35.96% in WD conditions (Table 4). However, at both WW and WD conditions, the highest WSD was obtained in BARI Mung-1, whereas the least value was found in BMX-08010-2 genotype. At WD stress, the WSD were notably increased more irrespective of all mung bean genotypes as compared to WW condition. The results also revealed that the WSD increased due to WD condition from 17.61%–67.88% over WW, and the genotype BMX-08010-2 showed the minimum increment (17.61%), while the genotype BARI Mung-1 showed the maximum increment (67.88%). A higher WSD indicates that the plants are subjected to a greater degree of water shortage.

The maximum WUC in a plant subjected to a greater degree of water deficit. The WUC of studied mung bean genotypes was greatly influenced by WD stress, and it increased under stress condition. However, it ranged from 2.13 to 2.56 under WW, and from 2.58 to 4.73 under WD conditions (Table 4). The findings revealed that sufficient supply of water (WW) exhibited minimum values of WUC. The genotype BARI Mung-1 showed the highest WUC, while BMX-08010-2 demonstrated the least value under WW and WD conditions. The WUC increased up to 84.77% in BARI Mung-1, whereas the least (21.13%) was in BMX-08010-2 under WD condition as compared to WW condition. These results indicate that BARI Mung-1 suffered more from WD stress than that of BMX-08010-2.

The WRC showed significant variation among the genotypes under WW and WD treatments (Table 4). The decrease of WRC was higher in plants raised under WD stress condition than that in the plants raised under an adequate supply of water (control condition). The present results displayed that the WRC decreased from 8.59% to 28.61% among the studied mung bean genotypes under WD as compared to their WW condition. However, the genotype BMX-08010-2 gave the minimum relative reduction, whereas the genotype BARI Mung-1 gave the maximum relative reduction.

The XER represented the discharge rate of plant cell-sap against gravitational force through the plant xylem vessels that remained higher under WW conditions compared to WD stress (Fig. 4). The diminished value of XER indicates inferior plant water uptake under DS. The XER ranged from 20.00 to 25.53 mg h^{-1} in the WW plants, whereas the corresponding value for WD was 8.13 to 12.97 mg h^{-1}. Moreover, the genotype BMX 05001 gave the highest XER in WW condition. Furthermore, under the WD stress condition, BARI Mung-1 showed the lowest exudation rate with the maximum relative reduction (66%), and BMX-08010-2 demonstrated the highest value with the minimum reduction (42%).

3.4 Yield and Yield Contributing Traits

The pods $plant^{-1}$ is the function of potential yield of any pulse crops. However, the number of pods $plant^{-1}$ was significantly reduced in all the studied mung bean genotypes due to WD stress (Table 5). Under WW condition, the highest number of pods $plant^{-1}$ was found in BARI Mung-8 which was significantly different from other genotypes, while the lowest in BMX-08009-7. At WD stress condition, BARI Mung-8 also showed the maximum pod bearing capacity, at the same time the lowest in BMX-05001. Considering the relative value, it varied among the genotype from 0.51 to 0.76. However, the BMX-08010-2 genotype showed the highest relative value (0.76) followed by BMX-08009-7 (0.75) as compared to others, and BARI Mung-1 demonstrated the lowest relative value (0.51) followed by BARI Mung-3 (0.55).

A remarkable decrease of pod length was observed among the mung bean genotypes under WD stress (Table 5). The genotype BMX-08010-2 produced the longest pod as compared to others both under WW and WD stress. At WD condition, the BARI Mung-1 gave the shortest pod. Regarding the relative performance, the maximum relative value (0.81) was obtained in BMX-08010-2 followed by BMX-08009-7 (0.80), whereas the minimum value (0.68) was in BARI Mung-1.

The number of seeds pod^{-1} in the mung bean genotypes considerably varied due to water deficit condition (Table 5). In WW condition, the highest number of seeds pod^{-1} was observed in the genotype BMX-01015, while the least was observed in BMX-05001. On the other hand, the genotype BMX-08010-2 gave the highest number of seeds pod^{-1} in WD stress condition. The relative values varied from 0.61 to 0.84 among the genotypes, and the highest value was in BMX-08010-2 followed by BMX-08009-7, whereas the lowest relative value was in BARI Mung-1.

Water stress condition remarkably decreased the 100-seed weight among the mung bean genotypes inconsistently (Table 5). The maximum 100-seed weight was recorded in BMX-05001 genotype under both WW and WD conditions. Similarly, BARI Mung-8 genotype gave the minimum 100-seed weight in both conditions. But the BMX-08010-2 genotype performed top by giving the highest relative value (0.89) followed by BMX-08009-7 (0.87). The least relative value (0.65) was observed in BARI Mung-1.

As per the findings of our study, a considerable decline in seed yield was observed in all mung bean genotypes indicating that WD stress imparts a remarkable adverse effect on plant growth (Fig. 5). Under WW condition, the genotype BMX-08010-2 remained unmatched by producing the highest seed yield, whereas the genotype BMX-08010-2 produced the highest seed yield under the WD stress condition. Nevertheless, the rate of decrease over control (relative values) ranged from 0.20 to 0.65 varying with the genotypes. The highest relative value was obtained in genotype BMX-08010-2 followed by BMX-08009-7, and the lowest was in BARI Mung-1. The highest relative values in BMX-08010-2 might be contributed influentially for giving their higher relative seed yield as compared to other genotypes. The canopy, as well as the growth architectural view of the genotypes under WD condition, also indicated that the plant growth appearance of BMX-08010-2 was found superior resulting in higher relative seed yield (Fig. 6), but reverse results were recorded in BARI Mung-1. In addition, Fig. 7 presented the heatmap using hierarchical cluster analysis, and the results underlined different responses of mung bean genotypes to drought among the studied traits. The hierarchical cluster analysis was partitioned into two groups, in which tolerant genotypes were plotted from group I and susceptible genotypes were from group II. Results showed that the genotype BMX-08010-2 was the most stress-tolerant (group I), whereas BARI Mung-1 was susceptible to drought stress (group II). These results reconfirmed the relative WD stress tolerance of BMX-08010-2 among the genotypes.

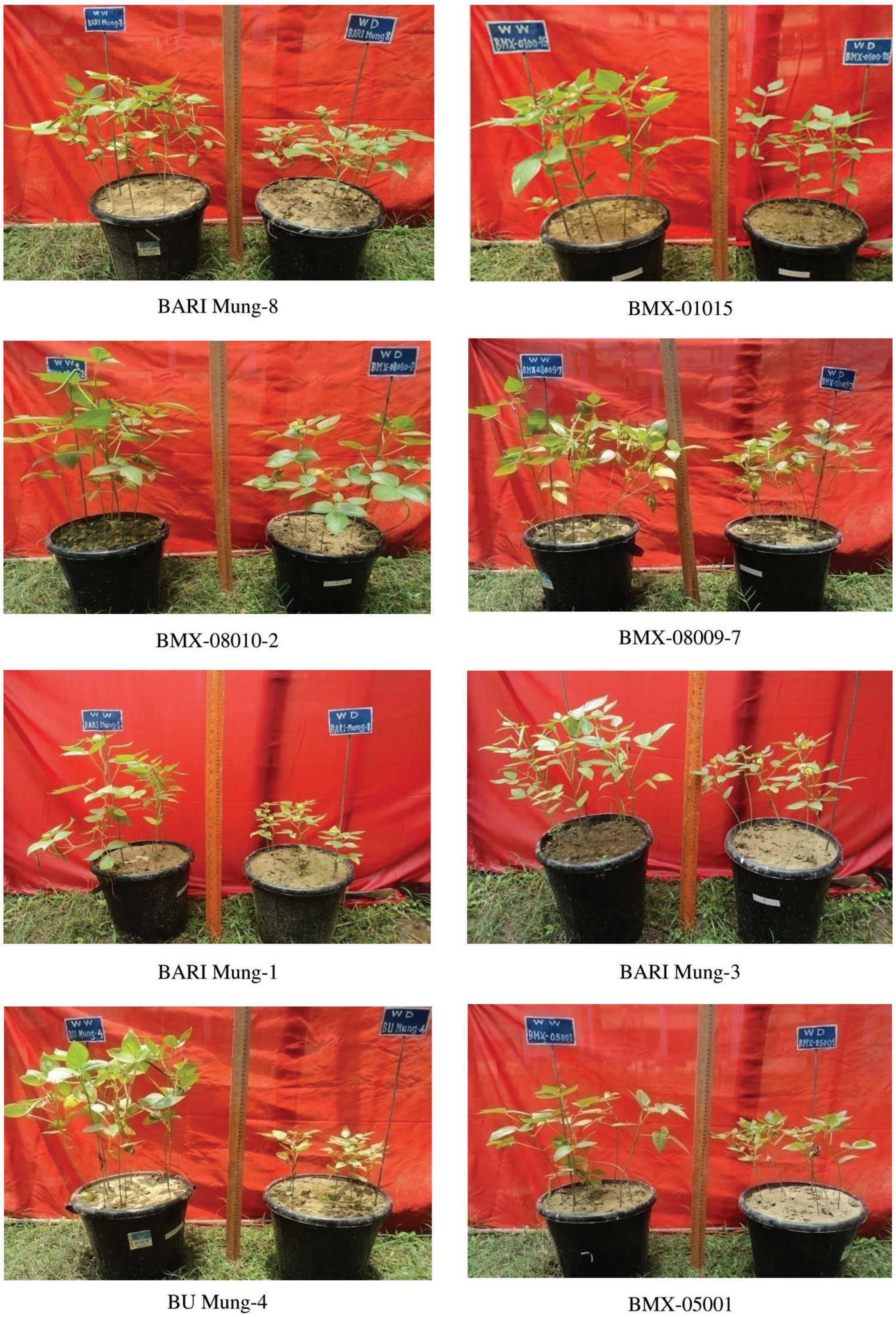

Figure 6: Growth and development of mung bean genotypes under well-watered (WW) and water deficit (WD) conditions

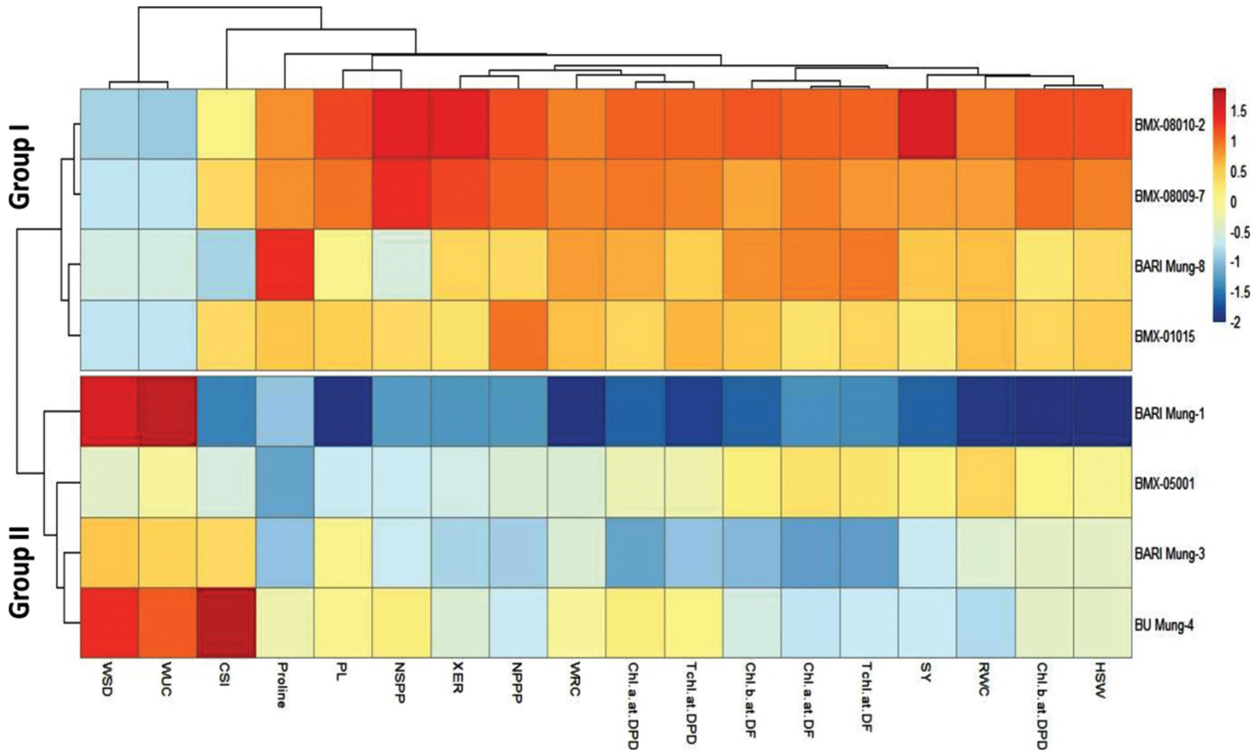

Figure 7: Graphical display of the relationships among the eight investigated mung bean genotypes including drought tolerant and susceptible, and 18 measured traits. Here, relative values obtained from studied traits of the mung bean genotypes were normalized and clustered. Two-row clusters (cluster numbers were determined by the machine language of gap statistic) were obtained at the genotype level. The kinds of colors and color intensity were adjusted supported association among genotypes and traits. These colors are representative of a relative scale (−2 to +1.5) derived after data standardization. The darker blue indicates susceptibility, conversely the darker red indicates tolerance against water deficit stress. WSD = Water saturation deficit; WUC = Water uptake capacity; CSI = Chlorophyll stability index; PL = Pod length; NSPP = Number of seeds pod^{-1}; XER= Xylem exudation rate; NPPP = Number of pods plant^{-1}; WRC = Water retention capacity; Chl = Chlorophyll; Tchl = Total chlorophyll; DF = Days to flowering; DPD = Days to pod development; SY = Seed yield; RWC = Relative water content; HSW = Hundred seed weight

3.5 Assortment of Mung Bean Genotypes Based on Tolerance Indices

The results of stress tolerance indices investigated in this experiment are presented in Table 6. On point of tolerance (TOL) level, the lowest value was observed in the genotype BMX-08010-2. This result indicates that the lesser the TOL value, the lower grain yield reduction under stress conditions, and as a result inferior stress sensitivity. However, the maximum values of TOL and SSI were observed in BARI Mung-1. The highest stress tolerance index (STI) was exhibited in the genotypes BMX-08010-2 followed by BARI Mung-8, whereas the least value was in BARI Mung-1. Based on the STI values recorded in this experiment, the genotype BMX-08010-2 could be considered as relatively the most drought tolerant genotype, whereas BARI Mung-1 remained the most drought susceptible genotype.

Table 6: Tolerance indices of selected mung bean genotypes and under variable water regimes

Genotypes	TOL	SSI	STI
BARI Mung-8	1.96	0.88	0.54
BMX-01015	2.17	0.96	0.33
BMX-08010-2	1.53	0.62	0.73
BMX-08009-7	1.86	0.82	0.32
BARI Mung-1	4.89	1.42	0.22
BARI Mung-3	3.05	1.20	0.29
BU Mung-4	3.05	1.11	0.31
BMX-05001	2.24	0.99	0.23

Note: Where, TOL = Tolerance; SSI = Stress susceptibility index; STI = Stress tolerance index.

4 Discussion

In this study, WD stress significantly changes the physio-chemical mechanism of the mung bean plant, which directly influenced the yield attributes resulting decreased seed yield. The levels of physio-chemical traits *viz*., proline, chlorophylls, RWC, WSD, WUC, WRC and XER under drought stress indicate the stress tolerance of crop plants. So, observation of these traits based on their variability and diversity could be a useful tool for identifying tolerance genotypes.

In our result, the proline accumulation in WD stress was higher than in the WW condition (Fig. 1). This is because of the reduction in the internal water content of the plant under WD condition which could be a reason for decreasing in leaf water potential. Besides, the optimum supply of moisture (WW) exhibited a lower level of free proline content. Genotypes having different levels of drought resistance differ in their capacity to accumulate proline under stress. Accumulation of proline content in the leaf tissues of the BMX-08010-2 genotype was higher under both conditions due to osmoregulation in cells. It also implies that the genotype BMX-08010-2 provided better recovery during stress conditions having its higher proline accumulation indicating more tolerance capacity to the imposed drought and better potential for osmoprotectants. Under prolonged stress conditions, proline acts hard on the yield [42]. A similar result was observed in young bean [43]. These results are also in line with the finding of Ludlow and Muchow [44], who reported higher accumulated proline possibly contributed to osmotic adjustment which plays a major role in maintaining turgor over fluctuating soil water potentials. In contrast, the lowest accumulation of proline in genotype BARI Mung-1 indicates its least potential for osmoprotectants during WD stress. Proline tends to regulate osmotic adjustments, producing several osmoprotectants, scavenging free radicals and antioxidants, and protecting macromolecules from degradation and denaturation. Furthermore, it reduces water losses from the cell under water deficit conditions by regulating cytosolic acidity, and by sustaining a reserve for carbon and nitrogen post-stress [45–49]. Higher proline levels in plants enable the maintenance of higher water potentials which permits the maintenance of water status under a stressful environment; hence it buffers the instant WD effect within the plants [50]. Higher proline accumulation in mung bean genotypes is possibly a constructive adaptive mechanism for overcoming the WD stress effect. Therefore, it is implied that drought-tolerant new mung bean genotype selection based on the higher accumulation of proline is advocated, and it is considered a vital indicator to identify drought-tolerant genotypes [51,52].

Usually, chlorophyll contents act as an important role in photosynthesis, which allow plants to absorb energy from light [53]. It is significantly decreased with increasing the level of drought stress in the plants of mung bean [54], and common bean [55]. However, the downward changes in chlorophyll contents under drought have been responsible for a distinctive indication of oxidative stress, and may be the outcome of pigment photooxidation and chlorophyll degradation [56]. Photosynthetic pigments are chief representatives of mung bean plants under DS conditions as reported by [57]. In this study, WD stress showed a considerable dissimilarity in Chl a, Chl b and chlorophyll a/b ratio at flowering stage (Table 3). The minimum relative reduction of Chl a, Chl b as well as total chlorophyll content was recorded in BMX-08010-2 under WD stress over WW condition, whereas the reverse result was found in BARI Mung-1. It might be owing to the remarkable reduction of the chlorophyllase function in BARI Mung-1 under WD stress situation, and this statement was highlighted earlier [58]. A similar conclusion is urged in a recent study where WD stress remarkably reduced the leaf chlorophyll contents [54,59]. The results are in also accordance with that drought stress significantly decreased the total chlorophyll content in mung bean [60–62]. In the study, a higher value of CSI in BMX-08010-2 in contrast to other genotypes indicated the comparatively superior tolerance to DS which might have been responsible for greater photosynthesis, and finally carrying on higher yield. The least value was found in BARI Mung-1 which might be happened due to early senescence of leaves, and it has been noticed earlier that lower CSI value under stress is a consequence of premature senescence of mung bean leaves [63].

The RWC is an effective measurement tool of the water status in the plant that reflects the metabolic activity in the plants, and is used as a most evocative indicator for stress tolerance [64]. Moreover, when plants were fallen water stress, leaves demonstrate a great reduction in RWC and water potential [65]. Among the studied genotypes, the highest relative reduction of RWC under WD condition was opined in BARI Mung-1, while the least one was in BMX-0801-2. The variation in RWC within genotypes might be imputed to the differences in their potential to survive and adapt under DS conditions [66]. Several researchers also recognized that the reduction of RWC affected the growth and development of crop plants like mung bean [54,67], chickpea [68], soybean [69], wheat [59], foxtail millet and proso millet [70]. The finding of the present study confirmed the above statements and supports the option that the RWC could be used as a pointer to stress tolerance. It is assumed that WD condition reduces the soil water potential ultimately trim downs the RWC by dehydration at a cellular level and also due to osmotic stress. WSD refers to the amount of water shortage in plant parts at an individual condition [71]. The maximum WSD was observed in plants under WD condition, and the highest value of WSD signposts the plants that are facing countless marks of DS [72]. The results exhibited that the genotype BMX-08010-2 displayed the least increment of WSD, while the genotype BARI Mung-1 showed the most increment over WW condition. However, a genotype with a higher deviation of WSD as compared to WW exposed that they suffered severely due to WD stress compared to other genotypes. The present result agrees with the finding of [54,73] in mung bean, and [74] in bush bean who also observed the increasing trends of WSD under WD condition. The WUC represents the efficiency of a plant to uptake water per unit of dry weight at a particular stage. A large amount of WUC indicates that plants absorb a colossal amount of water to reach turgid weight under moisture stress [75]. Under this experiment, the genotype BMX-08010-2 showed the lowest relative increment of WUC, and the highest relative increment was in BARI Mung-1. The highest relative value (% over control) of WUC of a genotype indicated that the genotype suffered more from WD stress than the others, and vice-versa. These results are in concurrence with the previously reported studies for mung bean [54], and bush bean [74], where it was reported that the tolerant genotypes acquired the lowest WUC under DS compared to the susceptible genotypes. The WRC (the proportion of turgid and dry weight) interprets the water holding capacity of a leaf under particular conditions [71]. This ratio is also ascertained by the cell structures [76]. The plant rising under optimal supply of water preserves a more WRC, and it might be due to lesser demolition of plant tissues under DS [75]. Furthermore, a reduction of leaf WRC signposted a shrinkage of cell size [77] that constitutes one of the most general anatomical modifications in leaves under DS [78]. In the present study, plants raised under an optimum soil moisture condition (WW) had a maximum ratio than that of the plant raised under WD stress conditions. However, the minimum relative reduction was obtained in the BMX-08010-2 genotype, and the maximum was in BARI Mung-1. The higher relative reduction of WRC in BARI Mung-1 indicated superior impairment in cell structure due to water deficit stress. Similar results were observed earlier with mung bean [54], and black gram [75,77]. The decrease in the leaf WRC could be the outcome of hemicellulose and cellulose derivatives in the cell [79]. An adequate supply of water (WW) also helps to repair damaged cells of plants as well as enhanced the WRC of plants. The XER can be used as an effective tool to determine the intensity of water stress. Our findings reveal that BARI Mung-1 passes through more water stress compared to that of BMX-08010-2 due to a decline of XER under WD stress resulting in lower uptake of water in the plant. This result is in agreement with the findings of [54] in mung bean, and [80] in wheat, who found a reduction of water uptake in the plant due to WD stress. The traits RWC and XER are also directly related to the flow of the transpiration stream [75]. Under WD stress condition, the soil moisture can be expected to be lower in different growth spans (Fig. 1), which affected the growth and development of plants especially produced lower branches, ultimately produced a little number of pods plant^{-1}, and finally decreasing grain yield. The results pointed out that BMX-08010-2 and BMX-08009-7 exposed lower stress injury as compared to BARI Mung-1 and BARI Mung-3 with the relative number of pods plant^{-1}. The present result which is the diminishing in the number pods plant^{-1} due to water stress is consistent with the findings in French bean [81,82], soybean [83,84], cowpea [85], pigeonpea [86], faba bean [87], and mung bean [73]. Moreover, the reproductive stage under water stress maximized the number of aborted flowers, and decreased the number of pods plant^{-1} in common bean [88]. A similar outcome could be projected for mung bean [89]. The pod length is an important parameter, which significantly influences the grain yield of mung bean. Stunted pod length under WD condition reduced the number of seeds pod^{-1} resulting reduced total yield. This result supports the findings in soybean [90], and mung bean [91]. The findings of the study pointed out that the genotypic differences appeared in the number of seed pod^{-1} under WD conditions. Nonetheless, drought-induced by water stress decreased the number of seeds pod^{-1} in faba bean [87], and snap bean [81]. Earlier results also reported that the number of pods plant^{-1}, and the number of seeds pod^{-1}, might be reduced due to the decrease in pollen fertility under DS [81]. The BMX-08010-2 genotype produced the highest relative value of the 100-seed weight, and the lowest was found in BARI Mung-1. Flowering and seed formation phases might be the sensitive periods for soil moisture in leguminous crops which affect 100-seed weight [92]. A similar trend was found in the case of seed yield plant^{-1}, indicating the genotype BMX-08010-2 was the most WD stress tolerant, while BARI Mung-1 was the most sensitive genotype to water stress. The previous study reported that the mung bean yield reduced to 64% and 34% due to the imposition of WD stress of 75% and 50% of field capacity, respectively [93]. The results of the present study were also closely in agreement with the findings obtained in mung bean [54,94], faba bean [87] and common bean [88], who reported that WD stress severely declined the grain yield when it imposed at reproductive stage, particularly at flowering and pod formation stages. Earlier studies also depicted that the decreased number of pods plant^{-1} under drought stress was owing to an increased rate of abortion of reproductive organs resulting in lower seed yield [84,95–97].

There were several tolerance indices that have predicted from the yield data of WW and WD conditions with a specific genotype, and they also indicating the susceptibility and tolerance of a genotypes. The TOL, SSI and STI are some of them. The lower value of TOL indicating the reduction of grain yield under stress condition, and categorized as stress sensitivity. The SSI also succeeded the trend as like as TOL in the same genotypes. The value of SSI is lower than 0.5 (<0.5) indicates the crop is highly tolerant to WD stress or very low drought susceptibility or higher yield stability, if SSI greater than 0.5 but less than l.0, then it is moderately tolerant, and values are higher than 1 (>1.0) signify susceptible to water stress or poor yield stability [36]. A higher STI value for a genotype is an indicator of greater drought tolerance, and the potential yield for that genotype [98]. In our study, BMX-08010-2 genotype showed the lowest TOL and SSI value along with the highest STI, and could be considered as drought tolerant genotype, whereas reverse result found in case of BARI Mung-1.

5 Conclusions

Accordance to the results, the BMX-08010-2 performed as the most drought tolerant genotype of mung bean due to higher proline accumulation, plant water status, relative performances of yield traits, STI, and less degradation chlorophyll contents and lower yield penalty under WD conditions than other genotypes, whereas BARI Mung-1 showed the most drought susceptible genotype generating reverse values of the traits. Therefore, BMX-08010-2 could be advocated for further varietal improvement programs in water-deficient farming areas.

Acknowledgement: The authors extend their appreciation to the Researchers Supporting Project No. (RSP-2021/298), King Saud University, Riyadh, Saudi Arabia. The author is highly thankful to the Head and lab Technicians, Department of Agricultural Chemistry, HSTU, Dinajpur, for providing laboratory facilities for chemical analysis of the plant samples. The author wishes to express special thanks to Hassan Nuur Ismaan, Md. Obaidullah Shaddam and Eunis Ali of Ex-MS student in the Department of Agronomy, HSTU, Dinajpur for their help for sample collection, data recording and biochemical analysis of experimental samples during the research. Finally, the author is very gratitude to the authority of Bangladesh Agricultural Research Institute (BARI) for granting the scholarship and allowing him leave for completion of the study.

Funding Statement: The authors extend their appreciation to the researchers Supporting Project No. (RSP-2021/298), King Saud University, Riyadh, Saudi Arabia.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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Supplementary Table 1: Effect of genotypes and stress levels on proline, chlorophyll content and plant water status of mungbean

Treatments	Proline content (mg/g FW^{-1}) at flowering stage (45 DAS)	Chlorophyll content (mg g^{-1} FW) at flowering stage (45 DAS)			RWC	WSD	WRC	WUC	XER
		Chl a	Chl b	Total Chl					
Mungbean genotypes									
BARI Mung-8	1.51c	1.85ab	0.94c	2.79b	79.58bcd	20.43bcd	13.08abc	2.57c	14.88b
BMX-01015	1.44c	1.80bc	0.90c	2.70bc	79.69bc	20.31cd	12.74bc	2.49c	15.72ab
BMX-08010-2	3.40a	1.97a	1.09a	3.05a	82.76a	17.24e	14.36a	2.35c	17.62a
BMX-08009-7	2.68b	1.90ab	0.98b	2.88ab	81.01ab	18.99de	13.85ab	2.50c	17.60a
BARI Mung-1	0.69e	1.39e	0.66e	2.05e	71.31e	28.69a	12.15c	3.64a	15.85ab
BARI Mung-3	0.87d	1.63d	0.81d	2.44d	76.57d	23.43b	12.73bc	2.98b	15.05b
BU Mung-4	0.85d	1.69cd	0.83cd	2.52cd	77.52cd	22.48bc	14.37a	3.23b	16.50ab
BMX-05001	0.97d	1.67d	0.84cd	2.51d	79.13bcd	20.87bcd	14.13a	2.93b	17.85a
LSD (5%)	0.16	0.13	0.04	0.18	3.07	3.07	1.31	0.35	2.27
CV (%)	8.17	5.91	3.43	5.62	3.16	11.45	7.89	9.88	11.19
SL	***	***	***	***	***	***	*	***	*
Stress levels									
Well water (WW)	0.42b	1.92a	1.00a	2.91a	81.82a	18.18b	14.53a	2.32b	22.55a
Water stress (WD)	2.68a	1.56b	0.76b	2.32b	75.08b	24.92a	12.32b	3.35a	10.22b
LSD (5%)	0.06	0.06	0.02	0.08	1.13	1.13	0.35	0.17	0.91
CV (%)	6.46	5.50	3.21	4.68	2.35	8.55	4.21	9.66	9.05
SL	***	***	***	***	***	***	***	***	***

Note: Where, LS = Level of significance; *significant at $P = 0.05$; ***significant at $P = 0.001$; RWC = Relative water content; WSD = Water saturation deficit; WRC = Water retention capacity; WUC = Water uptake capacity and XER = Xylem exudation rate; DAS = days after sowing; Chl = Chlorophyll.

Supplementary Table 2: Effect of genotypes and stress levels on yield contributing traits and seed yield of mungbean

Treatments	Number of pods plant^{-1}	Pod length (cm)	Number of seeds pod^{-1}	100-seed weight (g)	Seed yield plant^{-1} (g)
			Mungbean genotypes		
BARI Mung-8	6.51a	4.25c	4.96b	2.47d	1.60b
BMX-01015	4.94d	4.90b	5.96a	3.51b	1.05e
BMX-08010-2	5.75b	5.21a	5.75a	3.50b	1.85a
BMX-08009-7	4.14e	4.24c	3.84cd	3.78b	0.90f
BARI Mung-1	5.46bc	4.47c	4.90b	2.84c	1.31c
BARI Mung-3	5.83b	4.79b	3.65de	3.51b	1.16de
BU Mung-4	4.95cd	4.92ab	4.11c	3.62b	1.25cd
BMX-05001	4.29e	4.44c	3.31e	5.25a	0.73g
LSD (5%)	0.52	0.29	0.41	0.37	0.14
CV (%)	7.95	5.07	7.24	8.28	8.99
SL	***	***	***	***	***
			Stress levels		
Well water (WW)	6.40a	5.28a	5.31a	3.95a	1.72a
Water stress (WD)	4.07b	4.02b	3.81b	3.17b	0.74b
LSD (5%)	0.23	0.10	0.24	0.13	0.08
CV (%)	7.15	3.33	8.41	6.02	9.97
SL	***	***	***	***	***

Note: Where, SL = Significance level; ***significant at $P = 0.001$.