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# EVALUATION OF BLACKGRAM GENOTYPES TOLERANCE TO WATERLOGGING CONDITION DURING GERMINATION STAGE

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**ABSTRACT**

Rahman O, Naher N, Hosneara, Azam MG (2024) Evaluation of blackgram genotypes tolerance to waterlogging condition during germination stage. *Int. J. Expt. Agric*. 14(1), 01-12.

The black gram *Vigna mungo* (L.) Hepper is an important short-duration legume crop that often experiences waterlogging stress from unanticipated and frequent extreme rainfall events in the Kharif-II season due to climate change in Bangladesh. Seed germination and seedling growth are very important steps in plant survival. Waterlogging stress is one of the important factors affecting seedling growth. An experiment was carried out at the Agroforestry and Environmental Science Field Laboratory of Sher-e-Bangla Agricultural University, Dhaka, 1207, during the Kharif-II season, 2022, to evaluate 15 black-gram genotypes for understanding waterlogging tolerance with respect to germination characteristics. The experiment used a complete randomized design (CRD) with three replications. The waterlogging durations were 2 days and 4 days at the germination stage. In the pot experiment, different germination parameters were studied for two durations of waterlogging. The results revealed significant differences among the genotypes at each waterlogging level, and significant decreases in the germination percentage, germination speed, mean daily germination, root length, shoot length, root shoot ratio, and germination index were detected among all the tested genotypes. The eight black gram-type plants that survived after two days and four days of waterlogging were $V_{11}$ (MH 8569), $V_2$ (86169), $V_3$ (DHL 5), $V_6$ (DHL 4), $V_9$ (DHL 12), $V_{10}$ (RU 75), $V_{12}$ (BARI Mash-3) and $V_{13}$ (DHL 65), and their germination and germination efficiency were attributed to the waterlogging conditions. Therefore, these selected traits may be useful for developing waterlogging-tolerant black gams.

***Key words:*** *black gram, genotypes, germination, seedling traits and waterlogging*

## INTRODUCTION

Black gram [*Vigna mungo* (L.) Hepper; 2n = 22] is a highly nutritious grain legume crop mainly grown in South and Southeast Asian countries, including Afghanistan, Bangladesh, India, Myanmar, Pakistan, Sri Lanka, Thailand, and Vietnam (Kaewwongwal *et al.* 2015). Global black gram production reached 3.2 million tons in 2018, with India producing 1.9 million tons on 3.5 million ha and Myanmar generating 1.24 million tons on 9.78 million ha (Soe *et al.* 2020). India is the world's largest producer of black grams, contributing 70% of the global production, followed by Myanmar and Pakistan. Among pulses, the black-gram pulse is an important pulse, ranking fourth both in hectares and in terms of production in Bangladesh. The total cultivated area in Bangladesh is 102220 acres, and the production is 39003 metric tons (BBS 2022). The crop is a potential component of various cropping systems, especially rice and wheat fallows, owing to its short life cycle (70–90 days), capacity to fix atmospheric nitrogen, and relative drought tolerance. Black grams are generally intercropped with maize, sorghum, cotton, millet, or pigeon pea or rotated with cereal crops such as rice to increase soil fertility, minimize pest and disease incidence, and increase the dry matter yield of main crops (Yadav *et al.* 2006).

Waterlogging stress is a global constraint that limits crop yield (Borrego-Benjumea *et al.* 2021). It is ranked second to drought based on severe damage to crop production and substantial economic losses (Olorunwa *et al.* 2022). Among all abiotic stresses, 65% of agricultural crop losses are attributed directly to waterlogging stress, which costs the global economy an estimated 74 billion USD annually (FAO 2017). Recent data suggest that more than 16% of the world's cultivated land is affected by transient waterlogging (PLoSchuk *et al.* 2018), and more than 17 million $km^2$ of land is at risk of flooding (Ikram *et al.* 2022). According to the current climate change forecast (IPCC 2021), waterlogging events are predicted to increase and become a great challenge for sustainable mung bean cultivation. Waterlogging caused by excessive rainfall restricts stand establishment and root and shoot growth, which may result in the total loss of crop yield (Shibly *et al.* 2020). The inhibition of shoot and root dry mass by 60–65% in mung bean and by 40% in black g was reported under waterlogging stress for 8–16 days during the seedling stage (Kyu *et al.* 2021).

The black gram is a short-season nutritious legume. The crop is sown during August/September in Bangladesh. Crops face waterlogging stress at different growth stages due to the onset of monsoons, which coincides with the crop growth cycle.

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In Bangladesh, black gasses are usually grown under rain-fed conditions where crop damage is common. Excessive rain can cause massive damage to plants and delay their growth (Amin *et al.* 2016). Climatic variability may decrease black gram production due to unpredictable waterlogging in the future. Although waterlogging stress impedes crop growth at all stages, early vegetative and reproductive stages are highly detrimental to crop yield (Tian *et al.* 2019). Waterlogging may occur due to erratic rainfall, poor drainage or undulating land. The heavy soil texture may be a possible reason for water logging (Singh *et al.* 2017). Black gram rot is grown in the Kharif-II (mid-August to last week of September) season in Bangladesh. It usually suffers from unexpected heavy rainfall at sowing or at emergence, which can cause total crop failure. Pre sowing heavy rain causes delays in sowing, resulting in poor seed yield. Delayed sown crops face excess rainfall during the reproductive phase, which is the root cause of enormous losses in seed yield and quality. The reduction in growth and yield caused by waterlogging varies with crop species and genotype.

However, very little information is available on the responses of black gasses to waterlogging in Bangladesh. Waterlogging reduces plant growth by affecting one or several physiological processes. Several studies revealed that genotypes differed in their responses to water stress conditions. Considering the changing climate scenario, breeding for climate-smart varieties that are tolerant to prevailing biotic and abiotic stresses will ensure uninterrupted growth in genetic gains and increase future food demand. Therefore, waterlogging-tolerant varieties will be developed for unfavourable ecosystems. An increase in black gram production is highly needed to meet local demand, reduce imports and save foreign currency. Therefore, the present investigation was carried out to study the effect of waterlogging on black-gram genotypes and to determine the waterlogging-tolerant genotypes at the germination stage.

## MATERIALS AND METHODS

### Plant Materials

Fifteen black-gram genotypes were used in the experiment. A detailed list of the genotypes is given in Table 1. Out of 15 genotypes, 8 were collected from the National Bureau of Plant Genetic Resources, New Delhi, India; 5 from the Pulse Research Centre, Bangladesh Agricultural Research Institute (BARI); and 2 from local collections in Bangladesh.

### Experimental site and design

The field studies were performed in the experimental area of the Agroforestry and Environmental Science field lab of Sher-e-Bangla Agricultural University, Dhaka, 1207, during the Kharif-II season, 2022. The experimental site is located at 23.74°N latitude and 90.35°E longitude, with an elevation of 8.2 m above sea level. The experiment was performed in a complete randomized design (CRD) with three treatments, where each treatment was replicated three times.

### Growth Conditions

Seeds were surface sterilized with 1% commercial bleach (40 mg/L NaOCl) for 1 min and rinsed with deionized (DI) water four times. To control seed-borne and seedling root pathogens, 3 g/kg Provex fungicide [Thiram (360 g/L) + Thiabendazole (200 g/L)] was applied. The recommended dose of fertilizer for black grams according to the Bangladesh Agricultural Research Institute (BARI) was maintained (BARI 2017). The urea concentration was 40-50 kg/ha, the triple superphosphate (TSP) concentration was 90-95 kg/ha, the muraite of potash (MP) concentration was 30-40 kg/ha, and the gypsum concentration was 60 kg/ha. Cow dung, coconut dust, half of urea, total amount of TSP, MOP, gypsum and zinc sulphate were applied at the time of final pot preparation. The experimental plastic pots had a capacity of 250 ml, a diameter of 8 cm and a height of 10 cm. The soil used in the pots was silt clay. The experiment was performed in a complete randomized design (CRD) with three treatments, where each treatment was replicated three times. Three treatments, (i) no waterlogging (control), (ii) two days of waterlogging and (iii) four days of waterlogging, were used in the experiment. Fifteen black-gram genotypes were used in the experiment. A list of genotypes is given in Table 1. Five seeds of each genotype were sown in each pot. After sowing the seeds, the pots were set up in 60-liter plastic tanks under waterlogged conditions for two or four days. In the control treatment, 100% of the field capacity was maintained.

**Table 1**. Details of the black-gram genotypes used in this study

| Sl. No. | Name of Genotypes | Genotypes code | Source |
|---|---|---|---|
| 1 | DHL 14 | $V_1$ | NBPGR, India |
| 2 | 86169 | $V_2$ | NBPGR, India |
| 3 | DHL 5 | $V_3$ | NBPGR, India |
| 4 | RU 127 | $V_4$ | Local |
| 5 | BARI Mash-4 | $V_5$ | Released variety, BARI |
| 6 | DHL 4 | $V_6$ | NBPGR, India |
| 7 | BARI Mash-2 | $V_7$ | Released variety, BARI |
| 8 | BBLX020010 | $V_8$ | PRC, BARI |
| 9 | DHL 12 | $V_9$ | NBPGR, India |
| 10 | RU 75 | $V_{10}$ | Local |
| 11 | MH 8569 | $V_{11}$ | NBPGR, India |
| 12 | BARI Mash-3 | $V_{12}$ | Released variety, BARI |
| 13 | DHL 65 | $V_{13}$ | NBPGR, India |
| 14 | DHL 10 | $V_{14}$ | NBPGR, India |
| 15 | BARI Mash-1 | $V_{15}$ | Released variety, BARI |

Note: NBPGR, National Bureau of Plant Genetic Resources, New Delhi, India; PRC, Pulse Research Centre; BARI, Bangladesh Agricultural Research Institute

## RESULTS AND DISCUSSION

### *Per-searing* performance

Seedling emergence is one of the most sensitive growth stages in which plants are resistant to water deficit. Therefore, seed germination is a prerequisite for successful stand establishment in crop plants (Baloch *et al.* 2012). Because germination is one of the most valuable traits for the early seedling stage of crop plants, it seems that plants are more sensitive to water stress than are plants of other genotypes (Homayoun *et al.* 2011). The average germination percentages were 82.22%, 66% and 51.33% in the control, $T_1$ and $T_2$ treatments, respectively (Table 2). $V_{11}$ (MH 8569) exhibited the greatest percentage of germination (93.33%), followed by $V_{13}$ (DHL 65) (90%) under control conditions, whereas the overall minimum percentage of germination (73.33%) was recorded for $V_8$ (BBLX020010). The maximum germination percentage (73.33%) was recorded in $V_1$ (DHL 14), followed by $V_{11}$ (MH 8569) (73.33%) under the $T_1$ treatment. The minimum germination percentages (60%) were recorded for $V_{12}$ (BARI Mash-3), $V_7$ (BARI Mash-2), $V_8$ (BBLX020010) and $V_9$ (DHL 12) under $T_1$ conditions. Germination is considered one of the first and most fundamental life stages of a plant and contributes significantly to the growth and yield production of black gram varieties. Resistance to water logging during germination results in a stable, vigorous and healthy plant.

Germination speed and daily germination were not significantly different among the treatments. Among the seed growth parameters, root length in the black-gram crop is considered the most powerful trait in waterlogging tolerance selection programs (Hassan *et al.* 2016). Root growth is an important parameter for plant tolerance to waterlogged stress because roots are the main engine for meeting transpiration demand and play an important role in making water available to plants. A deeper and more extended root system allows the plants to extract more water from the surrounding soil. A decrease in root length might result from diminished relative turgidity and protoplasm dehydration, which decreases cell expansion and delays cell division (Mujtaba *et al.* 2016). The root lengths were recorded after 10 days of seedling growth (Table 3). In the present study, the data indicated that an increase in osmotic stress caused a significant decrease in root length, as presented in Table 3.

The greatest root length (5.63 cm) was recorded in $V_{11}$ (MH 8569), followed by $V_5$ (BARI Mash-4) (5.30 cm) and $V_6$ (DHL 4) (4.90 cm), whereas the minimum root length (3.56 cm) was recorded in $V_9$ (DHL 12). Root length decreased rapidly with increasing osmotic potential in the studied black-gram genotypes. In the $T_1$ treatment, $V_{11}$ (MH 8569) had the greatest root length (5.27 cm), followed by $V_6$ (DHL 4) (4.67 cm) and $V_{10}$ (RU 75) (4.5 cm). No root length was detected for seven genotypes ($V_1$ (DHL 14), $V_{14}$ (DHL 10), $V_{15}$ (BARI Mash-1), $V_4$ (RU 127), $V_5$ (BARI Mash-4), $V_7$ (BARI Mash-2) and $V_8$ (BBLX020010)) in the $T_1$ treatment. The root length of the $V_{11}$ genotype (MH 8569) decreased the least, followed by that of the $V_{10}$ genotype (RU 75), under stress conditions. The root length of all the genotypes used in the present study was significantly reduced by logged water conditions. Shoot length continuously decreases in response to exposure to different osmotic stress levels. The logged water tolerance of a genotype is characterized by a slight decrease in shoot growth in water-stressed environments. Measurements of shoot length of seedlings subjected to osmotic stress have been suggested for water stress tolerance (Ahmadizadeh *et al.* 2011). Shoot lengths were recorded after 10 days of seedling growth. All the black-gram genotypes showed variation in shoot length in response to water-induced stress (Table 3). An increase in the number of days to logged water caused a substantial decrease in shoot length in the black-gram genotype. The mean shoot lengths were 8.93, 4.52 and 4.32 cm under unstressed and waterlogged stress conditions, respectively, which clearly decreased compared with those under unstressed conditions. The greatest shoot length (10.23 cm) was recorded in $V_{12}$ (BARI Mash-3), followed by $V_7$ (BARI Mash-2) (10.03 cm), $V_{14}$ (DHL 10) (9.70 cm) and $V_1$ (DHL 14) (9.63 cm), while the lowest shoot length (7.86 cm) was recorded in $V_2$ (86169) in the control condition. Shoot length is inversely proportional to water stress.

Waterlogging stress caused a significant decrease in the root-shoot ratio and germination index (GI) of all the genotypes in the present study (Table 3). In terms of the germination index, $V_{11}$ (MH 8569) exhibited the maximum GI (15.56), followed by $V_{13}$ (DHL 65), $V_3$ (DHL 5) and $V_6$ (DHL 4) (15.00), whereas the minimum GI (12.22) was recorded in $V_8$ (BBLX020010). GI decreased with increasing water logged treatments. Among the $T_1$ treatments, $V_1$ (DHL 14), $V_{13}$ (DHL 65), $V_3$ (DHL 5) and $V_{11}$ (MH 8569) exhibited the greatest GIs (12.22), followed by $V_5$ (BARI Mash-4) (11.67). The lowest values of GI (10) were recorded for $V_{12}$ (BARI Mash-3), $V_7$ (BARI Mash-2), $V_8$ (BBLX020010) and $V_9$ (DHL 12) under the $T_1$ condition. Water logging depresses black gram shoot growth rather than root development. Moreover, distinct genetic differences were found among the genotypes with respect to shoot growth subjected to water logging.

**Table 2.** Mean performance of 15 black-gram genotypes at the germination stage under different treatments

| **Genotypes** | **Germination percentage (GP)** | | | **% over control** | **Germination speed (GS)** | | | **% over control** | **Daily germination (DG)** | | | **% over control** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Control** | **$T_1$** | **$T_2$** | **for $T_2$** | **Control** | **$T_1$** | **$T_2$** | **for $T_2$** | **Control** | **$T_1$** | **$T_2$** | **for $T_2$** |
| $V_1$ | 83.33 | 73.33 | 60.00 | 72.00 | 8.89 | 8.01 | 7.47 | 84.03 | 0.99 | 0.99 | 1.01 | 102.02 |
| $V_2$ | 86.67 | 63.33 | 50.00 | 57.69 | 8.79 | 7.77 | 6.89 | 78.38 | 0.99 | 0.99 | 1.00 | 101.01 |
| $V_3$ | 90.00 | 73.33 | 60.00 | 66.67 | 9.30 | 8.44 | 7.50 | 80.65 | 1.03 | 1.02 | 1.01 | 98.06 |
| $V_4$ | 80.00 | 63.33 | 53.33 | 66.66 | 9.16 | 8.03 | 7.22 | 78.82 | 1.01 | 1.00 | 0.99 | 98.02 |
| $V_5$ | 80.00 | 70.00 | 60.00 | 75.00 | 8.92 | 8.11 | 7.47 | 83.74 | 1.01 | 1.00 | 1.01 | 100.00 |
| $V_6$ | 90.00 | 66.67 | 50.00 | 55.56 | 9.30 | 7.93 | 6.88 | 73.98 | 1.00 | 0.99 | 0.97 | 97.00 |
| $V_7$ | 73.33 | 60.00 | 40.00 | 54.55 | 8.24 | 7.70 | 6.58 | 79.85 | 0.99 | 1.01 | 0.99 | 100.00 |
| $V_8$ | 73.33 | 60.00 | 46.67 | 63.64 | 8.51 | 7.70 | 6.88 | 80.85 | 1.01 | 1.01 | 0.97 | 96.04 |
| $V_9$ | 80.00 | 60.00 | 50.00 | 62.50 | 8.99 | 7.93 | 6.99 | 77.75 | 1.02 | 1.01 | 1.02 | 100.00 |
| $V_{10}$ | 80.00 | 66.67 | 56.67 | 70.84 | 8.76 | 8.28 | 7.47 | 85.27 | 1.02 | 1.03 | 1.03 | 100.98 |
| $V_{11}$ | 93.33 | 73.33 | 56.67 | 60.72 | 9.64 | 8.52 | 7.63 | 79.15 | 1.05 | 1.04 | 1.01 | 96.19 |
| $V_{12}$ | 80.00 | 60.00 | 40.00 | 50.00 | 8.82 | 7.70 | 6.58 | 74.60 | 1.01 | 1.01 | 0.99 | 98.02 |
| $V_{13}$ | 90.00 | 73.33 | 46.67 | 51.86 | 9.00 | 8.04 | 6.88 | 76.44 | 1.01 | 0.99 | 0.97 | 96.04 |
| $V_{14}$ | 73.33 | 63.33 | 53.33 | 72.73 | 9.08 | 8.03 | 7.39 | 81.39 | 1.00 | 1.00 | 1.00 | 100.00 |
| MS Error | 26.03 | 32.38 | 46.66 | | 0.11 | 0.10 | 0.11 | | 0.002 | 0.002 | 0.003 | |
| Mean | 82.22 | 66.00 | 51.33 | | 8.94 | 7.99 | 7.10 | | 1.02 | 1.00 | 0.99 | |
| CV (%) | 6.20 | 8.62 | 13.30 | | 3.77 | 3.98 | 4.87 | | 4.80 | 4.99 | 6.20 | |
| LSD (0.05%) | 8.53 | 9.51 | 11.42 | | 0.54 | 0.53 | 0.57 | | NS | NS | 0.11 | |

**Table 3.** Mean performance of 15 black-gram genotypes at the germination stage under different treatments

| Genotypes | Root length (RL) | | | % over control for $T_2$ | Shoot length (SL) | | | % over control for $T_2$ | Root-shoot ratio (RS ratio) | | | % over control for $T_2$ | Germination index (GI) | | | % over control for $T_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | $T_1$ | $T_2$ | | Control | $T_1$ | $T_2$ | | Control | $T_1$ | $T_2$ | | Control | $T_1$ | $T_2$ | |
| $V_1$ | 4.07 | 0.00 | 0.00 | 0.00 | 9.63 | 0.00 | 0.00 | 0.00 | 0.42 | 0.00 | 0.00 | 0.00 | 13.89 | 12.22 | 10.00 | 71.99 |
| $V_2$ | 4.63 | 4.37 | 4.47 | 96.54 | 7.87 | 7.83 | 7.97 | 101.27 | 0.58 | 0.56 | 0.56 | 96.55 | 14.44 | 10.55 | 8.33 | 57.69 |
| $V_3$ | 3.60 | 3.17 | 3.10 | 86.11 | 8.53 | 8.07 | 8.27 | 96.95 | 0.42 | 0.39 | 0.37 | 88.10 | 15.00 | 12.22 | 10.00 | 66.67 |
| $V_4$ | 4.43 | 0.00 | 0.00 | 0.00 | 8.63 | 0.00 | 0.00 | 0.00 | 0.51 | 0.00 | 0.00 | 0.00 | 13.33 | 10.55 | 8.89 | 66.69 |
| $V_5$ | 5.30 | 0.00 | 0.00 | 0.00 | 9.20 | 0.00 | 0.00 | 0.00 | 0.57 | 0.00 | 0.00 | 0.00 | 13.33 | 11.66 | 10.00 | 75.02 |
| $V_6$ | 4.90 | 4.67 | 4.57 | 93.27 | 7.93 | 7.73 | 8.03 | 101.26 | 0.61 | 0.60 | 0.57 | 93.44 | 15.00 | 11.11 | 8.33 | 55.53 |
| $V_7$ | 4.03 | 0.00 | 0.00 | 0.00 | 10.03 | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 0.00 | 0.00 | 12.22 | 10.00 | 6.67 | 54.58 |
| $V_8$ | 4.37 | 0.00 | 0.00 | 0.00 | 8.50 | 0.00 | 0.00 | 0.00 | 0.51 | 0.00 | 0.00 | 0.00 | 12.22 | 10.00 | 7.78 | 63.67 |
| $V_9$ | 3.57 | 3.43 | 3.40 | 95.24 | 9.20 | 8.93 | 9.00 | 97.83 | 0.38 | 0.38 | 0.38 | 100.00 | 13.33 | 10.00 | 8.33 | 62.49 |
| $V_{10}$ | 4.67 | 4.50 | 4.60 | 98.50 | 8.57 | 8.30 | 8.53 | 99.53 | 0.55 | 0.54 | 0.54 | 98.18 | 13.33 | 11.11 | 9.44 | 70.82 |
| $V_{11}$ | 5.63 | 5.27 | 5.13 | 91.12 | 9.00 | 8.87 | 9.00 | 100.00 | 0.63 | 0.59 | 0.57 | 90.48 | 15.55 | 12.22 | 9.44 | 60.71 |
| $V_{12}$ | 3.93 | 3.77 | 3.73 | 94.91 | 10.23 | 9.73 | 9.87 | 96.48 | 0.38 | 0.38 | 0.38 | 100.00 | 13.33 | 10.00 | 6.67 | 50.04 |
| $V_{13}$ | 4.00 | 3.83 | 3.87 | 96.75 | 8.57 | 8.33 | 8.67 | 101.17 | 0.47 | 0.46 | 0.45 | 95.74 | 15.00 | 12.22 | 7.78 | 51.87 |
| $V_{14}$ | 3.87 | 0.00 | 0.00 | 0.00 | 9.70 | 0.00 | 0.00 | 0.00 | 0.39 | 0.00 | 0.00 | 0.00 | 12.22 | 10.55 | 8.89 | 72.75 |
| MS Error | 0.02 | 0.02 | 0.07 | | 0.07 | 0.08 | 0.09 | | 0.001 | 0.003 | 0.007 | | 0.72 | 0.89 | 1.29 | |
| Mean | 4.34 | 2.2 | 2.19 | | 8.93 | 4.52 | 4.32 | | 0.49 | 0.26 | 0.25 | | 13.70 | 11 | 8.55 | |
| CV (%) | 3.91 | 7.22 | 3.96 | | 2.98 | 2.09 | 2.10 | | 5.35 | 7.28 | 5.23 | | 6.20 | 8.62 | 13.30 | |
| LSD(0.05%) | 0.28 | 0.26 | 0.14 | | 0.44 | 0.15 | 0.16 | | 0.04 | 0.03 | 0.02 | | 1.42 | 1.58 | 1.90 | |

**Germination percentage (%)**

The germination of black gids is considered the most important and crucial criterion for successful production in waterlogging areas. Considerable variations among the fifteen black-gram genotypes in response to waterlogging were observed for germination percentage. The germination percentages of the fifteen genotypes at different levels of waterlogging are presented in Figure 1.

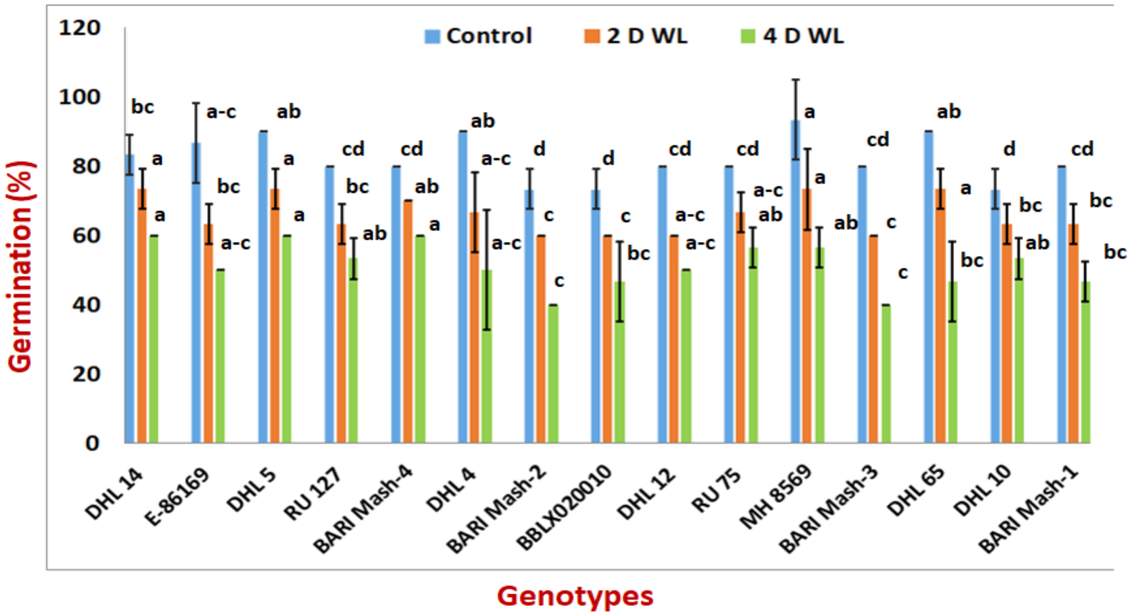


**Fig. 1.** Mean effects of waterlogging on the germination percentage of 15 black-gram-old plants

Germination progressively decreased with increasing duration of waterlogging. At four days, waterlogging germination was greatly reduced in all the genotypes, while a significant decreasing trend started after two days of waterlogging. Among the three different treatments, germination percentages reached a maximum at $T_0$ (control), varying from 73.333 to 93.333%, with an average of 82.222%. Moreover, the most germination was recorded for MH 8569 (93.333%). In contrast, the percent germination ranged from 60.000 to 73.333% at $T_1$ (2 days of waterlogging), with an average of 66.000%. In treatment $T_2$ (4 days of waterlogging), the percentage of germinated plants ranged from 40.000 to 60.000%, with an average of 51.333%. Two days of waterlogging and four days of waterlogging significantly affected the percentage (%) of germinated black gram-shaped seeds. In the experiment, a high germination percentage was recorded in the control treatment, whereas gradual decreases in the percentages of germination were observed with increasing waterlogging in all treatments. Comparable findings were reported by Amin *et al.* (2016), who reported that the percentage of germinated mung bean decreased under flooding conditions. The variation in the seed germination percentage (%) might be due to the varietal characteristics of the genotypes and adverse effects of continuous waterlogging for 4 days.

**Germination Speed (GS)**

The effect of waterlogging on germinating seeds of all the black-gram genotypes was not only on lowering the percentage of germination but also on lengthening the time needed to complete germination. Figure 2 illustrates the differences in the trend of black–green seed germination during the waterlogging treatment. Germination of all the genotypes in the control and waterlogging treatments commenced after two days and mostly completed after 5 days. Germination was delayed after 4 days of waterlogging, and the delay in germination was very obvious for $V_7$ (BARI Mash-2) and $V_{12}$ (BARI Mash-3) but occurred for the other varieties. In most of the varieties, the completion of germination at 4 days of waterlogging was also delayed to 4-5 days, except for $V_{13}$ (DHL 65). Under the $T_0$ treatment (control), 2 days of waterlogging and 4 days of waterlogging treatment, most of the varieties attained more than 80% germination on day two. At 2 days of waterlogging, all the varieties had less than 80% germination on day two, with the exception of $V_{10}$ (RU 75), which reached 90%. After 4 days of waterlogging, all the black-colored varieties had more than 50% germination on day two without $V_1$ (DHL 14). Germination was delayed on days 2 to 5, with most varieties attaining more than 50% germination after 4 days of waterlogging. Similar findings were reported by El-Enany *et al.* (2014), who reported that the impact of waterlogging on the germination speed of three legume plants, namely, Faba bean, common bean and pea plants, significantly decreased the day duration of germination during waterlogging.

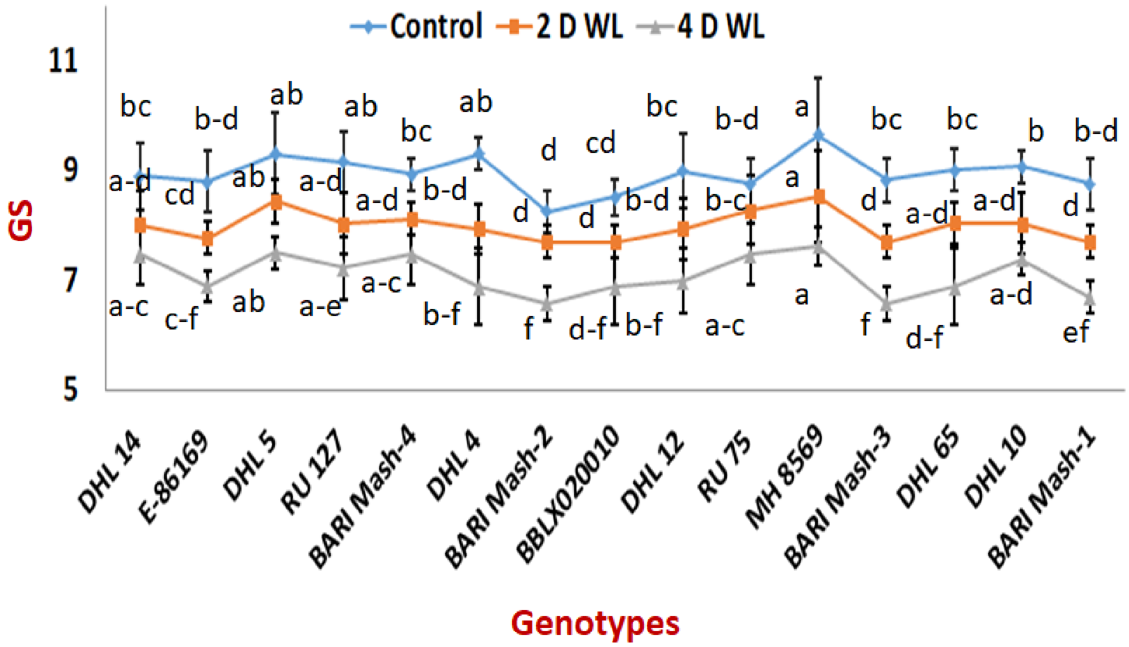


**Fig. 2.** Mean effects of waterlogging on germination speed (GS) in 15 blackgram genotypes

**Mean Daily Germination (MDG)**

The different durations of water logging had significant effects on the mean daily germination of black-grown seeds (Figure 3) at the germination stage. Mean daily germination is an important characteristic of seeds. The highest mean daily germination was found in the control treatment. In the $T_0$ (control) treatment, the greatest mean daily germination (1.05) was observed for the $V_{11}$ genotype (MH 8569). In contrast, the lowest mean daily germination was observed for the $V_6$ (DHL 4), $V_8$ (BBLX020010) and $V_{13}$ (DHL 65) $T_2$ (4 days of waterlogging) treatment (0.97). Similar findings were reported by Minchin *et al.* (1978), who reported a reduction in mean daily germination due to waterlogging at the cowpea germination stage.

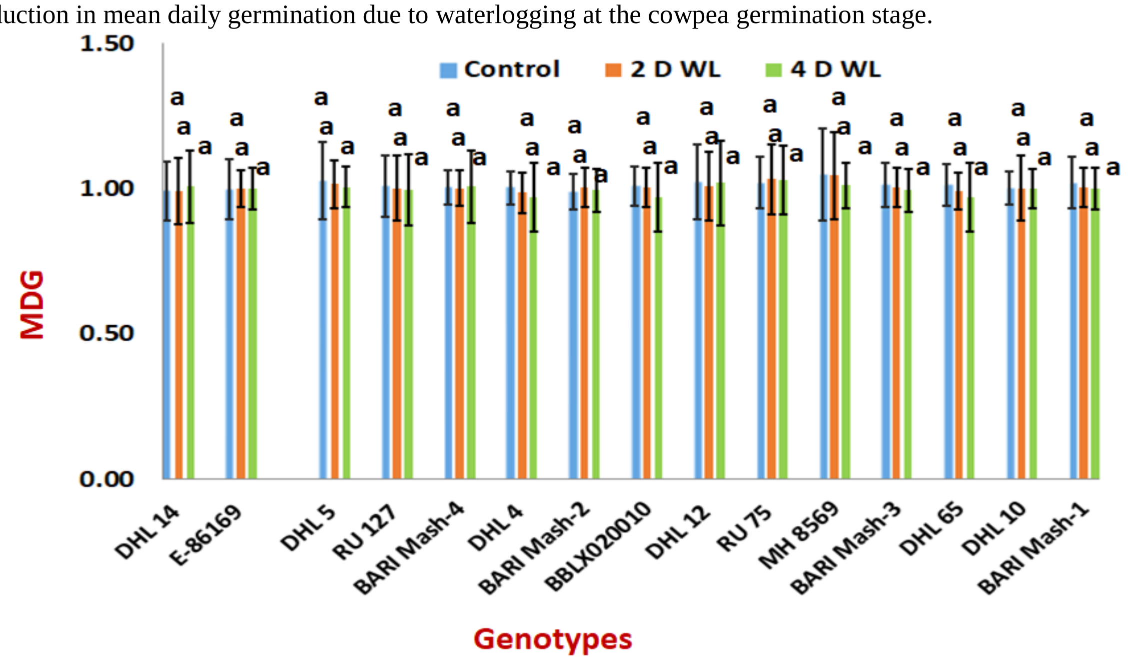


**Fig. 3.** Mean effects of waterlogging on the mean daily germination (MDG) of 15 black-gram-old plants

**Root length (RL)**

The duration of waterlogging had a significant effect on the length of the roots of black gasses (Figure 4) at the germination stage. Moreover, the decrease in root length was suppressed by waterlogging. Root length is an important characteristic of plants. Fifteen black gram varieties exhibited highly significant differences in root length between the $T_1$ and $T_2$ control treatments. At $T_0$ (control), the root length ranged from 3.567 cm to 5.633

cm, with an average of 4.349 cm. At $T_1$ (2 days of waterlogging), the root length ranged from 0.000 cm to 5.267 cm, with an average of 2.200 cm. This result indicated that an increase in waterlogging decreased the root length of the black-gram variety by 49.41%. On the other hand, the $T_2$ (4 days of waterlogging) root length ranged from 0.000 cm to 5.133 cm, with an average of 2.191 cm. This result also indicated that an increase in waterlogging duration from 2 days to 4 days decreased the root length of the black-gram variety by 12.40%. In the $T_0$ (control) treatment, the greatest root length (5.7 cm) was observed for the $V_{11}$ genotype (MH 8569). In contrast, the lowest root length was observed in the $T_2$ treatment (3 cm) for the V3 genotype (DHL5) (Figure 4). This result revealed that root length gradually decreased with increasing duration of waterlogging. Similarly, Islam (2003) reported that the length of mung bean roots was significantly affected by waterlogging stress.

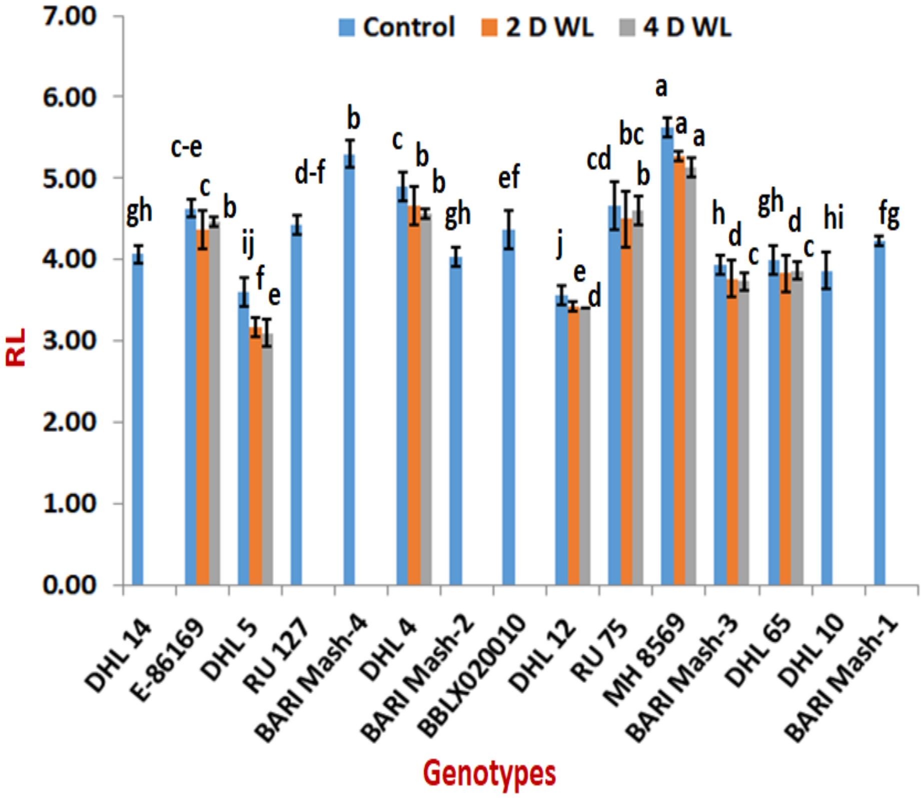


**Fig. 4.** Mean effects of waterlogging on the root length (RL) of 15 black-gram-old plants

**Shoot length (SL)**

Waterlogging slows black gram shoot growth. Considerable differences were found in the shoot lengths for all the varieties at different levels of waterlogging compared with those of the control. There were highly significant differences in shoot length at the $T_0$ (control), $T_1$ and $T_2$ waterlogging levels for the fifteen black gram genotypes. At $T_0$ (control), the shoot length ranged from 7.867 cm to 10.233 cm, with an average of 8.931 cm. At $T_1$ (2 days of waterlogging), the shoot length ranged from 0.000 cm to 9.733 cm, with an average of 4.520 cm. This result indicates that an increase in waterlogging decreases shoot length in black-gram-type plants by 49.39%. On the other hand, $T_2$ (4 days of waterlogging) shoot length ranged from 0.000 cm to 9.667 cm, with an average of 4.422 cm. This result also indicated that an increase in waterlogging duration from 2 days to 4 days decreased the shoot length of black gram-type plants by 2.17%. The duration of water logging had a significant effect on the shoot length of black gasses (Figure 5) at the germination stage. In the $T_0$ (control) treatment, the greatest shoot length of 10.7 cm was observed for the $V_7$ genotype (BARI Mash-2). In contrast, the shortest shoot length was observed in the $T_2$ treatment (7.6 cm) for the $V_6$ genotype (DHL 4) (Figure 5). This result revealed that shoot length gradually decreased with increasing duration of waterlogging. Similarly, Islam (2003) reported that the shoot length of mung bean was significantly affected by waterlogging stress.

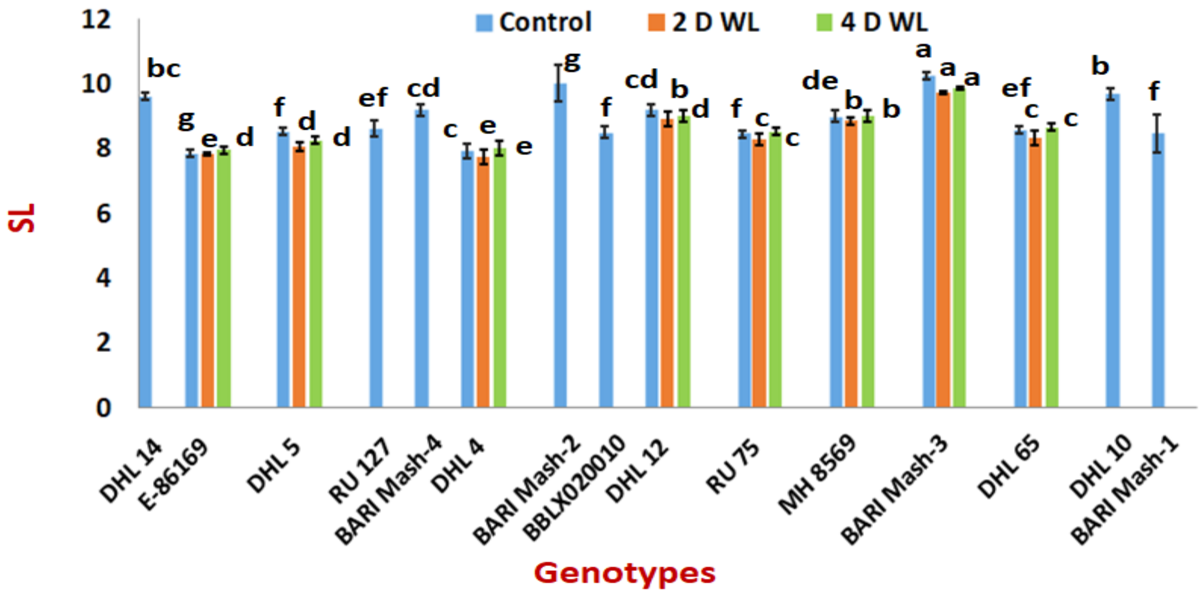


**Fig. 5**. Mean effects of waterlogging on shoot length (SL) in 15 blackgram genotypes

**Reduction in Root Length (RRL)**

The duration of waterlogging significantly affected the reduction in the length of the roots of the black plant roots (Figure 6) at the germination stage. In the $T_2$ treatment (4 days of waterlogging), the greatest reduction in root length (0.5 cm) was observed for the V3 genotype (DHL5). In contrast, the lowest reduction in root length was observed in the 0.1 cm $T_1$ treatment in the V10 genotype (RU 75) (Figure 6). This value clearly indicates a significant decrease in the number of roots with increasing waterlogging. The results also indicate that the too-reduction rate increased with increasing waterlogging level. The coefficients of variation were 1.135% and 1.292% at $T_1$ and $T_2$, respectively. Similarly, Islam (2003) reported that a reduction in the length of mung bean roots was significantly affected by waterlogging stress.

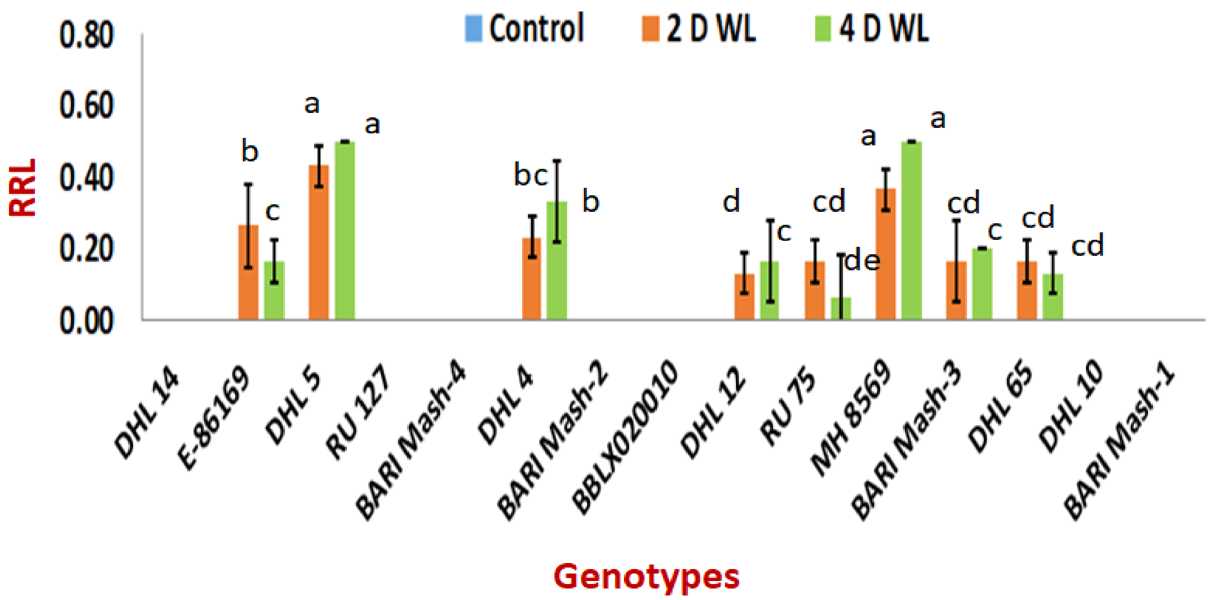


**Fig. 6.** Mean effects of waterlogging on the mean reduction in root length (RRL) in 15 black-gram-old plants.

**Reduction in Shoot Length (RSL)**

The duration of waterlogging significantly affected the reduction in the length of the roots of the black plant roots (Figure 7) at the germination stage.

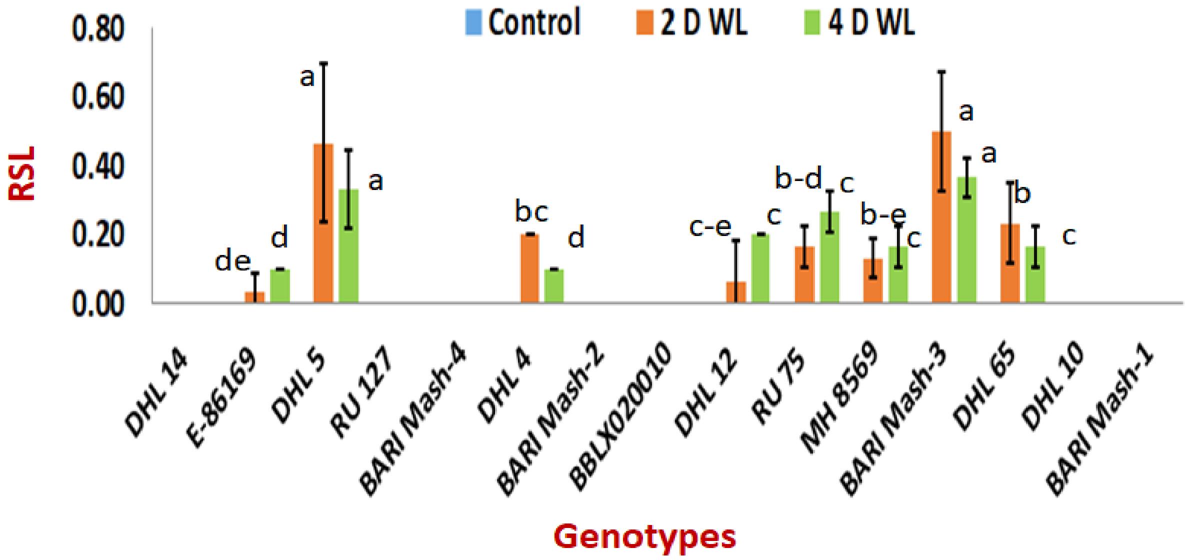


**Fig. 7.** Mean effects of waterlogging on the reduction in shoot length (RSL) in 15 black-gram-old plants

In the $T_1$ (2 days waterlogging) treatment, the greatest reduction in shoot length (0.6 cm) was observed for the $V_3$ genotype (DHL5). In contrast, the lowest reduction in shoot length was observed in the 0.1 cm $T_2$ treatment in the $V_2$ genotype (86169) (Figure 7). A significant variation in the reduction in shoot length was observed among all the varieties. A positive correlation was observed between a reduction in shoot length and a reduction in root length. Similarly, Khadeja *et al.* (2022) reported that a reduction in the shoot length of mung bean plants was significantly affected by waterlogging stress.

**Root Shoot Ratio (RSR)**

The root-shoot ratio indicates the root and shoot growth pattern of a crop. A high root shoot ratio indicates greater root growth, while a lower ratio indicates greater shoot growth. The analyses of variance showed that the differences among the varieties were significant. The mean root-to-shoot ratio of the varieties was the highest in the $T_0$ treatment (control) (0.491), followed by the $T_1$ treatment (0.261) and $T_2$ treatment (0.254). At $T_0$ (control), the RSR of the varieties ranged from 0.384 to 0.626. In contrast, $T_1$ ranged from 0.000 to 0.603, and $T_2$ ranged from 0.000 to 0.570. A decreasing trend in the root shoot ratio indicates greater shoot growth than root growth. The duration of waterlogging had a significant effect on the reduction in the length of the roots of black gasses (Figure 8) at the germination stage. In the $T_0$ (control) treatment, the highest root shoot ratio of 0.64 cm was observed for the $V_6$ genotype (DHL 4). In contrast, the lowest reduction in shoot length was observed in the 0.36 cm $T_1$ treatment in the $V_{12}$ genotype (BARI Mash-3) (Figure 8). Comparable findings were reported by Islam (2003), who reported that a reduction in the root-to-shoot ratio of mungbean was significantly affected by waterlogging stress.

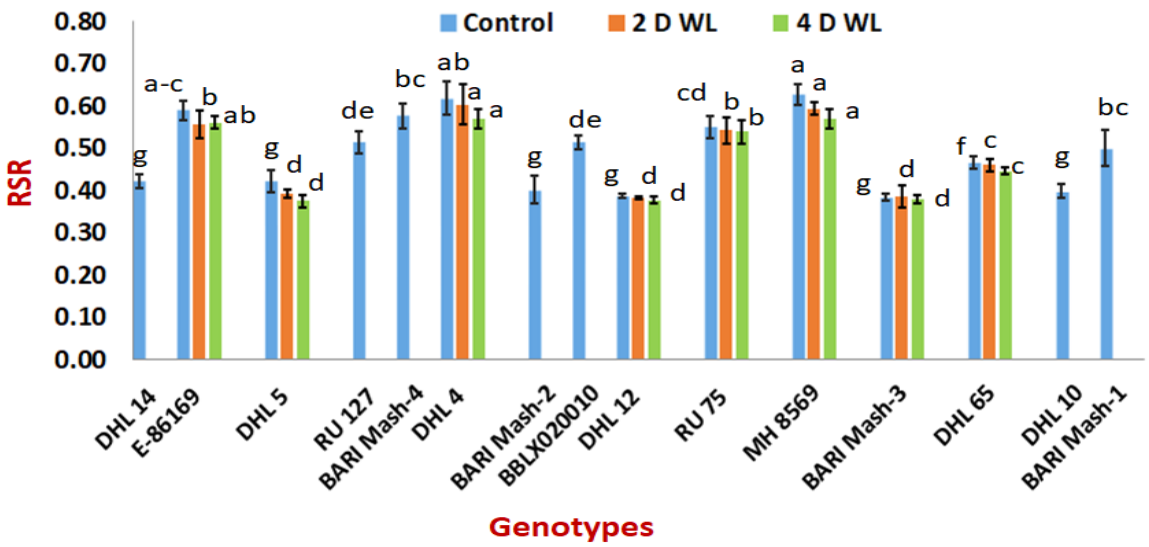


**Fig. 8.** Mean effects of waterlogging on the root-to-shoot ratio (RSR) in 15 black-gram-old plants

## Germination Index (GI)

Different levels of waterlogging significantly affected the germination index of black-gram-old seeds. The germination index is an important characteristic of seeds. The highest germination index was found in the control treatment. In the $T_0$ (control) treatment, the highest germination index of 15.556 was observed. In contrast, the lowest germination index (6.667) was observed in the $T_2$ treatment (4 days of waterlogging). The duration of waterlogging had a significant effect on the germination index of black gasses (Figure 9) at the germination stage. In the $T_0$ (control) treatment, the highest germination index (15.556) was observed for the $V_{11}$ genotype (MH 8569). In contrast, the lowest germination index was observed in the $T_2$ treatment (6.67) for the $V_{12}$ genotype (BARI Mash-3) (Figure 9). Comparable findings were reported by Ahmed *et al*. (2002), who reported that the germination index of mungbean decreased under waterlogging conditions.

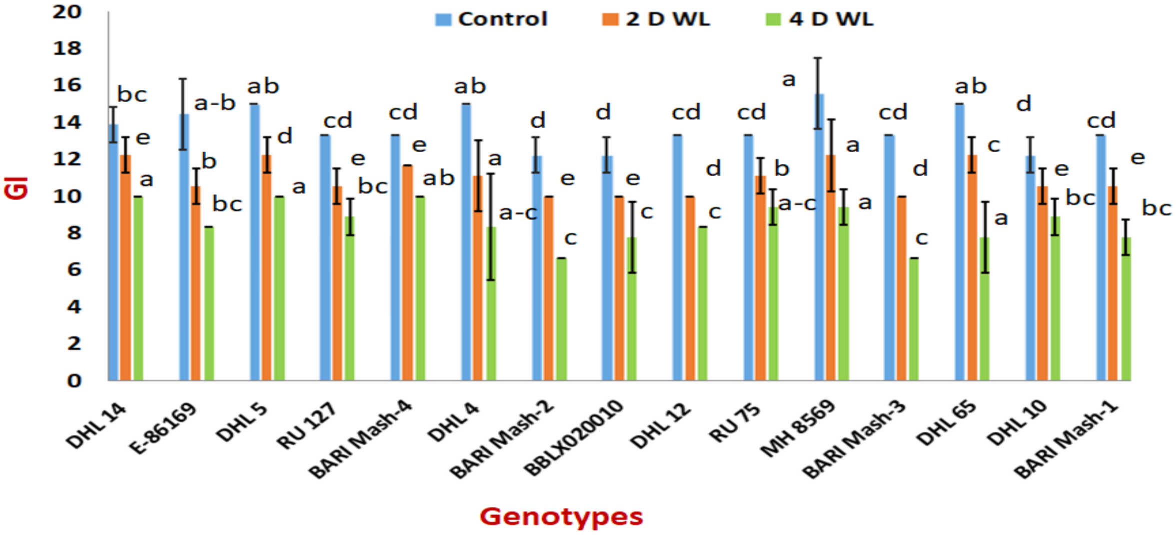


**Fig. 9.** Mean effects of waterlogging on the germination index (GI) of 15 black-gram genotypes

## CONCLUSION

Considering the results of this experiment, waterlogging reduced the germination percentage, germination speed, mean daily germination, root length, shoot length, reduction in root length, reduction in shoot length, root shoot ratio, and germination index. Compared with the control treatment, 2 days of waterlogging and 4 days of waterlogging decreased the germination percentage, germination speed, mean daily germination, root length, shoot length, root shoot ratio, and germination index. Eight (eight) black-gram genotypes, $V_2$ (86169), $V_3$ (DHL 5), $V_6$ (DHL 4), $V_9$ (DHL 12), $V_{10}$ (RU 75), $V_{11}$ (MH 8569), $V_{12}$ (BARI Mash-3) and $V_{13}$ (DHL 65), survived after six days of seed sowing. Therefore, these findings may be helpful for the selection of a water logged-tolerant black-gram genotype based on specific traits. Genotypes with improved traits may be used as parents in black-gram breeding for moisture conditions. Therefore, these selected genotypes may be useful for developing waterlogging-tolerant varieties of black gasses.

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