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ARTICLE

# Dry matter distribution, yield and seed quality of soybean (*Glycine max*) genotypes as affected by water stress

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**ABSTRACT** Water stress is a major constraint for crop productivity and culturing right cultivars may produce a considerable yield under such stressful condition. An experiment was conducted inside a vinyl house to evaluate the effect of water stress on dry matter distribution, yield, and seed quality of eight soybean genotypes, viz. G00006, BD2336, AGS383, PK472, BCS-1, NCS-1, BU Soybean-1 and BARI Soybean-6. They were grown in pots and subjected to water stress (20% of field capacity, FC) and control (80% of FC). The water stress reduced plant height, leaf number, leaf, stem, and root dry matter by 23, 45, 46, 45 and 19%, respectively, across the genotypes. Under water stress, the soybean genotypes G00006, BCS-1, NCS-1 and BARI Soybean-6 beard only 6 to 30% pod and 5 to 34% seed compared to the control condition. The results further indicated that yield of BD2336 and AGS383 were less affected by the stress than those of other genotypes. Interestingly, water stress exerted positive effect on seed germination, viability, speed of germination and vigor index in BD2336 and AGS383, respectively. Nitrogen and seed protein content were found the highest in BCS-1 under control (9.82 and 58.42% respectively) followed by AGS383. Phosphorus content in seed also reduced by the stress in the tested genotypes, except BD2336 (0.29% in control and 0.96% in water stress) and BARI Soybean-6. Potassium content in seed was reduced by the stress in the tested genotypes, except G00006 and BARI Soybean-6. Based on the findings related to water stress effects on yield and seed quality, particularly seed protein of the tested eight soybean genotypes, it was concluded that genotypes AGS383 and BD2336 might be considered for field trial under water deficit condition.
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## Introduction

Soybean (*Glycine max*), an important grain legume, plays an irreplaceable role for sustainable agricultural system, especially in relation to biological nitrogen fixation (Jha et al. 2018). It is a vital source of vegetable oil, protein, carbohydrate, minerals and vitamins for human (Mannan and Mamun 2018; Dola et al. 2022; Ahsan et al. 2023) and animal worldwide (Singer et al. 2019). The crop growth and development are constantly influenced by the change in environmental conditions, and any type of environmental stress is considered as the most important yield reducing factors in the world (Franklin et al. 2010). Water is necessary for the functioning of protoplasm of cell. Water deficit stress affects water relations in plant. Thus, too much or inadequate water is the limiting factor for maintaining life both in land and water environment. Drought is a major limiting factor seriously influencing worldwide soybean production, and its impact on yield, morphological and physiological traits depend on the timing it occurs and the intensity of water shortage (Yan et al. 2020; Franklin et al. 2010). It reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism, and growth promoters (Farooq et al. 2008). It affects both elongation and expansion of growth (Anjum et al. 2003) which ultimately affects the yield of plants. Soybean growth is negatively affected by drought, which cause less crop growth and substantial reductions in yield (Akand et al. 2018; Fatema et al. 2023; Mannan et al. 2023). Sustainability of soybean yields is, however, threatened by predicted climatic changes with persistent drought over many parts of the world (Dai 2013; Foyer et al. 2016). Selection of more drought-tolerant soybean cultivars is therefore required to address this imminent threat to food and protein security (Ku et al. 2013).

Soybean genotypes have been reported to have a wide variation in drought tolerance. As a means of natural adaptation, plants have been equipped with a wide spectrum of physiological responses to mitigate the damaging effects of drought stress. The response of plants to such stressors is polygenic, complex, and dynamic (Chaves et al. 2003). It is however, well known that drought stress induces the accumulation of abscisic acid which regulates stomatal closure thereby reducing photosynthetic activity (Chaves et al. 2009). In such conditions, resistance to abiotic stress becomes a favorable trait of crops. However, due to the wide range of plant stress responses with overlapping functions between their components and creating complex resistance mechanisms, the selection of a new variety becomes a challenge (Bartels and Souer 2004). Yardanov et al. (2003) claimed that water stress reduces the biomass, seed yield, number of pods in main stem, pod, and seed number per plant. According to Taiz and Zeiger (2002) mineral nutrients are essential chemical elements for plant growth and reproduction, which are primarily absorbed by the plants from soils in the form of inorganic ions. However, water stress disturbs smooth accumulation and maintenance of the balance ratio of the essential elements in plant cells.

The demand of soybean is increasing day by day in Bangladesh, mostly because of the development of consciousness among people about its high nutrition and use of the crop as a raw material for preparing animal feed (Haque et al. 2020). In Bangladesh, soybean area and production level have been increased substantially (USDA 2020; Mamun et al. 2022), and in 2019 the estimation on cultivation was 80,000 hectare and production was 152,000 tons, respectively. Furthermore, the soybean and soymeal imports were 1.1 million tons and 550,000 tons, respectively, to keep pace with the demand in the feed industry. So, soybean is a promising crop in this country and there is a spacious scope to increase further its production. Considering the above-described situation the present piece of research work was undertaken to find out the effect of drought on growth and dry matter production seed yield, nutrient uptake, and seed quality of some selected soybean genotypes.

## Materials and Methods

### *Experimental site*

The study was conducted in pots in vinyl house of Agronomy research field of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur (24° 03' North latitude and 90° 39' East longitude), Bangladesh. The site is in Madhupur Tract under Agro Ecological Zone 28. The experimental site is situated in a sub-tropical climatic zone, characterized by scanty rainfall during the month from October to May and heavy rainfall during the month from June to September. The mean monthly maximum air temperature of this area varies between 29 and 34 °C and minimum between 18 to 26 °C.

### *Pot preparation*

The experimental pots were filled with mixture of soil and cow dung (ratio was 4:1). The pot was 18 cm in height and 15 cm inner diameter. The weight of each pot was 12 kg along with soil and the soil was sandy loam with low organic matter. The soils of each pot were fertilized uniformly with 0.15 g of urea, 0.18 g of triple super phosphate, 0.36 g of muriate of potash and 0.10 g of gypsum. Total amount of all fertilizers was mixed with soil before the sowing of seeds.

### *Experimental treatment and design*

A randomized complete block design with five replications was followed to conduct the experiment. The experimental treatments consisted of two factors, viz. Factor A (8 soybean genotype) included G00006, BD2336, AGS383, PK472, BCS-1, NCS-1, BU Soybean-1 and BARI Soybean-6; and Factor B (growing condition) was drought (20% of field capacity (FC) and control (80% of FC)).

### *Sowing of seed and treatment imposition*

Healthy seeds were sown in soil by hand on 03 May 2018 in each pot. In every pot five seeds were sown maintaining uniform distance. Each pot was considered as a single replication. After sowing, the seeds were covered with soil and a light irrigation was applied. After sowing of seeds, light irrigation was given to ensure uniform germination of seeds in each pot. Pots were irrigated properly for the proper establishment of the young seedlings. After seedling establishment, one healthy plant was kept in each pot for subsequent treatment imposition. Water stress treatment was imposed after trifoliate stage of the crop (15 days after sowing). One day before treatment imposition, irrigation was applied to each pot to maintain equal soil moisture content in all the pots. Water stress condition was induced by withholding water until wilting symptom was observed in plants. Wilting symptom in plants was visually observed every day. Measured amount of water was applied to each pot at the first appearance of wilting symptom in plants to maintain 20% of FC. In control treatment, water was applied when it was needed to maintain 80% of FC.

### *Collection of growth and yield data*

Plant height was measured using a meter scale (100 cm) at the flowering stage. The plants were cut from ground level, and the height of the sample plants was measured from the base to the tip of the main shoot. To measure the number of leaves per plant, the leaves of the sample plants were counted (1, 2, 3, 4, etc.) at the flowering stage. After collecting, the leaves were dried in an oven for 72 h. Subsequently, the weight of the leaves was measured with an electronic balance, and the mean value was recorded. Total number of branches on the sample plants was recorded. Only branches bearing pods and leaves were included in this count. A plant with no branches was recorded as having zero branches; the total number of branches from the five plants was averaged and recorded. After collection, the stems of the sample plants were dried in an oven for 72 h. The weight of the stems then measured with an electronic balance, and the mean value was recorded. The roots of the sample plants were similarly treated: after drying in the oven for 72 h, their weight was measured, and the mean value was recorded. All pods from the sample plants were manually counted at harvest. Both filled and unfilled pods were counted and recorded, but only filled pods were considered for this measurement. The total number of seeds was counted, and the average value was recorded. The weight of 100 seeds was recorded for each genotype, from both control and drought conditions. The total seeds from the sample plants were weighed with an electronic balance. The moisture content of seeds was measured using a handheld moisture meter. The grain yield was adjusted to a moisture content of 14%.

### *Quantification of seed quality data*

A wet paper was put on top of plastic trays and kept it in a warm place. Hundred seeds were sown in every tray. They were checked regularly and counted germinated seeds, and kept the paper moist, until all the viable seeds were germinated. Final germination count was made according to International Seed Testing Association (ISTA 2006). Germination percentages were calculated by using the following formula:

$$\text{Germination (\%)} = (\text{Number of seeds germinated} / \text{Number of seeds incubated for germinated}) \times 100$$

A viable seed is one which is capable of germination under suitable conditions. The definition includes dormant but viable seeds, in which case the dormancy must be broken before viability can be measured by germination which is the most accurate and reliable method. So, germination test was done for seed viability. This indicated by the percent production of healthy, vigorous, and normal seedlings from pure seed of laboratory. Seed viability was measured by following formula:

$$\text{Seed viability} = \text{Analytical purity (\%)} \times \text{Germination (\%)}/100$$

The simplest method is to make preliminary germination counts at a standard time before germination is completed. The speed of germination of seed sample was monitored by counting the germinated seedling at an interval of 24 h and counted for twelve days (until germination is completed). An index of the speed of germination is then calculated by adding the quotients of the daily counts divided by the number of days of germination. Thereafter a germination index (G.I.) is computed by using the following formula:

$$\text{G.I.} = n/d$$

Where, n = number of seedlings emerging on day 'd'; d = day after planting. The seed lot having greater germination index was considered to be more vigorous.

Seeds were sown in the plastic tray like germination test. After seven days at 25 °C, the length of roots and shoots were measured with a ruler. The average length of seedlings per sample was calculated. Seedling vigor index (VI) was calculated using following formula:

$$\text{VI} = \text{Germination at last count (\%)} \times [\text{shoot length (mm)} + \text{root length (mm)}]$$

The electrical conductivity of the seed was tested using standard procedure. EC meter was used to determine electrical conductivity of seed. This electrical conductivity of seed was measured to know the quality of seed.

### *Determination of nutrient and protein content*

The Kjeldahl method was used to determine nitrogen percentage in plant sample. The plant sample was digested with a strong acid, and it released nitrogen which was determined by Automatic Kjeldahl Nitrogen/Protein Analyzer (UDK 159, VELP Scientifica, Italy). The amount of crude protein present in plant samples was also calculated automatically from the nitrogen concentration of the plant by Automatic Kjeldahl Nitrogen/Protein Analyzer (UDK 159, VELP Scientifica, Italy). The spectrophotometric method was used to determine of phosphorus in the plant sample. The potassium level in the plant material was measured by oxidising the sample and then mashing it with hydrochloric acid. This was then dissolved in acid and diluted. This solution was then measured against acidified standards.

### Analysis of the data

The recorded data was statistically analyzed using computer software "CropStat 7.2". The treatment means were compared by Duncan's Multiple Range Test (DMRT) at 5% level of significance (Gomez and Gomez 1984). Some calculations and graphs were prepared using Excel software (Microsoft Corporation, Redmond, WA, USA).

## Results and Discussion

### Plant height

Water deficit significantly affected the plant height of the tested soybean genotypes (Fig. 1). Among the eight soybean genotypes, NCS-1 reached the tallest height under control conditions. In these conditions, the second tallest plant was observed in BCS-1, which had statistically similar heights to both NCS-1 and BARI Soybean-6. Under control conditions, the plant height of NCS-1 was 196 cm, which decreased to 133 cm under water stress. Similarly, plant height was reduced by 32% and 26% due to drought in the soybean genotypes BCS-1 and BARI Soybean-6, respectively. Although plant height was reduced under water deficit conditions, the reduction was statistically insignificant in the genotypes PK472 and BU Soybean-1. These two genotypes exhibited similar plant heights under both control and drought conditions, measuring 135 cm and 118 cm in control, and 126 cm and 105 cm under drought conditions, respectively. The shortest plant height was recorded for AGS383, which reached 96 cm under drought conditions. Similarly, BD2336 had a plant height of 97 cm in drought conditions. The soybean genotypes G00006 (147 cm) and BD2336 (146 cm) had statistically similar plant heights under control conditions.

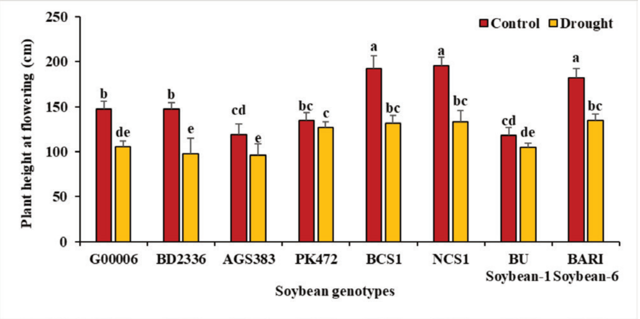


**Figure 1.** Effect of water stress on plant height of soybean genotypes at flowering stage. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

### Leaf number per plant

The interaction of genotype and water levels exerted a significant effect on leaf number per plant (Fig. 2). Among eight soybean genotypes, BARI Soybean-6 produced maximum leaf number per plant under control. In control condition, the second highest leaf number per plant was recorded in NCS-1, which was statistically similar with BARI Soybean-6 and by AGS383. The leaf number of BARI Soybean-6 was 55 in control that reduced to 22.6 in drought.

Similarly, leaf number reduced by 49.4% and 43.1% due to drought in soybean genotypes NCS-1 and AGS383, respectively. Although leaf number reduced under water deficit compared to control, but this reduction of leaf number was insignificant in case genotypes BU Soybean-1 and G00006. These two genotypes gave statistically similar leaf number under both control and drought conditions. BU Soybean-1 and G00006 produced leaf number of 29 and 31 in control, while 20.40 and 25.80 in drought condition, respectively. The lowest leaf number was measured in BCS-1 that produced leaf number of 13.20 in drought. BD2336 gave plant number 16 in drought condition which is identical to BCS-1. Soybean genotypes BCS-1 (44) and BD2336 (38) produced statistically similar leaf number in control. This finding agreed with the previous results (Wu et al. 2000; Fatema et al. 2023). Water stress condition reduces the leaf number because drought stress reduced leaf initiation and accelerated leaf senescence as reported by Chowdhury et al. (2015).

### Leaf weight

Shortage of water caused decreased in dry matter production of leaves in large extent when compared to control in all soybean genotypes. Among eight soybean genotypes, AGS383 produced the highest leaf weight under control.

In control condition, the second highest leaf weight was recorded in BCS-1, which was statistically identical with AGS383 followed by PK472. The leaf weight of AGS383 was 19.8 g in control that reduced to 14.7 g in drought.

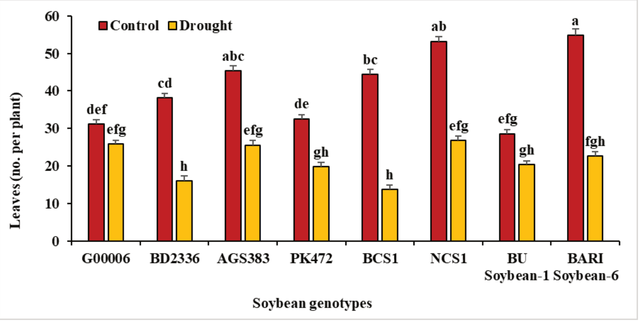


**Figure 2.** Effect of water stress on leaf number of soybean genotypes at flowering stage. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

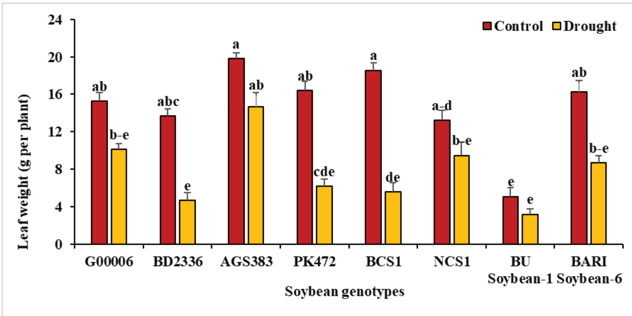


**Figure 3.** Effect of water stress on leaf weight of soybean genotypes at flowering stage. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

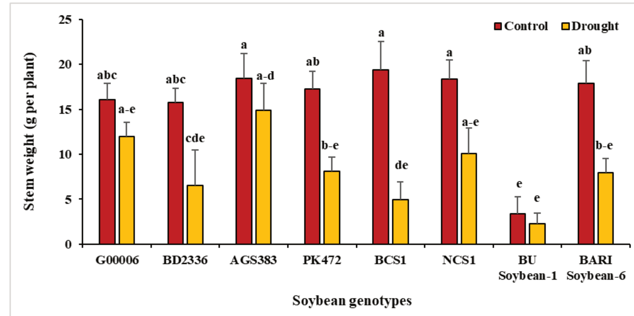


**Figure 5.** Effect of water stress on stem weight of soybean genotypes at flowering stage. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

Similarly, leaf weight reduced by 69.6% and 62.2%, due to drought in soybean genotypes BCS-1 and PK472, respectively (Fig. 3). Although, leaf weight reduced under water deficit compared to control, but this reduction of leaf weight was insignificant in case genotypes AGS383 and BU Soybean-1. These two genotypes gave statistically similar leaf weight under both control and drought conditions. AGS383 and BU Soybean-1 produced leaf weight of 19.8 g and 5.094 g in control, while 14.7 g and 3.148 g in drought condition, respectively. The lowest leaf weight was measured in BU Soybean-1 that produced leaf weight of 3.148g in drought. Similarly, BD2336 gave leaf weight of 4.678 g in drought condition which is identical with BU Soybean-1. G00006 (15.256 g), PK472 (16.39 g) and BARI Soybean-6 (16.246 g) produced statistically similar leaf weight in control. BU Soybean-1 (3.148 g), BD2336 (4.678 g) and BCS-1 (5.598 g) produced statistically similar leaf weight in drought.

### *Branch number per plant*

Branch number per plant was influenced significantly due to water stress in soybean genotypes (Fig. 4). Among eight soybean genotypes, BARI Soybean-6 produced maximum branch number per plant under control. In control condition, the second highest branch number per plant was recorded in G00006, which was statistically identical with BARI Soybean-6 followed by NCS-1. The branch number of BARI Soybean-6 was 18.2 in control that reduced to 4.4 in drought. Similarly, branch number reduced by 66.2% and 82.7 due to drought in soybean genotypes G00006 and NCS-1, respectively. Although, branch number reduced under water deficit compared to control, but this reduction of branch number was insignificant in case of genotypes BU Soybean-1, BD2336 and AGS383. These three genotypes gave statistically identical branch number under control. BU Soybean-1, BD2336 and AGS383 produced branch number of 4.8, 6 and 6.2 in control, while 4, 4.6 and 3.8 in drought condition, respectively. The lowest branch number was measured in PK472 that produced branch number of 2.8 in drought which was identical with AGS383 (3.8) and BCS-1 (3). Soybean genotypes NCS-1 (12.6) produced statistically similar branch number with BARI Soybean-6 (18.2) and G00006 (17.8) in control.

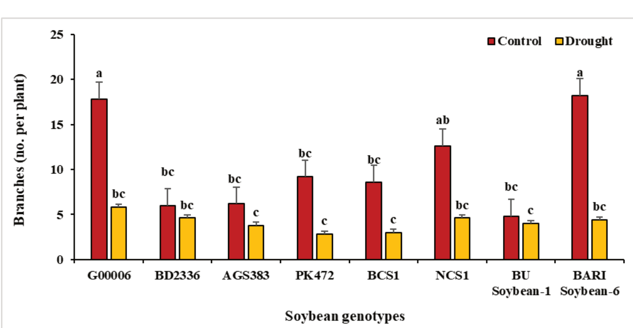


**Figure 4.** Effect of water stress on branch number of soybean genotypes at flowering. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

### *Stem weight*

Water stress significantly reduced the stem and whole plant biomass at the flowering stage for all soybean genotypes (Fig. 5). The highest dry stem weight was observed in genotype BCS-1, followed closely by AGS383, which showed statistically similar weights to NCS-1 and BCS-1 under control conditions. The reduction of stem weight of soybean genotype BCS-1 was 19.36 g to 4.93 g, AGS383 was 18.4 g to 14.9 g and NCS-1 was 18.32 g to 10.066 g in control and drought stress, respectively, at flowering stage. The reduction percentage of stem weight of genotype BCS-1, AGS383 and NCS-1, was 22.88%, 19.02% and 45.08%, respectively. The minimum dry stem weight was

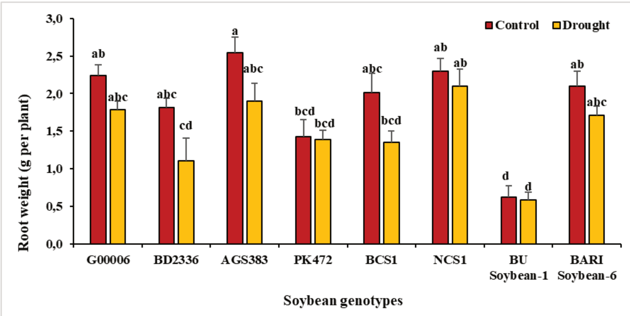


**Figure 6.** Effect of water stress on root weight of soybean genotypes at flowering stage. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

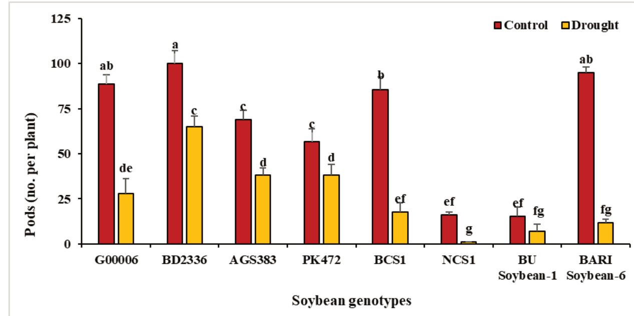


**Figure 7.** Effect of water stress on pod production of soybean genotypes. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

observed in BU Soybean-1 in both control and drought condition. The reduction of dry stem weight of soybean genotype BU Soybean-1 was 3.346 g in control which decreased to 2.31 g in drought. Although, stem weight reduced under water deficit compared to control, but this reduction of stem weight was insignificant in case of genotypes BU Soybean-1, G00006 and AGS383.

### *Root weight*

It was observed that root weight of soybean reduced significantly under water deficit condition (Fig. 6). Among eight soybean genotypes, AGS383 produced the highest root weight under control. In control condition, the second highest leaf weight was recorded in NCS-1, which was statistically similar with AGS383 and identical with G0006. The root weight of AGS383 was 2.5 g in control that reduced to 1.9 g in drought. Similarly, root weight reduced by 8.69% and 19%, due to drought in soybean genotypes NCS-1 and G00006, respectively. Although, root weight reduced under water deficit compared to control, but this reduction of root weight was insignificant in case of genotypes PK472, BU Soybean-1 and NCS-1. These three genotypes gave statistically similar root weight under both control and drought conditions. PK472, BU Soybean-1 and NCS-1 produced root weight of 1.4, 0.6 and 2.3g and in control, while 1.392 g, 0.588 g and 2.1 g in drought condition, respectively. The lowest root weight was measured in BU Soybean-1 that produced root weight of 0.588 g in drought. PK472 (1.4 g) and BCS-1 (1.348 g) produced statistically identical root weight in drought. NCS-1 (2.3 g), G00006 (2.2 g) and BARI Soybean-6 (2.1 g) produced statistically identical root weight in control. Chowdhury et al. (2015) found that root dry weights of selected genotypes were significantly affected by the stress.

### *Pod production*

Water stress caused significant differences in pods per plant of soybean genotypes (Fig. 7). Among eight soybean genotypes, BD2336 produced the highest number of pods per plant under control. In control condition, the second highest number of pods per plant was recorded in BARI Soybean-6, which was statistically similar with BD2336 and identical with G00006. The number of pods per plant of BD2336 was 100 in control that reduced to 65 in drought. Similarly, pod production reduced by 68.46% and 87.78%, due to drought in soybean genotypes G00006 and BARI Soybean-6, respectively. Although, number of pods per plant reduced under water deficit compared to control, but this reduction of number of pods per plant was insignificant in case of genotypes BU Soybean-1. In case of other seven genotypes (without BU Soybean-6) significant reduction was observed. The lowest number of pods per plant was measured in NCS-1 that produced only one pod per plant in drought. Similar results also reported by Akand et al. (2018). Results showed that water deficiency in seed filling phase reduced the numbers of

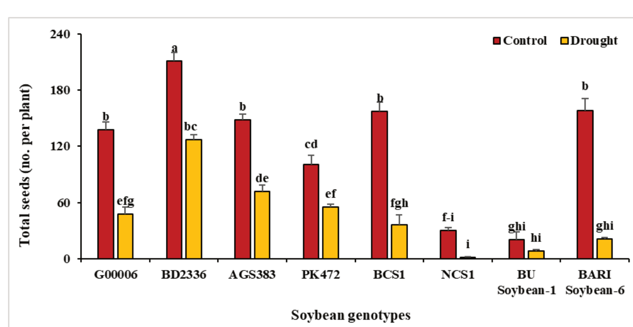


**Figure 8.** Effect of water stress on total seed production of soybean genotypes. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

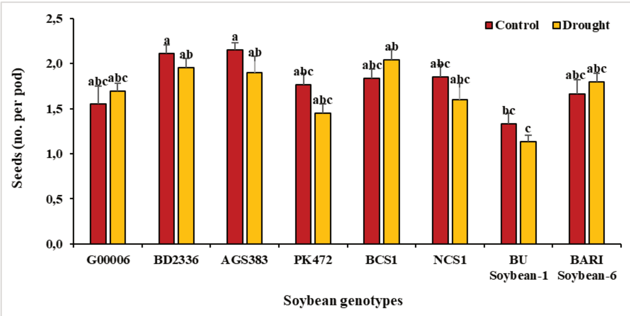


**Figure 9.** Effect of water stress on no of seeds per pod of soybean genotypes. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

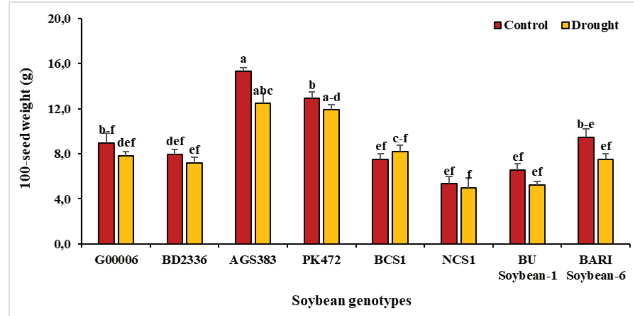


**Figure 10.** Effect of water stress on 100-seed weight of soybean genotypes. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

fertile pods per plant. Loss of flowers and pods during early reproductive phase is a possible reason for reduction of the number of pods per plant (Maleki et al. 2013). The reduction in pod number per plant due to water stress was reported earlier in French bean (Omae et al. 2005), in soybean (Kokubun et al. 2001; Liu et al. 2004; Tareq et al. 2022) and in mung bean (Islam 2008).

### *Seed production*

Drought stress reduced the number of seed production per plant in all the tested soybean genotypes (Fig. 8). Under control condition, the highest number of seeds per plant (211.20) was found in BD2336 which was closely followed by BARI Soybean-6 and BCS-1 while the lowest number of seeds per plant was produced by BU Soybean-1. Among those BARI Soybean-6, BCS-1, AGS383 and G00006 were identical in control. Number of seed significantly reduced in six genotypes (G00006, AGS383, BD2336, PK472, BCS-1 and BARI Soybean-6) among eight genotypes in stress condition. Akand et al. (2018) also stated that soybean plants exposed to drought produced reduced number of seeds per plant. Chowdhury et al. (2015) recorded that seed yield of selected genotypes was reduced from 42 to 68% due to drought (water) over non-stress.

Under control condition, AGS383 produced highest number of seeds (2.2 / pod) and the second highest was BD2336 (2.1) which is identical with AGS383 and followed by NCS-1. The seed number per pod of AGS383 was 2.2 in control that reduced to 1.9 in drought. Similarly, seed number per pod reduced by 15.78% and 6.67% due to drought in soybean genotypes NCS-1 and BD2336 respectively (Fig. 9). Although, seed number per pod reduced under water deficit compared to control, but this reduction of leaf number was insignificant in case of all genotypes. Four genotypes (G00006, PK472, NCS-1 and BARI Soybean-6) gave statistically identical seed number per pod under both control and drought conditions. The lowest seed number per pod was measured in BU Soybean-1 that produced seed number per pod of 1.3 and 1.13 in control and drought respectively. G00006, BCS-1 and BARI Soybean-6 performed better in drought than in control. The number of seeds per pod and seed weight were reported to be more stable and less affected by environmental stress.

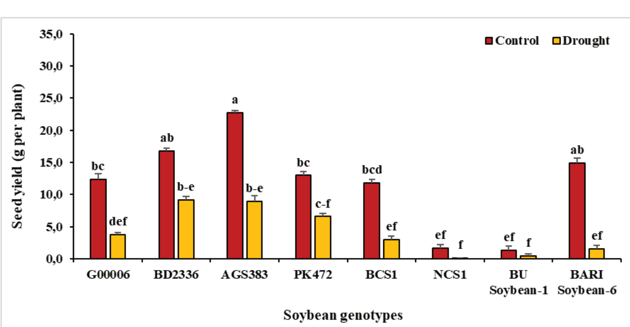


**Figure 11.** Effect of drought on seed yield per plant of soybean genotypes. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

### *100-seed weight*

A significant reduction in 100-seed weight of soybean genotypes was observed due to water stress (Fig. 10). Among eight soybean genotypes, AGS383 produced the highest 100-seed weight under control. In control condition, the second highest 100-seed weight was recorded in PK472 and followed by BARI Soybean-6. The 100-seed weight of AGS383 was 15.3 g in control that reduced to 12.45 g in drought. Similarly, 100-seed weight reduced by 8.52% and 20.1% due to drought in soybean genotypes PK472 and BARI Soybean-6, respectively. Although, 100-seed weight reduced under water deficit compared to control, but this reduction of plant height was insignificant in

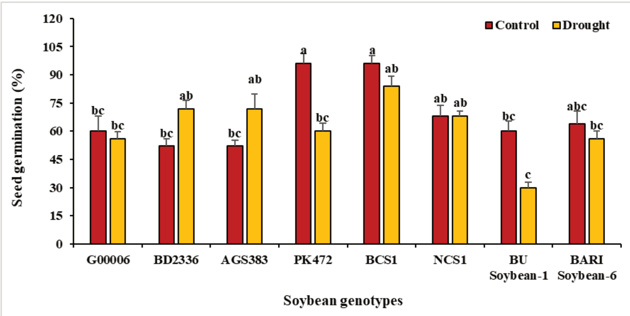


**Figure 12.** Effect of water stress on germination of different soybean genotypes. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

case of genotypes NCS-1 and BU Soybean-1. These two genotypes gave statistically similar 100-seed weight under both control and drought conditions. NCS-1 and BU Soybean-1 produced 100-seed weight of 5.3 and 6.5 g in control, while 5 and 5.2 g in drought condition, respectively. The lowest 100-seed weight was measured in NCS-1 that produced a plant of 5 g in drought. Similarly, BU Soybean-1 gave a plant of 5.20 g in drought condition. Soybean genotypes AGS383 and PK472 are top performer in both control and drought. Compared with the control, drought stress significantly reduced the 100-seed weight of soybean reported by Du et al. (2020).

### *Seed yield*

Seed yield of soybean reduced significantly under water stress in all soybean genotypes (Fig. 11). Among all the genotypes, seed production was minimum affected by drought in AGS383. It produced significantly highest seed yield under control and second highest under drought condition which was 22.70 and 8.97 g seed per plant in control and drought stress, respectively. BD2336 and BARI Soybean-6 yielded 16.75 and 14.89 g seed per plant in control, which reduced to 9.16 and 1.51 g per plant under drought stress, respectively. As compared to control, the yield of BD2336, AGS383 and BARI Soybean-6 were reduced by 45.31, 60.48 and 89.52%, respectively, under drought condition. Moreover, AGS383 was the top yielder under control and BD2336 was the top yielder under drought conditions. The heavier grain size in AGS383 mostly contributed to the higher grain yield as compared to the other genotypes. Although, seed yield reduced under water deficit compared to control, but this reduction of seed yield was insignificant in case of genotypes NCS-1 and BU Soybean-1. These two genotypes gave statistically identical seed yield under both control and drought conditions. NCS-1 and BU Soybean-1 produced seed yield 1.6 and 1.3 g in control, while 0.08 and 0.41g in drought condition, respectively. The lowest seed yield was measured in NCS-1 that produced a plant of 0.08 g in drought. Soybean genotypes BARI Soybean-6 and BD2336 produced statistically identical seed yield in control. Akand et al. (2018) also reported that AGS383 performed better under both control and water deficit conditions. Reduction of leaf number area under drought is an important cause of reduced crop yield through reduction of Pn (Kramer 1983). The water stress reduces grain yield through reducing the number of pods per plant and seed size. The results of this study concerning the effect of water stress on grain yield also comparable with the findings of other researchers (Sadasivam et al. 1988; Taiz and Zeiger 2002; Liu et al. 2003). The decrease in pod number per plant and seed size under drought stress was possibly due to reduction of photosynthesis, translocation of assimilates and increased rate of reproductive organs abortion (Liu et al. 2003 and 2004).

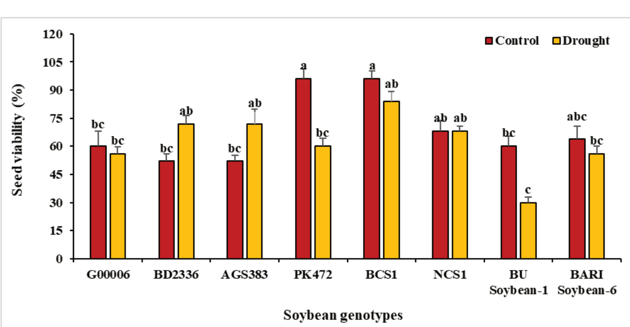


**Figure 13.** Effect of water stress on viability of soybean genotypes. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

### *Seed germination*

The effect of water stress on seed germination was evident across all soybean genotypes (Fig. 12). Among the eight soybean genotypes, BCS-1 exhibited the highest germination rate under control conditions. In this setting, the second highest germination rate was noted in PK472, which was statistically equivalent to BCS-1, followed by NCS-1. The germination rate for BCS-1 was 96% under control conditions, which decreased to 84% during drought. Similarly, the germination rate decreased by 37.5% in PK472 and remained unchanged in NCS-1 under drought conditions. Although germination generally decreased under water deficit compared to control conditions, this reduction was statistically insignificant for all genotypes. BD2336 and AGS383 exhibited statistically identical germination rates under both control and drought conditions. G00006 and NCS-1 showed no statistically significant reduction in germination across

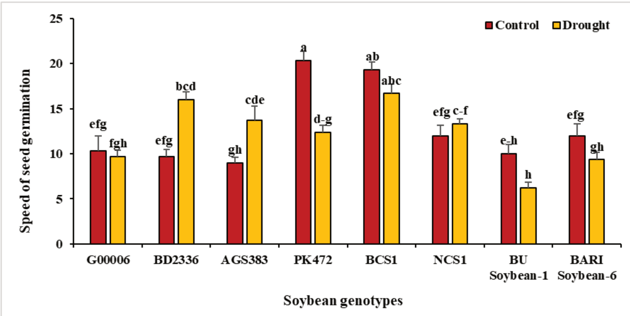


**Figure 14.** Effect of water stress on speed of soybean seed germination. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

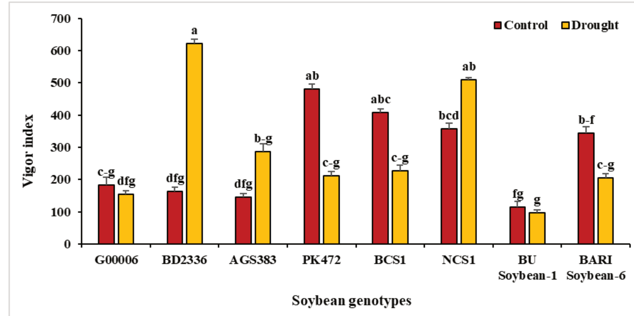


**Figure 15.** Effect of water stress on vigor of soybean seed. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

both conditions. The lowest germination rate was recorded in BU Soybean-1, with a 30% germination rate under drought. BCS-1 demonstrated the highest performance under both control and drought conditions. BD2336 and AGS383 performed better under drought than under control conditions.

### *Seed viability*

Water deficit significantly affected seed viability among the tested soybean genotypes (Fig. 13). Among the eight soybean genotypes, BCS-1 exhibited the highest germination rate under control conditions. In this setting, the second highest germination rate was recorded in PK472, which was statistically comparable to BCS-1 and followed by NCS-1. The germination rate for BCS-1 was 96% under control conditions, which decreased to 84% during drought. Similarly, the germination rate decreased by 37.5% in PK472 and remained unchanged in NCS-1 under drought conditions. Although the overall germination rate decreased under water deficit compared to control conditions, this reduction was statistically insignificant for all genotypes. BD2336 and AGS383 demonstrated statistically identical germination rates under both control and drought conditions. Both G00006 and NCS-1 showed no statistically significant reduction in germination across both conditions. The lowest germination rate was observed in BU Soybean-1, with a 30% germination rate under drought. BCS-1 maintained the highest performance under both control and drought conditions. BD2336 and AGS383 performed better under drought than under control conditions.

### *Speed of seed germination*

The speed of seed germination was significantly influenced by water stress in soybean genotypes (Fig. 14). Among the eight soybean genotypes, PK472 exhibited the highest speed of seed germination under control conditions. In this setting, the second highest speed was recorded for BCS-1, which was statistically similar to PK472 and followed by BARI Soybean-6. Under control conditions, the germination speed of PK472 was 20, which decreased to 12.13 under drought conditions. Similarly, the speed of seed germination decreased by 12.26% and 32.25% for the soybean genotypes BCS-1 and BARI Soybean-6, respectively. Although most plants experienced a reduction in germination speed under water deficit compared to control conditions, this reduction was statistically insignificant for most of the genotypes. Only PK472 exhibited a significant reduction in the speed of seed germination. A few genotypes, such as BD2336, AGS383, and NCS-1, performed better under drought conditions. BCS-1 maintained a comparatively higher speed of seed germination in both control and drought conditions than other genotypes.

### *Seed vigor*

It was observed that seed vigor in soybean significantly decreased under water deficit conditions (Fig. 15). Among

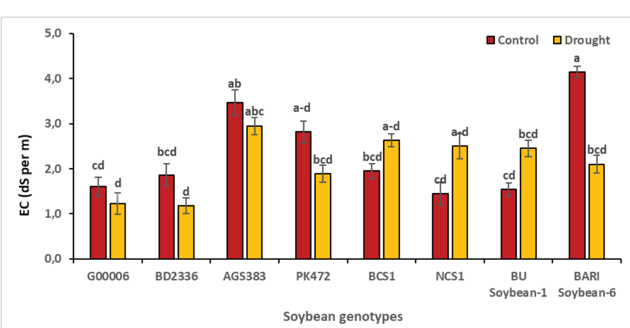


**Figure 16.** Effect of water stress on electrical conductivity of soybean seed. Bars are means ±SD taken from three observations. Groups sharing the same letter indicate no significant difference. *P*-values lower than 0.05 were considered as significant.

**Table 1.** Effect of water stress on nitrogen and protein content of soybean seeds of different genotypes.

| Soybean genotypes | Nitrogen (%) | | Protein (%) | |
|---|---|---|---|---|
| | Control | Drought | Control | Drought |
| G00006 | 8.29 bc | 8.21 bc | 49.32 bc | 48.84 bc |
| BD2336 | 8.83 ab | 8.15 bc | 52.52 ab | 48.50 bc |
| AGS383 | 8.97 ab | 8.35 bc | 53.35 ab | 49.67 bc |
| PK472 | 8.31 bc | 9.04 ab | 49.44 bc | 53.77 ab |
| BCS-1 | 9.82 a | 8.04 bc | 58.42 a | 47.86 c |
| NCS-1 | 8.31 bc | 7.52 c | 49.41 bc | 44.76 c |
| BU Soybean-1 | 8.29 bc | 8.22 bc | 49.33 bc | 48.91 bc |
| BARI Soybean-6 | 8.35 bc | 8.48 bc | 49.71 bc | 50.43 bc |
| CV (%) | 15.2 | 12.8 | | |

Similar letters in a column did not vary significantly.

eight soybean genotypes, PK472 exhibited the highest seed vigor under control conditions. The second highest seed vigor was recorded in BCS-1, which was statistically like PK472 and followed by NCS-1. In control conditions, the seed vigor of PK472 was 481, which decreased to 212 during drought. Similarly, seed vigor decreased by 44% in BCS-1 due to drought. Although seed vigor generally decreased under water deficit compared to control conditions, this reduction was statistically insignificant in the genotypes G00006 and BU Soybean-1. A different phenomenon was observed in BD2336, NCS-1, and AGS383. These three genotypes demonstrated better seed vigor under drought conditions compared to control. BD2336 showed the highest seed vigor (621.40) in drought conditions. NCS-1 exhibited seed vigor statistically similar to BD2336, measuring 508 under drought conditions. The lowest seed vigor was observed in BU Soybean-1 in both control and drought conditions.

### *Electrical conductivity of seed*

Water stress caused significant differences in the electrical conductivity of seeds among all tested soybean genotypes (Fig. 16). Among eight soybean genotypes, the highest electrical conductivity of seeds was observed in BARI Soybean-6 under control conditions. In this setting, the second highest electrical conductivity was recorded in AGS383, which was statistically similar to BARI Soybean-6 and followed by PK472. The electrical conductivity of BARI Soybean-6 seeds was 4.1 under control conditions, which decreased to 2.1 under drought conditions. Similarly, the electrical conductivity of seeds decreased by 15.71% in AGS383 and 32.5% in PK472 due to drought.

Although electrical conductivity of seeds decreased under water deficit compared to control, this reduction was insignificant for the AGS383 and G00006 genotypes. In control conditions, AGS383 and G00006 had electrical conductivities of 3.5 and 1.6, respectively, which changed to 2.95 and 1.23 under drought. The lowest conductivity, 1.5, was measured in BD2336 under drought conditions. G00006 also recorded a similar conductivity of 1.23, matching BD2336 statistically in drought. In control conditions, BD2336 and BCS-1 both had identical conductivities of 1.9. In contrast, BCS-1 (2.63), NCS-1 (2.5), and BU Soybean-1 (2.45) registered higher conductivities under drought than in control.

### *Nutrient content of seeds*

Drought significantly affected nitrogen and protein levels in soybean genotypes, evident from genotypic variations (Table 1). BCS-1 had the highest nitrogen content under control conditions at 9.82%, closely followed by AGS383 and BD2336, which were statistically similar to BCS-1. Under drought, BCS-1's nitrogen content dropped to 8.04%, with AGS383 and BD2336 experiencing 7% and 8% reductions, respectively. Despite these changes, the reduction in nitrogen was insignificant for AGS383 and BD2336, maintaining similar levels in both conditions. For instance, AGS383's nitrogen content changed from 8.97% in control to 8.35% in drought, and BD2336's from 8.83% to 8.15%. NCS-1 registered the lowest nitrogen at 7.52% in drought. The genotypes G00006, PK472, NCS-1, BU Soybean-1, and BARI Soybean-6 were statistically similar in control, while in drought, G00006, BD2336, AGS383, BCS-1, BU Soybean-1, and BARI Soybean-6 matched statistically. Interestingly, G00006, BU Soybean-1, and BARI Soybean-6 showed no statistical difference in both conditions, and PK472 recorded a higher nitrogen percentage in drought than in control.

In protein content, BCS-1 led under control with 58.42%, followed by AGS383 at 53.35% and BD2336 at 52.52%, all statistically similar. In drought, protein content for BCS-1 fell to 47.86%, with AGS383 and BD2336

**Table 2.** Effect of drought on phosphorus and potassium content (%) of soybean seeds of different genotypes.

| Soybean genotypes | Phosphorus (%) | | Potassium (%) | |
|---|---|---|---|---|
| | Control | Drought | Control | Drought |
| G00006 | 0.65 cd | 0.44 ef | 0.37 c | 0.45 abc |
| BD2336 | 0.29 h | 0.96 a | 0.66 a | 0.65 a |
| AGS383 | 0.67 cd | 0.51 e | 0.57 ab | 0.45 abc |
| PK472 | 0.84 ab | 0.27 h | 0.56 abc | 0.46 abc |
| BCS-1 | 0.58 de | 0.31 g | 0.43 bc | 0.47 abc |
| NCS-1 | 0.55 de | 0.48 ef | 0.55 abc | 0.53 abc |
| BU Soybean-1 | 0.48 ef | 0.43 efg | 0.41 bc | 0.38 bc |
| BARI Soybean-6 | 0.35 fg | 0.79 bc | 0.59 ab | 0.65 a |
| CV (%) | 11.7 | 14.2 | | |

Similar letters in a column did not vary significantly.

seeing 7% and 8% decreases, respectively. The reductions were statistically insignificant for AGS383 and BD2336, who showed similar protein levels in both conditions: 53.35% and 52.52% in control, and 49.67% and 48.50% in drought, respectively. The lowest protein was in NCS-1, with 44.76% in drought. Like nitrogen, G00006, PK472, NCS-1, BU Soybean-1, and BARI Soybean-6 were statistically identical in control, with G00006, BD2336, AGS383, BU Soybean-1, and BARI Soybean-6 matching in drought, showing no differences in both conditions. PK472 had a higher protein percentage in drought than in control (Table 1).

#### *Phosphorus and potassium content*

Phosphorus and potassium levels in soybean were significantly affected under water deficit conditions, as shown in Table 2. Among the eight genotypes, PK472 had the highest phosphorus content under control conditions at 0.84%. The next highest levels were found in AGS383 (0.67%) and G00006 (0.65%), both statistically comparable to PK472. In drought conditions, PK472's phosphorus content dramatically decreased to 0.27%. Similarly, phosphorus levels decreased by 23.88% in AGS383 and 32.30% in G00006 due to drought. Although phosphorus decreased under water stress, this reduction was not significant in the BU Soybean-1 genotype. The lowest phosphorus during drought was recorded in PK472 at 0.27%. G00006 and AGS383 were statistically identical under control conditions, while G00006 and NCS-1 were identical in drought. Notably, BD2336 showed an increase in phosphorus, recording 0.96% under drought compared to control.

In terms of potassium, BD2336 recorded the highest levels under control, with BARI Soybean-6 and AGS383 (0.57%) closely following, both statistically similar to BD2336. The potassium level in BD2336 was 0.66% in control and slightly decreased to 0.65% in drought. Potassium decreased by 21.5% in AGS383 due to drought, whereas BARI Soybean-6 experienced a 10.12% increase. Although overall potassium levels decreased under water deficit, the reduction was insignificant in AGS383 and BD2336, both maintaining similar levels in control and drought conditions. The lowest potassium was recorded in BU Soybean-1 at 0.38% in drought. PK472 and NCS-1 were statistically identical in both control and drought conditions. Notably, G00006, BCS-1, and BARI Soybean-6 showed higher potassium percentages in drought compared to control (Table 2).

## Conclusions

Water stress negatively affected growth and yield of soybean genotypes. Among the yield components, pod and seed production reduced by 33 to 94% and 40 to 95% due to water stress across the genotypes, respectively. Grain yield of soybean varied from 1.34 to 22.70 g per plant in control, while that reduced to 0.10 to 9.16 g per plant due to drought across the genotypes. The grain yield of AGS383 was the highest under control, while the 2$^{nd}$ highest after BCS-1 under drought condition. This genotype produced 22.70 and 8.96 g per plant in control and drought, respectively. On the other hand, water stress reduced grain yields up to 89 to 95% in NCS-1 and BARI Soybean-6, respectively. Water stress hampered seed germination, viability, speed of germination, and vigor of soybean. Similarly, nitrogen, potassium, phosphorus, and protein concentrations in seed were also decreased under water stress in soybean. Nitrogen and seed protein content were found the highest in BCS-1 under control (9.82 and 58.42%, respectively) followed by AGS383 (8.97 and 53.35%, respectively), while that under water stress by PK472 (9.04 and 53.77%, respectively) followed by BARI Soybean-6 and AGS383. Considering grain yield and nutrient contents, particularly protein content under both control and water stress conditions the genotypes AGS383 and BD2336 are recommended for field trial under water deficit conditions.

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