Research article

Ecology Journal

ISSN (Print): 2957-4471, ISSN (Online): 2957-448X, Website: https://journal.esbangladesh.org
Ecol. J. (2023) 5 (1) : 37-47

GROWTH AND YIELD VARIATIONS IN MUNGBEAN VARIETIES UNDER WATER STRESS

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Received: 5 May 2023, revised: 25 May 2023, accepted: 30 May 2023, DOI: https: //doi.org/10.59619/ej.5.1.6

ABSTRACT

Mungbean [*Vigna radiata* (L)], an important grain legume in Bangladesh, is grown during kharif1 (pre-monsoon) season, when drought is a common abiotic stress. This study was thus conducted in pots inside semi-controlled vinylhouse to assess the effect of water stress on growth and yield of some popular mungbean varieties, viz. BUmug 2, BUmug 4, BARI Mung-5, BARI Mung-6, Binamoog-5 and Binamoog-8. Two water regimes, 80% field capacity (FC; non-stress) and 50% FC (water stress) were maintained. The experiment was laid out in a completely randomized design having four replications. Under water stress the variety Binamoog-5 had the largest leaf area (850.4 cm^2), while BUmug 4 had the smallest (695.1 cm^2). At maturity the reduction of shoot dry weight due to water stress was the highest in BUmug 4 (20.6%) while that was the lowest in Binamoog-5 (12.5%). The highest reduction of pod number due to water stress was recorded in BUmug 4 (45.1%) and the lowest was in Binamoog-5 (32.9%) followed by Binamoog-8 (34.5%). The highest reduction in seed number pod^{-1} due to water stress was in BUmug 4 (21.8%) and the lowest was in Binamoog-5 (16.79%). Water deficit did not exert significant effect on 100-seed weight in the varieties except BUmug 4. Binamoog-5 had the maximum yield $plant^{-1}$ under both control (12.8 g) and water deficit (7.4 g) conditions followed by Binamoog-8, while BUmug 4 had the lowest in both control (11.6 g) and water deficit (6.3 g) conditions. It was concluded that Binamoog-5 and Binamoog-8 can be potential varieties for field trial under water deficit conditions.

Keywords: Morphology; growth parameters; *Vigna radiate*; water stress, yield components

Introduction

Water stress is one of the most devastating agricultural problems in the world for crop production (He *et al.* 2018). However, plant responses to water scarcity differ based on the severity of the stress and the developmental stage at which the plant is under stress (Kareem *et al.* 2019). Water stress has multidimensional complexity, such as disturbance in physiological, morphological, biochemical, and molecular states which govern the growth, development, and economic yield of a crop (Basu *et al.* 2016). According to Srivalli *et al.* (2003) water stress disturbs normal turgor pressure, and the loss of cell turgidity may stop cell enlargement resulting in reduced plant growth. Water stress was also reported to decrease plant water status, photosynthetic pigment and membrane stability index, and increased proline and soluble sugar content in mungbean (Islam *et al.* 2021).

Mungbean (*Vigna radiata* L.) is the third most important grain legume after chickpea and pigeon pea, and is widely grown in the Asian countries. It has a wider adaptability and low input requirement and is grown mainly in rain-fed conditions at relatively high temperature (27–30 °C), with low humidity and moderate rainfall ranging from 60 to 80 cm (Bangar *et al.* 2019). It is a self-pollinating, fast-growing, short-duration crop that contributes to increased cropping intensity and total production (Singh *et al.* 2016). It also improves soil fertility and productivity by fixing atmospheric nitrogen into the soil via symbiosis with Rhizobium (Lindström and Mousavi 2020). Despite an economically important crop, the productivity of mungbean is stagnant due to various biotic and abiotic stresses (Basu *et al.* 2019). Among the abiotic stresses, drought is the most limiting factor for mungbean cultivation (Singh *et al.* 2021). Persistent exposure of mungbean to water stress modifies the plant's morpho-physiological, biochemical,

and molecular responses, thereby impacting a variety of processes such as growth, yield, and quality. Drought stress also affects the nutrients uptake by affecting root growth (Bista *et al.* 2018). However, mungbean varieties respond differently to drought stress depending on the duration of the stress, crop growth stage and genetic potential (Bangar *et al.* 2019).

In Bangladesh mungbean is grown in kharif1 (pre-monsoon) season when drought along with high temperature is a common climatic phenomenon. However, there is a lack of comprehensive study to recommend a suitable drought tolerant varieties for cultivation by the farmers. This experiment was therefore carried out to select a suitable mungbean variety for growing under water deficit conditions.

Materials and Methods

A pot experiment was carried out in a Vinylhouse of the Departemnt of Agronomy, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur. The soil used in the pot belongs to Salna series of Shallow Red-Brown Terrace soil type (AEZ 28) with a silty clay in surface and silty clay loam in sub-surface region (Brammer 1971). The experimental site is situated in the sub-tropical region characterized by heavy rainfall during the months from July to September and scanty or no rainfall in the rest of the year. Plastic pots of 30 cm diameter and 24 cm height were used in the experiment that were filled with 14 kg air-dried soil with a mixture of soil and cowdung at a ratio of 4:1. The pot soil was fertilized with 0.20g, 0.80g, 0.40g and 0.20g of Urea, TSP, MoP and Gypsum @) 15.5-25.5-30.5-15.5 kg N-P-K-S ha^{-1}, respectively (FRG 2012). All the fertilizers except half of the urea were applied as basal and rest half of urea was applied at 25 days after emergence (DAE). The experiment was laid out in a factorial Completely Randomized Design (CRD) with four replications. The treatment variables were: (i) non-stress (80% of field capacity) (T_1) and (ii) water stress (50 % of field capacity) (T_2), and five cowpea varieties, namely BUmug 2 (V_1), BUmug 4 (V2), BARI mung-5 (V3), BARI mung-6 (V_4), Binamoog-5 (V_5) and Binamoog-8 (V_6).

Pre-soaked six healthy seeds were sown in a pot by hand and covered with soil by hand. After sowing of seeds light irrigation was given to ensure uniform germination of seeds. Seedlings were thinned out after one week of emergence keeping two healthy seedlings of uniform growth in each pot. Water stress treatments were imposed at 18 DAE, after completely 1st trifoliate development. One day before treatment imposition, 500 ml of water was applied to each pot to maintain similar soil moisture content in all the pots. Water stress condition was induced by withholding water until wilting symptom was observed in plants. In control treatment, water was applied to maintain moisture of 80% of field capacity when it was needed. In water stress treatment the moisture was maintained at 50% filed capacity. Intercultural operations were done uniformly in each pot to ensure normal growth of the crop. The crop was harvested when the plants attained full maturity. The plant was cut at the soil surface level then threshing, cleaning and drying of seed were done separately. The weight of seed and pod wall were recorded pot wise and adjusted at 12% moisture content.

The data on different parameters were recorded from two plants of each replication on plant height, number of leaves, dry matter of different plant parts, yield and yield components. Plant height was recorded from four selected plants at 28, 35, 42, 49 56 and 63 DAE and at final harvest (70 DAE). Pods $plant^{-1}$, seeds pod^{-1}, 100-seed weight and grain yield $plant^{-1}$ were collected after harvest. Seed weight was adjusted at 12% moisture content as follows:

$$\text{Seed yield at 12\% MC (g plant}^{-1}) = \frac{100 - \text{Sample MC}}{100 - 12\%} \times \text{fresh weight of seed}$$

The harvest index (HI) was calculated by dividing the economic yield by the biological yield of each plant.

$$HI\ (\%) = \frac{\text{Seed yield at 12\% moisture}}{\text{Total dry matter weight}} \times 100$$

Different plant growth parameters were calculated following Gardner *et al*. (1985), such as

$$\text{Crop Growth rate (CGR) PGR} = \frac{W_2 - W_1}{T_2 - T_1}\ g\ plant^{-1}\ day^{-1}$$

Where,
W_1 = Dry weight at time T_1 (g)
W_2 = Dry weight at time T_2 (g)

Relative growth rate (RGR):

$$RGR = \frac{(\log_e W_2 - \log_e W_1)}{W_1 (T_2 - T_1)}\ (g\ g^{-1} day^{-1})$$

Where,
W_1 = Dry weight of plant at time T_1
W_2 = Dry weight of plant at time T_2

Net assimilation rate (NAR):

$$NAR = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1}\ (g\ m^{-2} day^{-1})$$

Where,
W_1 = Dry weight of plant at time T_1 (g)
W_2 = Dry weight of plant at time T_2 (g)
L_1 = Leaf area at time T_1 (m^2)
L_2 = Leaf area at time T_2 (m^2)

Reduction percentage of yield due to water stress was calculated following Choukan *et al*. (2006) as follows:

$$\%\ \text{Reduction} = \frac{Y_P - Y_S}{Y_P} \times 100$$

Where, Yp is the yield under non-stress condition and Ys the yield under stress.

The data were analyzed by MSTAT-C statistical package program. The difference between the treatments means were compared by least significant difference (LSD) test. Functional relationships among different parameters as affected by water stress were established by using Excel program.

Results and Discussion

Morphological Characters: Water stress had an adverse effect on morphological characteristics such as plant height, number of leaves, leaf area and the root and shoot ratio (Table 1). As expected, the plants under non-stress were taller than those under water stress both at pre-flowering and maturity stages. Plant height during pre-flowering stage varied from 31.9 to 34.7 cm and from 27.4 to 31.8 cm, respectively in control and water deficit conditions.

The tallest plants were recorded in variety BARI mung-6 and Binamoog-5 (34.7 cm), respectively whereas the BUmug 4 was the shortest (31.9 cm) in control condition. Under water deficit condition, Binamoog-5 had the highest plant height (31.9 cm) whereas the lowest was in BUmug 4 (27.4 cm). The plant height reduced the least in Binamoog-5 (8.1%), while the highest reduction was in BUmug 2 (13.7%). Plant height at maturity ranged from 58.9 to 63.4 cm and from 51.9 to 56.1 cm, respectively in control and water deficit condition, respectively. In control conditions, BUmug 2 (63.4 cm) was the tallest and BARI mung-5 (58.9 cm) was the shortest. The tallest plant in a water deficit environment was Binamoog-5 (56.1 cm), whereas BARI mung-5 had the least plant height (51.9 cm). The lowest plant height reduction was found in Binamoog-5 (10.1%), and the largest was in BUmug 4 (15.9%). The reduction of plant height in mungbean varieties due to water stress was probably associated with the reduced relative turgidity and protoplasmic dehydration, which are linked to decreased cell expansion and cell division as reported by Hussain *et al.* (2008) and Bangar *et al. (*2019).

Water deficit stress reduced leaf number in plant significantly in all the six varieties (Table 1). At pre-flowering stage the leaf number varied from 9.3 to 10.0 and from 7.0 to 9.0 under control and water stress, respectively. Binamoog-5, Binamoog-8, BARI mung-6, and BARI mung-5 had the similar and highest number of leaves (10) under control conditions, whereas Binamoog-5 and Binamoog-8 had the highest (9.0) under stress conditions.

The reduction was the greatest in BUmug 4 (24.3%), which was similar to BUmug 2, while the lowest was

in Binamoog-5 (10.0%), which was at par with Binamoog-8. In control and water shortage situations the leaf number at maturity stage varied between 10.3 and 10.8 and 8.3 and 9.0, respectively. The variety BUmug 4 had the greatest reduction in leaf number (19.5%), followed by BUmug 2 and BARI mung-5 (17.1%), while Binamoog-5 and BARI mung-6 had the lowest reduction (13.9%) (Table 1). Earlier reports indicated that drought stress affects leaf number production through its effect on initiation of new leaves, leaf senescence and finally death of leaf tissues, resulting in leaf dropping (De Souza *et al*. 1997, Kumari and Chakraborty 2019).

Leaf area varied markedly among varieties both in control and water deficit conditions over the different stages. At the pre-flowering stage, the variety Binamoog-5 had the most leaf area under control (710.5 cm^2) and water deficit conditions (659.5 cm^2), while BUmug 4 had the lowest leaf area under control (623.70 cm^2) as well as water deficit conditions (518.8 cm^2). The varieties BUmug 4 showed the greatest drop in leaf area (16.8%), whilst Binamoog-5 showed the least (11.4%). At maturity, the variety Binamoog-5 (994.6 cm^2) displayed the largest leaf area, while the lowest leaf area was found in BUmug 4 (869.1 cm^2) in the control condition. Under water stress the variety Binamoog-5 had the largest leaf area (850.4 cm^2), followed by Binamoog-8 (830.0 cm^2), while BUmug 4 had the smallest leaf areas (695.1 cm^2). The varieties BUmug 4 had the greatest reduction in leaf area $plant^{-1}$ (20.0%), whereas Binamoog-5 had the lowest (14.5%). Leaf area expansion is often limited under drought stress mostly due to imbalance in water relation that decreases the expansion and development of the transpiration surface (Rucker *et al*. 1995, Mondal *et al.* 2012).

In all the six varieties the water shortage enhanced the root: shoot ratio at both the pre-flowering and maturation stages compared to the control condition. Root: shoot ratio ranged from 0.09 to 0.11 at the pre-flowering stage and from 0.12 to 0.14 at maturity in control and water shortage conditions, respectively (Table 1). The cultivar BUmug 4 had the highest root

Table 1. Morphological characters as influenced by water stress at pre-flowering and maturity stages of six mungbean varieties

Variety	Plant height (cm)				Number of leaves $plant^{-1}$				Leaf area (cm^2 $plant^{-1}$)				Root: shoot ratio			
	PF stage		Maturity stage		PF stage		Maturity stage		PF stage		Maturity stage		PF stage		Maturity stage	
	control	water stress	control	water stress	control	water stress	control	water stress	control	water stress	Control	water stress	control	Water stress	control	water stress
BUmug 2	32.6	28.2 (13.7)	63.4	53.6 (15.4)	9.3	7.0 (24.3)	10.3	8.5 (17.2)	651.1	548.8 (15.7)	888.3	722.5 (18.7)	0.10	0.14 (22.9)	0.056	0.07 (21.4)
BUmug 4	31.9	27.4 (14.3)	62.9	52.8 (15.9)	9.3	7.0 (24.3)	10.3	8.3 (19.5)	623.7	518.8 (16.8)	869.1	695.1 (20.0)	0.11	0.14 (22.6)	0.06	0.07 (23.3)
BARI mung-5	33.8	29.8 (11.9)	58.9	51.9 (11.8)	10.0	8.3 (17.5)	10.3	8.5 (17.1)	671.7	581.9 (13.4)	927.8	775.1 (16.5)	0.10	0.13 (24.6)	0.05	0.07 (20.9)
BARI mung-6	34.7	30.6 (11.9)	59.3	53.2 (10.4)	10.0	8.3 (17.5)	10.8	9.3 (13.9)	697.0	604.4 (13.3)	948.4	794.5 (16.2)	0.09	0.12 (25.6)	0.05	0.06 (21.5)
Binamoog-5	34.7	31.9 (8.1)	62.4	56.1 (10.1)	10.0	9.0 (10.0)	10.8	9.3 (13.9)	710.5	659.5 (11.4)	994.6	850.4 (14.5)	0.09	0.12 (26.5)	0.05	0.07 (27.3)
Binamoog-8	34.5	31.3 (9.4)	62.9	55.9 (11.2)	10.0	9.0 (10.0)	10.8	9.0 (16.3)	708.0	614.1 (13.3)	987.8	830.0 (15.9)	0.09	0.12 (23.3)	0.05	0.06 (23.8)
CV (%)	7.8		9.9		7.7		9.1		5.8		9.8		5.8		6.6	
LSD(0.05)	0.8		1.6		0.4		0.7		8.7		10.2		0.02		0.02	

PF stage: Preflowering stage; CV: coefficient of variations; LSD: Least significance difference at 5%. Values in parenthesis indicate percent reduction compared to the control.

to shoot ratio (0.11 and 0.14) under both non-stress and water shortage conditions, respectively. At the pre-flowering stage, Binamoog-5 (26.5%) had the highest increases in root: shoot ratio, while BUmug 4 (22.6%) had the lowest. At maturity, BUmug 4 also had the highest root: shoot ratio under both the control (0.56) and water shortage condition (0.07). The rise in the root-to-shoot ratio was the largest in Binamoog-5 (27.3%). According to Aslam *et al.* (2013) a decrease in the root: shoot ratio due to water shortage indicated a lower root growth, whereas an increase in the root: shoot ratio reflected the enhanced root extension relative to shoot to reach to deeper soil to absorb water. The increase in root: shoot ratio in mungbean due to PEG induced drought stress was also found under laboratory conditions by Imtiaz *et al.* (2020).

Dry Matter Partitioning: Water stress at pre-flowering and maturation stages in mungbean significantly enhanced root dry matter (Table 2). At pre-flowering stage root dry weight plant^{-1} ranged from 0.48 to 0.52 g, and from 0.52 to 0.62 g cm in control and water deficit conditions, respectively. In the control condition, Binamoog-8 had the highest root dry weight (0.52 g) and BUmug 4 had the lowest (0.47 g). Under water stress Binamoog-5 had the highest root dry weight (0.62 g), whereas BUmug 4 had the lowest (0.52 g). The increase in root dry weight was maximum in Binamoog-5 (17.7%), whereas BUmug 4 had the lowest (9.6%). BARI mung-6 had the maximum root weight at maturity (0.91 g), whereas BUmug 2 had the lowest (0.85 g) under non- stress condition. Under water deficit condition, Binamoog-5 had the highest root dry weight (1.02 g), whereas BUmug 4 and BU mug 2 had the lowest (0.89 g). The highest increase in root dry weight was observed in Binamoog-5 (11.8%), while the lowest was observed in BUmug 4 (3.4%). Similar findings were found by Kumar and Sharma (2009) who stated that drought-induced plants exhibited increased root growth as a result of extensive conversion of dry materials to roots.

Water stress significantly reduced leaf dry matter at both the pre-flowering and maturity stages (Table 2). In control and water stress conditions, leaf dry weight

Table 2. Dry matter partitioning at pre-flowering and maturity stages as affected by water stress of six mungbean varieties

Variety	Root dry weight ((g plant^{-1})				Leaf dry weight (g plant^{-1})				Stem dry weight (g plant^{-1})			
	PF stage		Maturity stage		PF stage		Maturity stage		PF stage		Maturity stage	
	control	water stress	control	Water stress	control	water stress	control	water stress	Control	water stress	control	water stress
BUmug 2	0.48	0.54 (11.1	0.85	0.89 (4.5)	2.6	2.26 (13.1)	3.2	2.8 (14.3)	1.4	1.3 (13.2)	3.2	2.8 (12.9)
BUmug 4	0.47	0.52 (9.6)	0.86	0.89 (3.4)	2.7	2.21 (17.8)	3.2	2.6 (16.5)	1.4	1.2 (16.6)	3.1	2.7 (14.5)
BARI mung-5	0.49	0.57 (14.0)	0.90	0.95 (5.3)	2.9	2.54 (12.1)	3.5	3.1 (11.7)	1.7	1.5 (11.2)	3.5	3.1 (12.0)
BARI mung-6	0.50	0.59 (15.3)	0.91	0.98 (7.1)	3.1	2.8 (10.9)	3.8	3.4 (10.4)	1.8	1.6 (11.5)	3.7	3.3 (10.9)
Binamoog-5	0.51	0.62 (17.7)	0.90	1.02 (11.8)	3.3	2.9 (8.6)	3.9	3.6 (7.5)	1.9	1.7 (10.5)	3.7	3.4 (8.6)
Binamoog-8	0.52	0.61 (14.8)	0.87	0.96 (9.4)	3.2	2.9 (10.6)	3.7	3.4 (9.4)	1.9	1.7 (11.1)	3.6	3.3 (9.9)
CV (%)	6.8		8.7		8.1		6.90		6.6		9.8	
LSD(0.05)	0.02		0.01		0.05		0.09		0.01		0.05	

PF stage: Preflowering stage; CV: coefficient of variations; LSD: Least significance difference at 5%. Values in parenthesis indicate percent reduction compared to the control.

plant^{-1} varied from 2.2 g to 2.9g at pre-flowering stage. Binamoog-5 showed the highest leaf weight under control (3.3g) and water deficit conditions (2.9 g), whereas BUmug 4 recorded the lowest leaf weight under control (2.7g) and water deficit conditions (2.2g), respectively (Table 2). Leaf dry weight was reduced under water deficit condition where BUmug 4 experienced the most drop (17.8%) and Binamoog-5 had the least reduction (8.6%). Binamoog-5 showed the largest leaf dry weight at maturity (3.9 g) and (3.6 g), while BUmug 4 showed the lowest (3.2 g) and (2.64 g) in control and water shortage conditions, respectively. Water deficit stress mostly reduces leaf growth due to suppression of cell expansion and cell growth due to loss of turgor (Zhang *et al*. 2008).

Water stress also decreased stem dry weight in all the varieties at both the pre-flowering and maturation stages (Table 2). At the pre-flowering stage the highest and lowest stem dry weights under control and water stress conditions were observed in Binamoog-5 (1.9 and 1.7 g) and BUmug 4 (1.4 and 1.2 g), respectively. The higher reduction in stem dry weight was observed in BUmug 4 (16.6%) and the lowest was in Binamoog-5 (10.5%). At mature stage, variety Binamoog-5 had the highest stem dry weight plant^{-1} (3.7 g and 3.4 g) and BUmug 4 had the lowest (3.1 g and 2.7 g) under control and water deficient conditions. The reduction percentage was the highest in BUmug 4 (14.5%) and the lowest in Binamoog-5 (8.6%). The decrease in stem dry weight in water deficit condition might be due to less photoassimilate translocation towards the stem, and similar to this finding a decrease in shoot dry weight in mungbean due to water stress was also reported by (Kumari and Chakraborty 2019).

Petiole dry matter considerably decreased at both the growth stages in all the mungbean varieties (Table 3). The cultivar Binamoog-5 had the highest petiole dry weight plant^{-1} (0.6 g) in the control condition, while BUmug 4 had the lowest value (0.43 g) under the water stress. At the pre-flowering stage, Binamoog-5 had the lowest reduction of petiole dry matter (9.8%). At maturity stage, the highest petiole dry weight plant^{-1} was recorded in variety Binamoog-5 and Binamoog-8 (0.63 g) in non-stress, and under water stress condition the lowest value was found in BUmug 4 (0.45 g). Under water stress, Binamoog-5 (9.52%) showed the lowest drop in petiole dry weight.

Shoot dry weight plant^{-1} ranged from 4.6 g to 5.8 g and from 3.8 g to 5.2 g in control and water deficit condition, respectively at pre-flowering stage (Table 3). Variety Binamoog-5 had the highest shoot dry matter (5.8 g and 18.4 g) under control conditions, while BUmug 4 had the lowest (3.8 g and 12.2 g) under conditions of water deficit at pre-flowering and maturity stages respectively. BUmug 4 had the maximum decrease of shoot dry matter (17.8%), however Binamoog-5 and Binamoog-8 had the lowest reductions (9.4% and 10.8%) under non-stress conditions. On the other hand, under water stress, at maturity, the reduction of shoot dry weight was the highest in BUmug 4 (20.6%) and the lowest in Binamoog-5 (12.5%). The result of the study was in accordance with that of Ranawake *et al.* (2011) who stated that as water stress increased, the shoot dry matter was progressively reduced in mungbean.

Total dry matter significantly differed at the both growth stages under control and water stress (Table 3). At the pre-flowering stage, total dry matter accumulation plant^{-1} ranged from 5.1 to 6.3 g, and from 4.3 to 5.8 in control and water deficit, respectively. The highest dry matter (6.28 g and 5.84 g) was recorded in variety Binamoog-5 under both control and water stress. The variety BUmug 2 produced the lowest dry matter (5.0 g) in control whereas BUmug 4 (4.3 g) in water deficit condition. BUmug 4 showed the highest reduction of dry matter (15.1%) followed by BUmug 2 (10.7%), whereas the lowest in Binamoog-5 (7.0%) followed by Binamoog-8 (8.6%). At maturity, the range of dry matter production was 28.8 to 34.5 g for control and 18.2 to 24.3 g for water stressed, respectively. The variety BUmug 4 had the lowest dry matter (28.78 g and 18.17 g), both under control and water stress conditions, while Binamoog-5 had the highest (34.4 g and 24.3 g). At maturity, when there is a water shortage, Binamoog-5 had the lowest decrease of dry matter (29.7%), followed by Binamoog-8 (31.2%), while BUmug 4 had the highest reduction of dry matter (36.9%) (Table 3). This findings are in line with the result of Zare *et al.* (2012) who found that plant dry weight was affected to a great extent due to drought stress. Savaliya *et al.* (2019) also stated that increase of irrigation intervals leads to a significant increase in mungbean growth and production to some extent.

Table 3. Dry matter partitioning at pre-flowering and maturity stage as affected by water stress of six mungbean varieties

Variety	Petiole dry weight ((g plant^{-1})				Shoot dry weight (g plant^{-1})				Total dry weight (g plant^{-1})			
	PF stage		Maturity stage		PF stage		Maturity stage		PF stages		Maturity stage	
	control	water stress	control	water stress	control	water stress	control	water stress	control	water stress	control	water stress
BUmug 2	0.53	0.46 (13.2)	0.57	0.48 (15.8)	4.6	3.9 (13.1)	15.5	12.7 (18.0)	5.0	4.5 (10.7)	29.6	19.1 (35.5)
BUmug 4	0.54	0.43 (20.4)	0.56	0.45 (19.6)	4.6	3.8 (17.80	15.3	12.2 (20.6)	5.1	4.3 (15.1)	28.8	18.2 (36.9)
BARI mung-5	0.58	0.50 (13.8)	0.62	0.53 (14.5)	5.2	4.6 (11.9)	16.9	14.0 (17.3)	5.7	5.1 (9.4)	31.5	20.9 (33.7)
BARI mung-6	0.59	0.50 (15.3)	0.61	0.53 (13.1)	5.5	4.9 (11.4)	17.9	15.1 (15.5)	6.0	5.5 (8.9)	32.6	22.2 (32.1)
Binamoog-5	0.61	0.55 (9.8)	0.63	0.57 (9.5)	5.8	5.2 99.4)	18.4	16.1 (12.5)	6.3	5.8 (7.0)	34.5	24.3 (29.7)
Binamoog-8	0.58	0.51 (12.1)	0.63	0.56 (11.1)	5.7	5.1 (10.8)	18.1	15.4 (14.9)	6.2	5.7 (8.6)	33.1	22.8 (31.2)
CV (%)	5.5		6.5		5.7		7.8		9.7		10.0	
LSD(0.05)	0.01		0.01		0.05		0.17		0.05		0.80	

PF stage: Preflowering stage; CV: coefficient of variations; LSD: Least significance difference at 5%. Values in parenthesis indicate percent reduction compared to the control.

Growth parameters: Plant growth rate (PGR) expresses the increase in dry matter of plants in a unit of time. Initially, the PGR increased progressively in all the varieties irrespective of control and water deficit condition (Figure 1). After a certain period of growth, the PGR reached to a peak and thereafter, it declined. The maximum PGR was recorded at 49 DAE in control and at 42 DAE under water deficit condition in all the varieties (Figure 1 A-B). At initial stage i.e. 28 DAE, the PGR was more or less same in all the six varieties in control and water deficit conditions. Thereafter, PGR increased progressively in case of BARI mung-6, Binamoog-5 and Binamoog-8 compared to other varieties under both control and water deficit conditions. At 49 DAE, the highest PGR was recorded in variety Binamoog-5 and BARI mung-6 (0.95 g plant^{-1}day^{-1}) in control condition (Figure 1A). Under water stress the highest PGR was recorded in variety Binamoog-5 (0.582 g plant^{-1}day^{-1}) at 42 DAE (Figure 1B). The results clearly indicated thus that the variety Binamoog-5 and Binamoog-8 maintained a good PGR throughout the growth period, and the high PGR was an indication of their tolerance to water stress. Whereas, the lowest PGR in variety BUmug 4 and BUmug 2 indicated their drought susceptibility. The Relative growth rate (RGR) was recorded in mungbean varied significantly under control and water deficit conditions as presented in Figure 2. The RGR was higher at the early growth stages and thereafter showed a decreasing trend with the advancement of plant age. The RGR was always higher in control than that under water deficit conditions. At 35 DAE, the highest RGR was recorded in Binamoog-5 (0.13 g g^{-1}day^{-1}) and the lowest in BUmug 2 and BUmug 4 (0.10 g g-1day^{-1}) in control condition (Figure 1C). On the other hand, the highest RGR was recorded in variety Binamoog-5 and Binamoog-8 (0.10 g g^{-1}day^{-1}), whereas the lowest from BUmug 2 (0.07 g g^{-1}day^{-1}) under water stress (Figure 1D). The NAR in mungbean varieties differed significantly in control and water deficit conditions as presented in Figure 1 (E-F). The NAR decreased almost linearly from early stage and the maximum value was observed at 35 DAE in control and water deficit condition irrespective of varieties. The variety Binamoog-5 and Binamoog-8 exhibited the highest

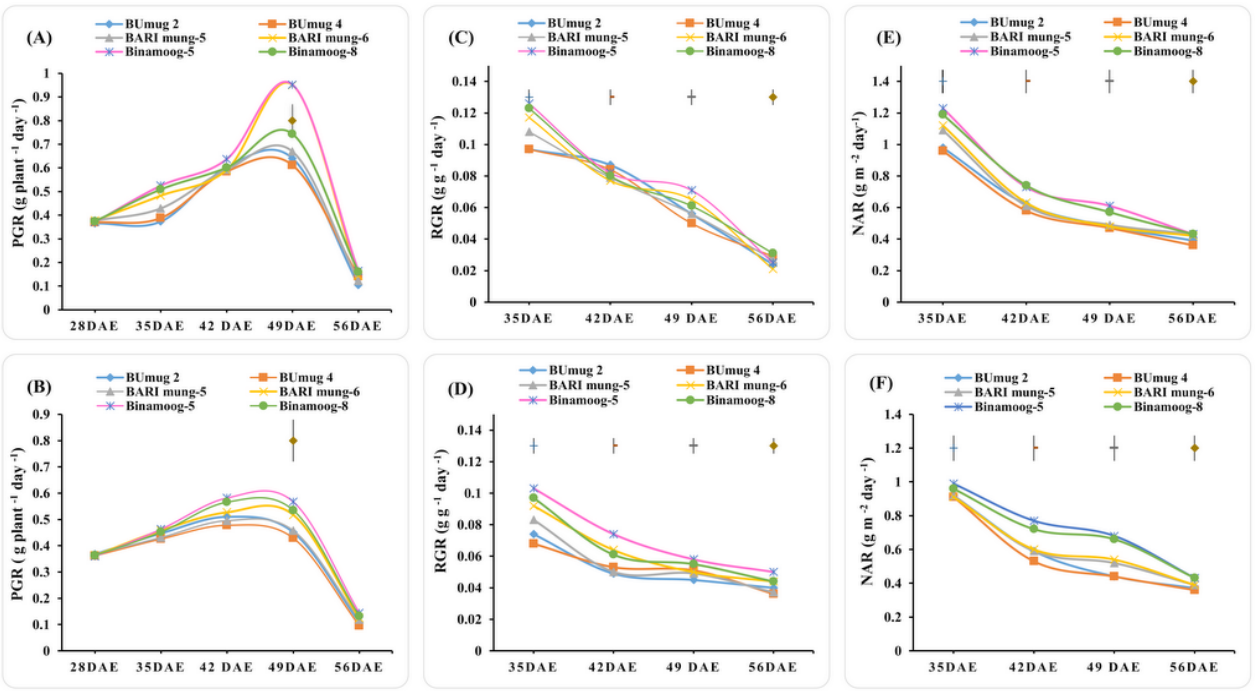


Figure 1. Plant growth parameters as influenced by water stress of six mungbean varieties.

NAR throughout the growth period both in control and water deficit conditions. indicated that water deficit had a significant effect on the reduction in NAR and other growth parameters, and the adverse effects reflected on the overall biomass production of mungbean. Water stress creates imbalance in maintaining turgor in plant cells, and the consequence presumably reflected in disturbance in normal growth of mungbean as found in this study.

Yield and yield contributing characters: Water stress reduced number of pods plant^{-1} in all the six varieties. The pods plant^{-1} ranged from 25.3 to 30.6 and from 13.9 to 20.5 in control and water deficit conditions, respectively (Table 4). The variety Binamoog-8 had the most pods plant^{-1} in both the control (29.9) and water stress (19.4), while BUmug 4 had the fewest pods plant^{-1} in both the control (25.3) and water stress (13.9) conditions. The highest reduction of pod number due to water stress was recorded in BUmug 4 (45.1%), whereas the lowest in Binamoog-5 (32.9%) (Table 4). The reduction in number of pods plant^{-1} might be due to water shortage at the flowering stage that increased pollen abortion (Teran and Singh 2002, Gölgül *et al.* 2022). Water deficit significantly reduced the length of pod in all six varieties. The pod length ranged from 8.2 to 8.5 cm and from 7.6 to 8.0 cm in control and water deficit conditions, respectively (Table 4). The highest pod length was recorded in variety Binamoog-8 (8.5 cm) in control. The highest reduction in pod length was seen in BUmug 4 (7.3%), followed by BUmug 2 (7.2%), and the lowest in Binamoog-5 (5.1%). The reduction in pod length might be due to water shortage in early stage of pod development (Islam 2008). The seeds pod^{-1} ranged from 9.2 to 9.5, and from 7.2 to 7.9 in control and water deficit conditions, respectively (Table 4). The variety Binamoog-5 produced the most pod^{-1} seeds in both the control (9.5) and water stress (7.9), while BUmug 4 produced the least under both the conditions. Seed pod^{-1} reduction was the highest in BUmug 4 (21.8%), followed by BUmug 2 (20.3%), and the lowest in Binamoog-5 (16.79%). Similar to the finding of this study Mujahid *et al.* (2022) stated that the pod length, number of pods per plant, and number of seeds per pod were significantly affected by drought stress in mungbean.

Water deficit did not exert significant effect on 100-seed weight in the varieties except BUmug 4. The highest 100-seed weight was recorded in BARI mung-6 (5.0 g) in control condition, while the highest 100-seed weight was recorded in BARI mung-6 (4.5 g) under water deficit

Table 4. Yield and yield components as affected by water stress of six mungbean varieties

Variety	Pods plant^{-1}		Pod length (cm)		Seeds pod^{-1}		100 seed weight(g)		Yield plant^{-1}		Harvest index (%)	
	control	water stress	control	water stress	control	water stress	control	water stress	control	water stress	control	water stress
BUmug 2	26.7	15.6 (41.8)	8.2	7.6 (7.2)	9.3	7.4 (20.3)	4.9	4.4 (11.7)	11.9	6.5 (45.3)	37.2	30.1 (18.9)
BUmug 4	25.3	13.9 (45.1)	8.2	7.6 (7.3)	9.2	7.2 (21.8)	4.8	4.2 (11.9)	11.6	6.3 (46.1)	38.0	30.5 (19.6)
BARI mung-5	28.2	17.5 (37.9)	8.3	7.9 (5.7)	9.4	7.6 (19.5)	4.8	4.4 (8.3)	12.4	6.7 (45.7)	39.4	31.9 (18.8)
BARI mung-6	29.4	18.8 (36.0)	8.4	7.9 (6.4)	9.5	7.7 (18.9)	5.0	4.5 (10.8)	12.6	6.9 (44.9)	38.5	31.2 (18.9)
Binamoog-5	30.6	20.5 (32.9)	8.4	8.0 (5.1)	9.5	7.9 (16.8)	4.7	4.4 (7.8)	12.8	7.4 (42.3)	39.9	33.2 (16.8)
Binamoog-8	29.9	19.4 (35.1)	8.5	7.9 (6.4)	9.4	7.7 (17.9)	4.8	4.4 (8.0)	12.6	6.9 (44.7)	39.9	32.3 (18.9)
CV (%)	7.3		8.6		5.9		5.8		7.6		5.6	
LSD(0.05)	0.4		0.01		0.1		0.12		0.08		1.1	

CV: coefficient of variations; LSD: Least significance difference at 5%. Values in parenthesis indicate percent reduction compared to the control.

condition. Water stress reduced seed yield plant^{-1} considerably in all the six mungbean cultivars, where seed yield ranged from 11.6 to 12.8 g in control conditions and from 6.3 to 7.4 g under water stress. Binamoog-5 had the maximum yield under both control (12.8 g) and water deficit (7.4 g) conditions, while BUmug 4 had the lowest yield in both control (11.6 g) and water deficit (6.3 g) conditions. The highest reduction in seed yield plant^{-1} was recorded in variety BUmug 4 (46.1%) followed by BARI mung-5 (45.7%), whereas the lowest in Binamoog-5 (42.3%). The reduction of seed yield due to water stress was also in agreement with other reports, such as Nair *et al*. (2019) reported that mungbean plants under water stress induced early flowering, poor pod setting and attained maturity earlier than the well-watered ones and creates significant impact on seed yield. Water stress induced significant reduction of all growth parameters, photosynthetic pigments, yield components and seed yield in mungbean was also reported by Ambachew *et al.* (2014).

Harvest index (HI) differed significantly among the varieties and that was decreased significantly due to the water stress. The HI varied from 37.2 to 39.9% in control and from 30.1 to 33.2% under water deficit condition (Table 4). In the control condition, the highest HI was obtained in Binamoog-8 and Binamoog-5 (39.9%), and the lowest in BU mug 2 (37.2%). However, under water stress conditions, the variety Binamoog-5 had the highest HI (33.2%) followed by Binamoog-8 (32.3%), while the lowest was in BUmug 2 (30.14%). The least reduction was observed in Binamoog-5 (16.8%). These results align with Islam *et al*. (2021) who noticed that the growth and yield of mungbean considerably increased under adequate soil moisture conditions compared to that under water in mungbean varieties.

Conclusion

Mungbean growth and yield was affected by water stress, and varietal differences were conspicuous. With respect to the varietal performance in relation to growth and yield Binamoog-5 and Binamoog-8 were found to be most tolerant and promising

varieties. Field study of the two varieties in the drought prone areas is recommended for ascertaining the results.

Acknowledgement

We acknowledge greatly the Research Management Committee (RMC) of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) for financial assistance for conducting the present study.

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