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Research Article

Dissecting drought stress tolerance of soybean genotypes based on morphological and physiological attributes

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ABSTRACT

Soybean genotypes G00006, BD2336, AGS383, PK472, BCS1, NCS1, BU Soybean1 and BARI Soybean6 were evaluated under 20% (drought) and 80% (control) of field capacity based on morpho-physiological and yield response to drought. The results revealed that plant height, leaf number, chlorophyll content, photosynthesis, stomatal conductance, transpiration rate, relative water content and water uptake capacity of soybean drastically reduced due to drought. However, root: shoot ratio increased under drought condition. Across the genotypes, the root : shoot ratio ranged from 0.20 to 0.47 in control, while 0.22 to 59 in drought condition. Genotypes BD2336, AGS383 and G00006 produced higher number of pods and seeds, whereas minimum yield reduction was recorded in AGS383 under drought. Based on drought tolerance index, AGS383 ranked 1st, while BD2336 and PK472 ranked 2nd and 3rd position, respectively. High grain yielding ability of AGS383 suggested that it could be cultivated in drought prone environment.

Introduction

Drought, scarcity of water, is the single most vital factor distressing the agricultural production and world food security. It hampers normal plant growth, alter phenotypic characters resulting decreasing of yield significantly (Mannan et al., 2022; Ku et al., 2013). Water shortage also affects physiological and developmental processes of plants that alter the yield of a crop (Allahmoradi et al., 2011). The development of high yield potential crop cultivars with drought tolerance ability has a great significance for increasing yield in dry land condition.

Globally, soybean (*Glycine max* L. Merrill) is a vital grain legume (Kumar et al., 2008; Ahmed et al., 2010). Hundred years ago, it was domesticated in East Asia. The management and production technology of soybean have been improved immensely throughout the world due to its nutritional value (Liu et al., 2005). It is a remarkable source of oil, protein, carbohydrate, minerals and vitamins (Mannan and Mamun, 2018; Dola et al., 2022). It is also very useful in improving the soil, because it has capability to fix atmospheric nitrogen for itself and other plants also (Kumar et al., 2008; Purcell et al., 2000; Ahmed et al., 2010; Mugendi et al., 2010). Drought negatively affects soybean growth and causes less crop growth and substantial reductions in yield (Akand et al., 2018; Fatema et al., 2023; Chowdhury et al., 2017; Mannan et al., 2023). The reproductive and grain filling stage of soybean is very sensitive to drought stress (Wijewardana et al., 2019; Liu et al., 2004). However, long-term water stress during vegetative phase also causes substantial yield loss. The scar city of water reduces stomatal conductance (Gs), lower photosynthesis (Pn),

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chlorophyll (Chl) content, and transpiration rate (Tr). Biomass production negatively affected due to low leaf area under drought condition (Brown et al., 1985). Yield of grain legume depends on dry matter production in shoot (Saxena et al., 1990). Drought negatively affected the production of shoot and root biomass in soybean grown under water stress condition (Fatema et al., 2023). Roots play a vital role in drought tolerant because they uptake water and nutrient from soil (Eureka et al., 2000).

The climatic and the edaphic conditions allows soybean to grow throughout the year in Bangladesh. The area of soybean cultivation has been expanded dramatically from only 5000 ha in 2005 to 62508 ha in 2018-2019 (BBS, 2020; Mamun et al., 2022). The expansion of cultivation of soybean occurred mainly in the districts of Noakhali, Luxmipur, Bhola, Patuakhali, Faridpur, and even in the northern Bangladesh due to its high demand for making animal feed. Though, soybean can be cultivated throughout the year, but it is difficult to fit with existing cropping patter in rabi and kharif II due to high crop competition. Aman rice is popularly cultivated in kharif II, while winter crops in rabi season. However, only few field crops are grown during kharif I and this season may be a good option for growing soybean.

But, scarcity of water and high temperature hamper a harvest of good crop in kharif I season. Therefore, it is necessary to screen out soybean genotypes which would be well adapted to that low moisture regime. Miah et al. (2020) recommended dwarf variety BU Soybean1 that gave higher yield in rabi season when plant suffer for the scarcity of water due to less or no rainfall. G00006, BD2350, Shohag, BD2336, AGS383 and GMOT22 were found fairly drought tolerant as reported by Akand et al. (2018). Considering the above facts, this study was conducted to analyze the effect of drought on the changes in growth and productivity of soybean, and to determine the morpho-physiological mechanisms of drought tolerance in soybean.

Materials and methods

Experimental site

A pot experiment was conducted in a vinyl house of the Department of Agronomy, BSMRAU, Gazipur, Bangladesh during kharif I, 2018. The site is located in Madhupur Tract (Agroecological Zone 28).

Pot preparation

Total 80 pots were used in this experiment and they were filled with soil collected from Kodda, Gazipur. The soil was sandy loam and each pot contained 12.0 kg of soil. Urea, triple super phosphate, muriate of potash and gypsum was applied at 0.15, 0.18, 0.36 and 0.1 g pot^{-1}, respectively before sowing 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, BCS1, NCS1, BU Soybean1 and BARI Soybean6; and Factor B (growing condition) drought (20% of field capacity (FC) and control (80% of FC).

Sowing soybean seeds and imposition of drought treatments

Five healthy seeds were sown in each pot uniform spacing on 03 May, 2018. After sowing of seeds, light irrigation was given for uniform seed germination. Before imposition of drought treatment, extra seedlings were removed by keeping one healthy plant pot^{-1}. Water stress treatments were imposed after trifoliate stage of the crop (15 days after sowing, DAS). To maintain equal soil moisture content in all pots, irrigation was applied one day before treatment imposition. Water stress condition was induced by withholding water until wilting symptom was observed in plants and irrigation was applied in each pot at the first appearance of wilting symptom in plants to maintain 20% of FC.

However, irrigation water was applied after 3-5 days of the previous application. A soil moisture meter was used to determine the soil moisture level before applying irrigation. At FC, the experimental soil contains 30% moisture. Therefore, 6% of soil moisture was maintained to ensure 20% of FC of the soil. Further, about 24% soil moisture was maintained for control treatment, where 80% of FC was ensured.

Phenological attributes

Data on days to emergence, flowering, and pod formation were recorded for each genotype under both treatments. Days to first emergence were counted when at least one radical emerge throughout the seed coat in each genotype. Days to 50% emergence were counted when most of the plants of each genotype had more than 50% radical emergence. Days to first and 50% flowering were counted when at least one and more than 50% flowers opened, respectively. Days to first pod and 50% pod formation were counted when at least one pod and more than 50% pod was developed in most of the plants of each genotype, respectively. A plant was considered to have maturity when majority of the plant leaves turned yellow and color of pods became brownish and hard.

Collection of morphological parameters

Plant height was measured by a meter scale (100 cm) at 25 and 50 DAS. The height of plant was taken from the base to the tip of the plants. The height of the five plants was averaged. To record leaves number plant^{-1}, the leaves of sample plants were count down as 1, 2, 3, 4 and so on at 25 and 50 DAS. Leaves per plant of the five plants was averaged. The growth duration was determined from gap between date of seed sowing to date of physiological maturity of each genotype.

Quantification of physiological traits

At 50 DAS, Chl was determined on fresh weight (FW) basis extracting with 80% acetone by using double beam spectrophotometer according to Talukder et al. (2022). The formulae for computing Chl a, b and total chl were-

Chl a (mg g^{-1} FW) = [{12.7 (D663) - 2.69 (D645)} × {V/(1000× W)}]

Chl b (mg g^{-1} FW) = [{22.9 (D645) - 4.68 (D663)} × {V/(1000× W)}]

Total chl (mg g^{-1} FW) = [{20.2 (D645) + 8.02 (D663)} × {V/(1000× W)}]

Where, D (663,645) = Optical Density of the chl extract at wavelength of 663 and 645 nm, respectively. V = Final volume (ml) of the 80 % acetone with chl extract and W = Weight of fresh leaf sample in g. Leaf temperature was recorded at flowering stage of the crop. The average value was recorded. The Pn, Gs and Tr were determined during flowering stages of the crop with a portable Pn system (LiCOR-6400, Lincoln, Nebraska). Measurement was taken in a clear sunny day. For determining FW, sampling was done at flowering stage of each genotype. Fully expanded leaves of each genotype were collected from both control and drought condition at noon. After collecting leaves from pot, they are transferred to the laboratory and FW was taken immediately. The leaves were soaked in distilled water for 24 hours to record the turgid weight (TW). Dry weight (DW) of leaf was obtained after oven drying for 72 h at 70 ºC. The relative water content (RWC) was calculated in following equation according to (Schonfeld et al. (1988).

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

Water saturation deficit (WSD) and water retention capacity (WRC) was calculated following Sangakkara et al. (1996).

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

$$WUC = \frac{FW - DW}{DW}$$

Where, FW= fresh weight, DW= dry weight and TW= turgid weight of the sample.

The root and shoot weight were taken at 50 DAS. From both treatments of control and drought, a soybean plant of each genotype was cut just above the soil surface. The weight of stem and leaves were obtained after oven drying for 72 h at 70 ºC. All the roots were collected carefully by hand and washed them in running tap water on a sieve. After washing, the roots were soaked with a cotton towel. Roots were dried in electric oven and weight of root were recorded after oven drying for 72 h at 70 ºC. The root and shoot ratio were determined from their weight.

$$\text{Root : shoot} = \frac{\text{Root weight}}{\text{Shoot weight}}$$

Yield and yield contributing data

Data on total number of pods per plant, total number of seeds per plant, number of seeds per pod, 100-seed weight and yield per plant were recorded. To measure yield per plant, total seeds from the sample plants were weighted by an electrical balance. The moisture content of seeds was measured by a hand-held moisture meter. The grain yield was adjusted to 14% moisture content using the following formula:

$$\text{Adjusted weight} = \frac{W \times (100 - M_1)}{(100 - M_2)} \times 100$$

Where, W is the fresh grain weight; and M_1 and M_2 were the fresh and adjusted moisture percent of the grain, respectively.

Data analysis

Computer software package "CropStat 7.2" version was used to analyze the collected data. The treatment means were separated using 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). Using cluster analysis, soybean genotypes were scored on multiple agronomic parameters simultaneously. Drought tolerance index was determined as the observations under drought divided by the means of the controls. Cluster analysis was done according to Khrais et al. (1998) and cluster group rankings were obtained based on Ward's minimum variance. The cluster groups were identified in dendrogram and rankings were obtained from the average of means over multiple parameters in each cluster group. A sum was obtained by adding the numbers of cluster group ranking in each genotype. The genotypes were finally ranked based on the sums in order that those with the smallest sums were ranked as the most tolerant and those with the largest sums were ranked as the least tolerant in terms of relative drought tolerance.

Results and discussion

Phenological attributes

First emergence occurs within 2 DAS. For 50% emergence, the lowest time required for AGS383, PK472 and NCS1, while the highest for G00006 and BCS1 (Table 1). Under control, BU Soybean1 took 27, 30 days for first and 50% flowering, respectively. Similarly, this variety needed 35 and 42 days for first and 50% pod formation, respectively under control condition. On the contrary, BU Soybean1 flowered and pod produced 2-4 days earlier under drought conditions than control. Similarly, all the genotypes needed longer time for flowering and pod formation in control than drought condition. Among the genotypes, NCS1 and BCS1 took more time for flowering and pod development in both treatments. Akand et al. (2018) and Fatema et al. (2023) also reported that soybeans needed less time for flowering and maturity when they are grown in water deficit condition. For maturity, BU Soybean1 required 96 days in control condition and 92 days in drought condition (Fig. 1). However, the growth duration of NCS1 and BCS1 were the highest both control (144 days) and drought (140 days) conditions. Highly positive correlation was reported between days to flowering and days to maturity (Malek et al., 2014). Similarly, yield showed a positive association with days to maturity (Liu et al., 2005). Fenta et al. (2014) proved that drought exposure generally causes faster plant maturation.

Morphological parameters

Water stress inserted negative impact on root and shoot biomass. However, AGC383 produced the highest root biomass, which was followed by NCS1 under drought. On the other hand, BU Soybean1 gave the lowest root biomass, which was followed by BARI Soybean6. However, genotype G00006 produced the highest shoot biomass under control and drought condition, which was followed by BD2334 (Table 2). The root: shoot ratio increased due to drought stress. The root: shoot was increased in BCS1 and NCS1 on 50 DAS under drought condition as compare to control. Irrespective of soybean genotypes, the root : shoot ratio ranged from 0.20 to 0.47 in control, while the ratio was 0.22 to 59 in drought stress.

Drought decreased the plant height of soybean at both 25 and 50 DAS (Fig. 2). At 25 DAS, the height of PK472 was 70 cm in control, which decreased to 57.60 in drought. Similarly, the height of genotype PK472 was decreased by 19% under drought condition at 50 DAS. Rest of the genotypes also exhibited similar trend of reduction in plant height. Khan et al. (2014) reported that the height of soybean plant decreased due to water stress. Hamid et al. (1990) stated that water stress induced reduction in plant height due to lower Pn.

Drought caused decreased in number of leaves compared to control on 25 and 50 DAS in all soybean genotypes (Fig. 3). Regarding leaf production, the genotypic variation was obvious in soybean. On 25 DAS, PK472 showed lowest leaf reduction and BU Soybean1 showed highest leaf reduction. PK472 produced 7 mean leaf number in control which decreased to 6.80 mean leaf number in drought condition and BU Soybean1 produced 23 mean leaf number in control which decreased to 13.40 mean leaf number in drought condition. On 50 DAS, G00006 showed lowest leaf reduction and BARI Soybean6 showed highest leaf reduction. G00006 produced 25.40 mean leaf number in control which decreased to 23.60 mean leaf number in drought condition and BARI Soybean6 produced 39 mean leaf number in control which decreased to 21.80 mean leaf number in drought condition. Wu et al. (2008) and Fatema et al. (2023) reported similar results. Under water stress condition, the initiation of new leaf is hampered and senescence of existing leaves are accelerated in plants as reported by Chowdhury et al. (2015).

Physiological traits

There was a significant decrease in Chl content under drought stress in soybean leaves as reported by Makbul et al. (2011). Drought stress decreased leaf Chl a content. However, minimum reduction in Chl a content was recorded in the case of genotypes AGS383. Othe other hand, the higher amount of Chl a was obtained in the leaf of BD2336, while G00006 showed the minimum. Similarly, genotype AGS383 showed the highest Chl a under drought condition, followed by BCS1.

G00006 showed the lowest amount of Chl a. Photosynthetic pigments Chl a capture sunlight. However, Chl a more cope with in drought condition than Chl b. Reactive oxygen species were developed under water stress condition, which damaged chloroplast of plant cell resulting decreased Chl content.

Fatema et al. (2023) also reported similar results. Like Chl a, drought stress also decreased Chl b content of leaf to a large extent. However, Chl b was reduced more than Chl a. Among the eight genotypes, G00006 showed minimum decrease in Chl b content and followed by AGS383 (Fig. 4).

Table 1. Phenological changes due to drought in eight soybean genotypes

Soybean genotypes	FPE (days)		FF (days)		FPF (days)		FPoF (days)		FPPoF (days)	
	Cont.	Drout.	Cont.	Drout.	Cont.	Drout.	Cont.	Drout.	Cont.	Drout.
G00006	6	6	30	30	37	34	41	39	48	45
BD2336	5	5	31	30	39	35	45	42	51	48
AGS383	4	4	33	32	37	33	43	41	49	47
BU Soybean1	5	5	27	26	30	28	35	32	42	38
PK472	4	4	38	36	43	40	50	46	55	51
NCS1	4	4	60	57	66	62	70	67	75	70
BCS1	6	6	60	57	66	62	70	67	75	70
BARI Soybean6	5	5	55	54	62	56	66	61	71	67

FPE = 50% emergence, FF = First flowering, FPF = 50% flowering, FPoF = First pod formation, FPPoF = 50% pod formation, Cont. = Control, Drout. = Drought.

Table 2. Root and shoot weight of soybean genotypes under control and drought

Soybean genotypes	Root weight (g plant^{-1})		Shoot weight (g plant^{-1})		Root : shoot	
	Control	Drought	Control	Drought	Control	Drought
G00006	1.72±0.42	1.36±0.33	8.58±2.2	6.16±1.1	0.20±1.2	0.22±1.0
BD2336	1.29±0.16	1.23±0.12	5.16±0.34	4.25±0.31	0.25±0.1	0.29±1.1
AGS383	1.29±0.15	1.04±0.11	5.29±0.22	3.40±0.19	0.24±0.6	0.31±1.3
BU Soybean1	1.96±0.52	1.82±0.51	7.41±2.9	5.36±1.0	0.26±1.4	0.34±1.1
PK472	1.84±0.48	1.78±0.49	5.26±2.8	3.90±1.2	0.35±1.2	0.46±1.2
NCS1	1.76±0.51	1.80±0.54	5.42±2.0	3.31±1.2	0.32±1.0	0.54±1.3
BCS1	1.54±0.42	1.71±0.38	3.29±2.2	2.92±1.1	0.47±1.2	0.59±1.2
BARI Soybean6	1.65±0.11	1.15±0.10	4.92±0.26	4.09±0.22	0.34±1.0	0.28±1.1

Data are means±standard error of three replications.

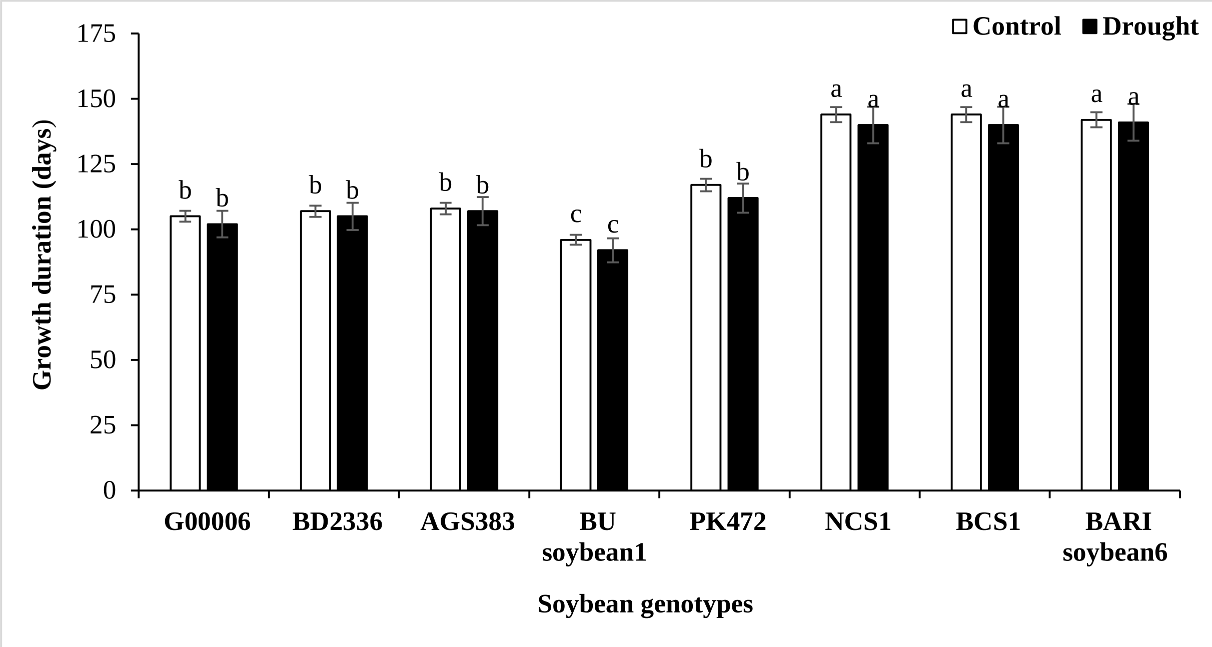


Fig. 1. Growth duration of soybean genotypes under drought and control

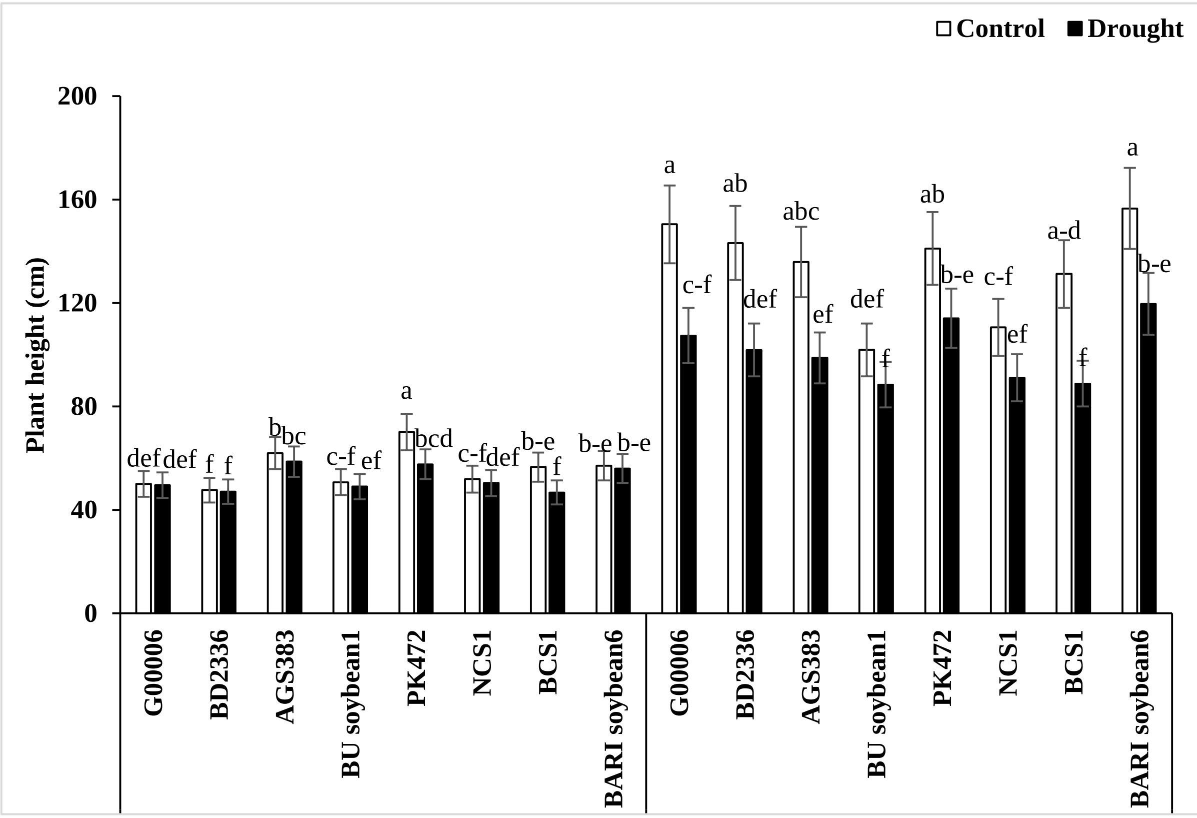


Fig. 2. Plant height of soybean genotypes under drought and control

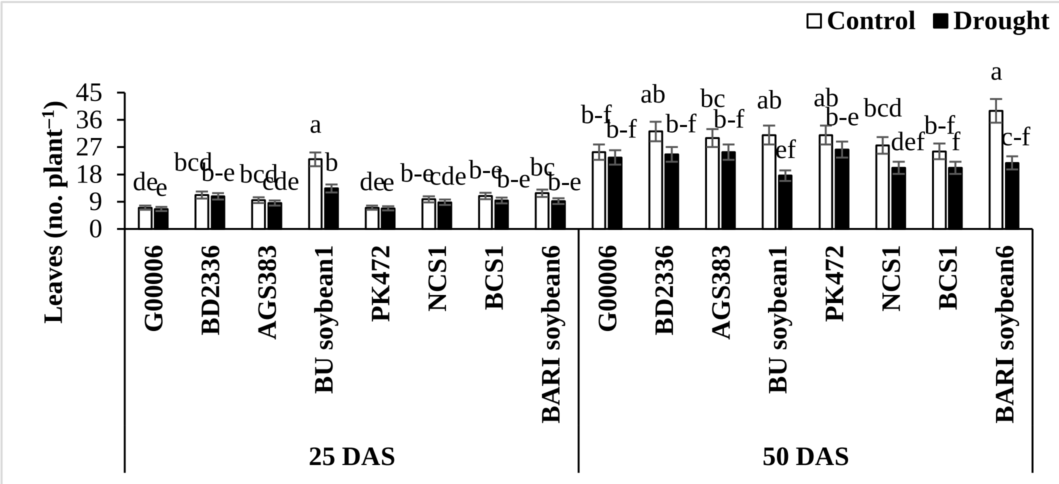


Fig. 3. Leaf production of soybean genotypes under drought and control

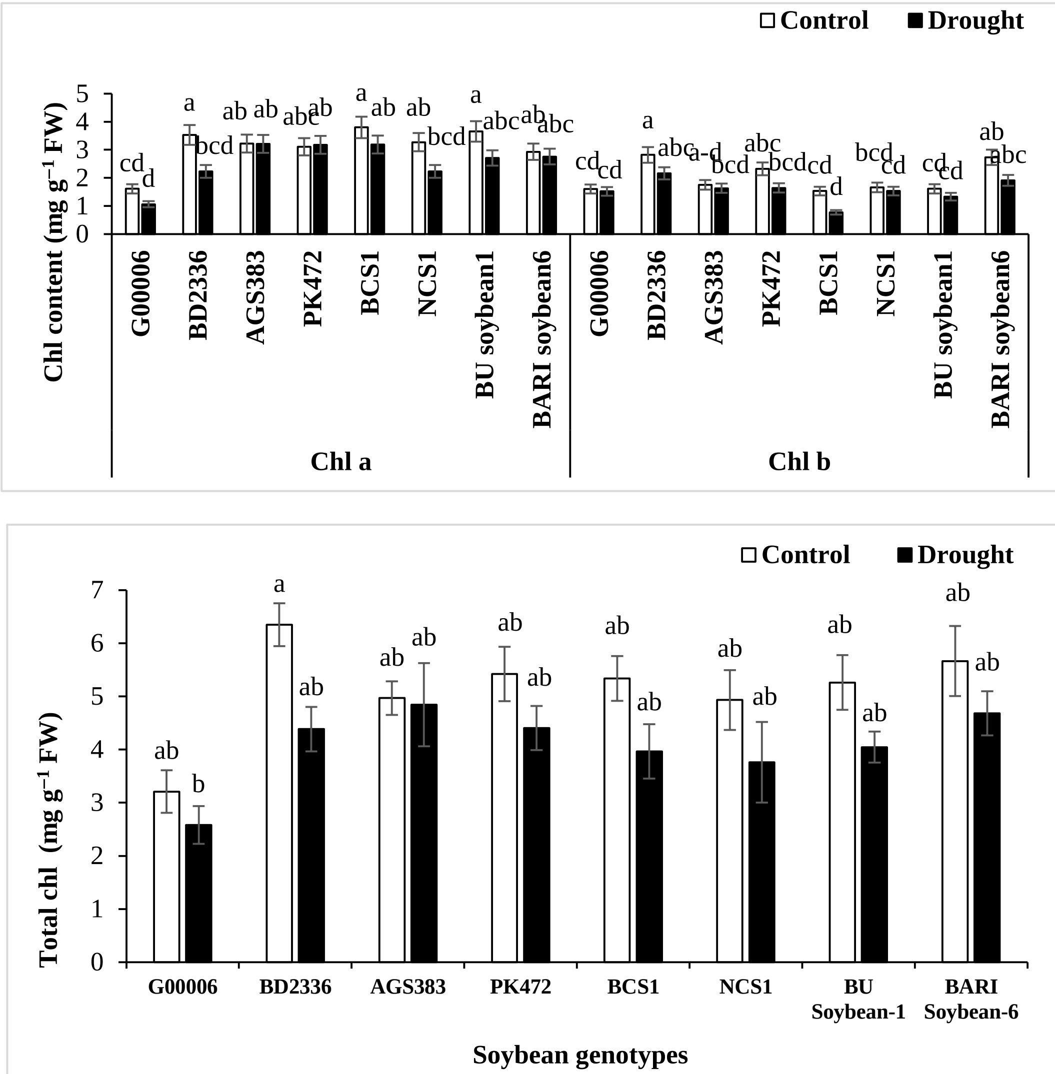


Fig. 4. Chlorophyll content of soybean genotypes at flowering stage under drought and control

The higher amount of Chl b was obtained in the leaf of genotype BD2336, while BCS1 showed the minimum under both growing conditions. Drought stress reduced total Chl content in leaves of soybean genotypes (Fig. 4). However, the content of total Chl was higher in the leaves of BD2336, which was followed by BARI Soybean6 and PK472. The minimum total Chl was obtained in the leaves of G00006. Interestingly, the maximum amount of total Chl (4.84 mg g^{-1} FW) content was determined in the genotype AGS383 in drought condition. Chl content reduced under drought condition also stated by Fatema et al. (2023).

Photosynthetic traits

Under water deficit condition, leaf Pn reduced in all the soybean genotypes (Fig. 5). The highest Pn reduction was found in BU Soybean1 where Pn value was 40.11 and 21.59 μ mol CO_2 m^{-2} s^{-1} in control and drought conditions, respectively. The lowest Pn reduction was found in AGS383 where Pn value was 30.54 and 30.39 μ mol CO_2 m^{-2} s^{-1} in control and drought condition respectively and the reduction was non-significant. Under drought stress, the stomata remain closure resulting lower Pn (Mahajan and Tuteja, 2005). Reduction of leaf number area vis a vis reduced Pn under drought is an important cause for reduced crop yield. Under water deficit condition, leaf Gs reduced in all soybean genotypes (Fig. 5).

The Gs was significantly affected by drought in BARI Soybean6, NCS1, BU Soybean1 and PK472. On the other hand, the Gs did not reduced significantly in the case of G00006, BD2336, AGS383 and BCS1. The RWC regulate the stomatal opening and closing and lower Gs under drought due to decreased RWC. Makbul et al. (2011) reported that Gs decreased during the drought period in leaves. About 42% lower Gs was obtained in drought condition as compared to control. The Tr significantly reduced under drought in all the soybean genotypes (Fig. 5). The Tr was 11.43 m mol m^{-2} s^{-1} in control which was reduced to 3.74 m mol m^{-2} s^{-1} in drought for genotype G00006. Similar trend was also observed for other genotypes. Zhang et al. (2016) and Fatema et al. (2023) also found lower Tr in leaves under water stress condition.

Plants under drought stress showed high leaf temperature compared to control condition in most of the soybean genotypes (Fig. 5). Under control condition AGS383 showed the highest leaf temperature which was 31 °C, and BARI Soybean6 showed the lowest leaf temperature which was 26 °C. Under drought condition BU Soybean1 showed the highest leaf temperature which was 33 °C followed by AGS383 and NCS1 where both the genotypes showed 32 °C and the differences among them were non-significant. BARI Soybean6 showed the lowest leaf temperature under drought condition which was 28 °C. As the drought continued, leaf temperature of the soybean increased earlier in the day and decreased later in the afternoon as was reported by Jung and Scott (1980). A significant difference in leaf temperature was also found between drought and control as reported by Winter et al. (1988).

Water related parameters

The RWC of eight soybean genotypes varied significantly and non-significantly due to water stress at flowering stage (Fig. 6).

RWC content was higher in BU Soybean1 under both control and drought stress condition. RWC of BU Soybean1 was 79.93% and 74.89% in control and drought condition respectively, which was statistically similar. Under drought condition, reduced RWC was found in soybean leaf as reported by Chowdhury et al. (2017). The water content of soil in drought treatment was 20% of FC, which was not enough for plants and cause dehydration of leaf tissue. Many earlier studies also showed that leaves exhibited a reduction of RWC when subjected to drought (Nayyar and Gupta, 2006) or salinity (Tareq et al., 2022). The WSD of eight soybean genotypes varied significantly and non-significantly due to water stress at flowering stage (Fig. 6).

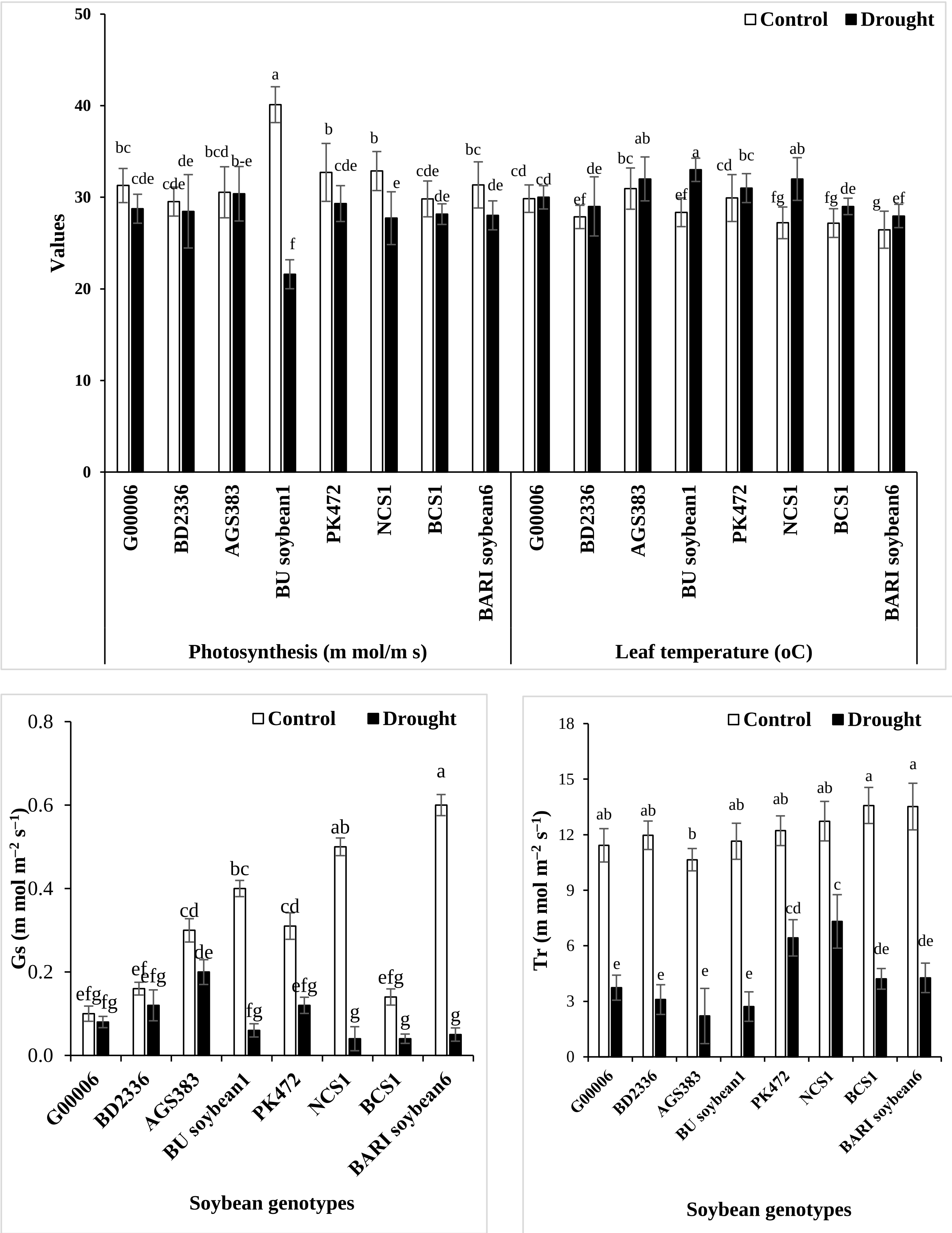
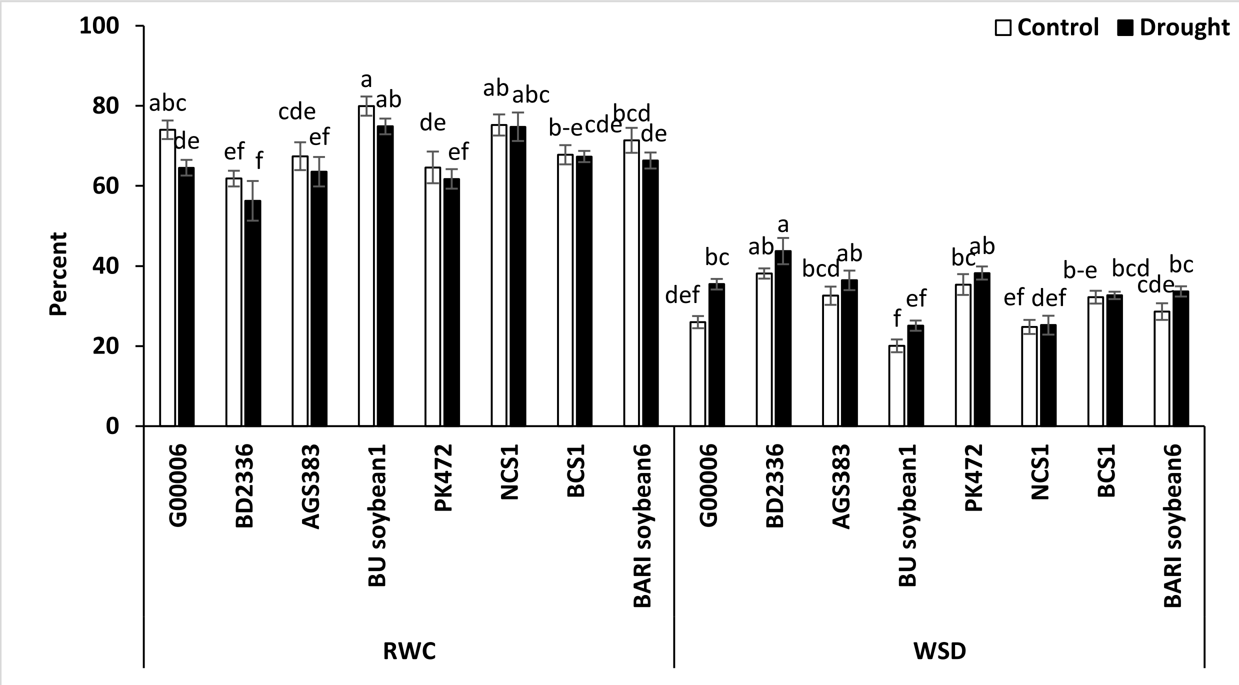


Fig. 5. Photosynthetic traits of soybean genotypes at flowering stage under drought and control



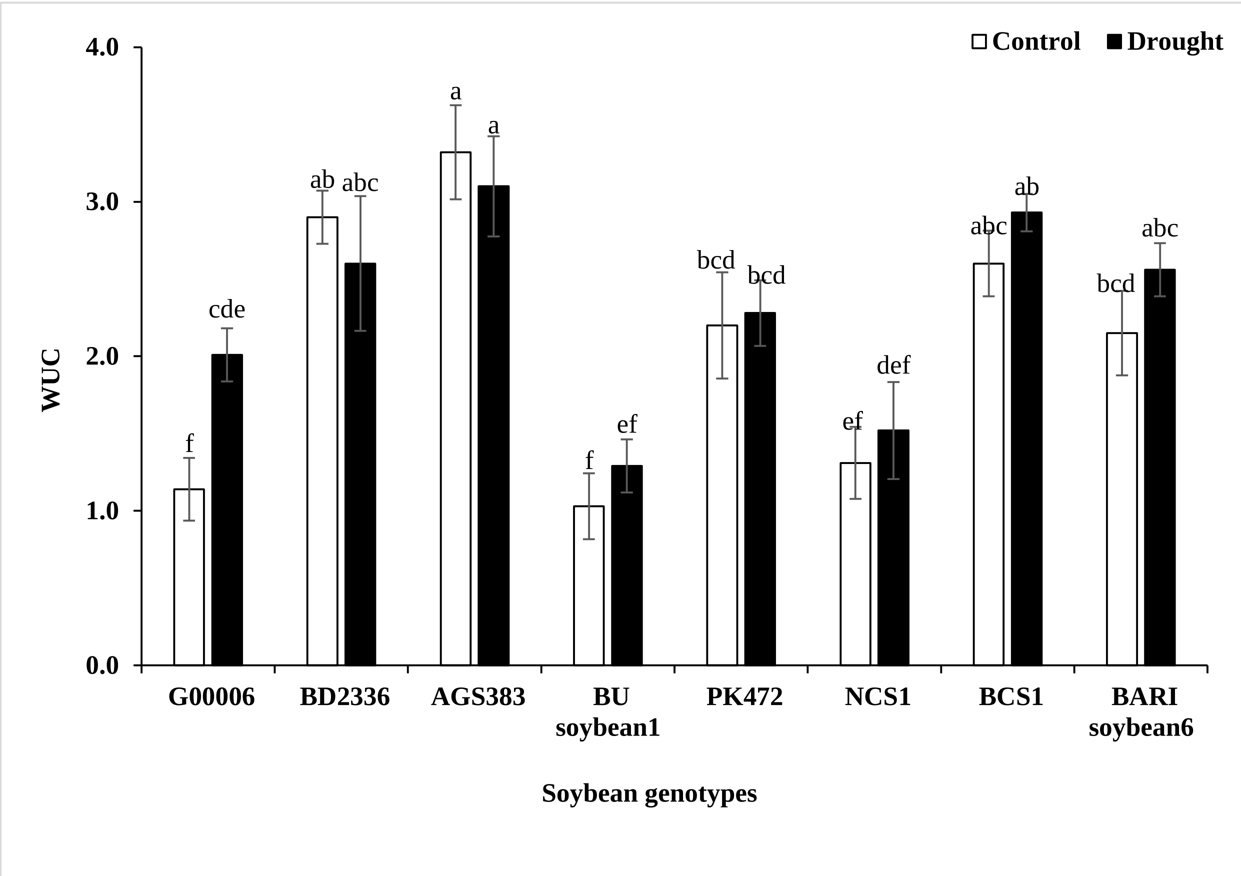


Fig. 6. Relative water content of soybean genotypes at flowering stage under drought and control

Under drought condition BU Soybean1 showed the lowest WSD followed by NCS1 and the relationship between them were non-significant. BD2336 showed highest WSD followed by AGS383 and PK472 under drought condition which was also non-significant. Chowdhury et al. (2017) also reported that WSD of soybean increased under water stress. Drought increased leaf WUC in most of the tested soybean genotypes (Fig. 6). AGS383 showed highest WUC under both control and drought condition, and the relationship between control and drought treated plant of AGS383 was statistically similar. The water use is maintained by drought tolerant genotypes under less water condition.

Yield attributing parameters

Water stress caused significant differences in pods plant^{-1} (Fig. 7). BD2336 produced the highest number of pods plant^{-1} (116), which was followed by BCS1 and AGS383. The lowest number of pods plant^{-1} (21) was produced by BU Soybean1. Similar results also reported by Akand et al. (2018). The number of fertile pods plant^{-1} reduced due to scarcity of water in seed filling stage. The findings of the present study is also supported by the findings of earlier studies in French bean (Omae et al., 2005), in soybean (Kokubun et al., 2001; Liu et al., 2004) and in mungbean (Islam, 2008).

The abortion of flowers and pods under water stress condition might be the possible reason for reduction of the number of pods plant^{-1} (Maleki et al., 2013).

Drought stress reduced the number of seed production per plant in all the tested soybean genotypes (Fig. 7). The highest number of seeds plant^{-1} (204) was recorded in BCS1, which was followed by BD2336 and AGS383. The lowest number of seeds plant^{-1} was produced by BU Soybean1. Under control condition, the highest number of seeds plant^{-1} (204) was found in BCS1 which was closely followed by BD2336 and AGS383 while the lowest number of seeds plant^{-1} was produced by BU Soybean1. Under drought conditions, AGS383 had maximum number of seeds plant^{-1} (81.16) followed by G00006 and BD2336 while NCS1 had the minimum (3.72 plant^{-1}) which was closely followed by BU Soybean1 and BARI Soybean6. Akand et al. (2018) and Fatema et al. (2023) also stated that soybean plants exposed to drought produced reduced number of seeds per plant. Drought stress reduced the number of seed production pod^{-1} in all the tested soybean genotypes (Fig. 7). Under control condition, NCS1 produced significantly highest number of seeds (2.1 pod^{-1}) than other genotypes and the lowest was produced by BD2336.

Under drought conditions, BCS1 had maximum number of seeds (1.42 pod^{-1}) followed by BARI Soybean6, AGS383 and PK472 while BD2336 had the minimum seeds (1.04 pod^{-1}) which was closely followed by BU Soybean1 and NCS1. The seeds number pod^{-1} and individual seed weight are genetically controlled and comparatively stable character. They are also less affected by environmental stress (Tera'n and Sigh 2002). In case of 100-seed weight, AGS383 produced significantly higher seed weight (15.4 g) than other genotypes followed by PK472 and BARI Soybean6 in control condition (Fig. 7). AGS383 produced the seeds of highest 100-seed weight (12.49 g), while NCS1 had the minimum 100-seed weight (3.27 g). Compared with the control, drought stress significantly reduced the 100-seed weight of soybean as reported by Du et al. (2020).

Seed yield

Seed yield of soybean reduced significantly under water stress in all soybean genotypes (Fig. 8). Among all the genotypes, seed production was minimum affected by drought in AGS383. It produced significantly highest seed yield under both control and drought condition which was 26 and 10.25 g plant^{-1} seed in control and drought stress, respectively. Under drought condition the genotype G00006 yielded 4.02 g plant^{-1} which was next to AGS383 followed by BD2336. The heavier grain size in AGS383 mostly contributed to the higher grain yield as compared to the other two genotypes. Regarding yield performance, AGS383 was the best under both well irrigated and waster stress condition as reported by Akand et al. (2018).

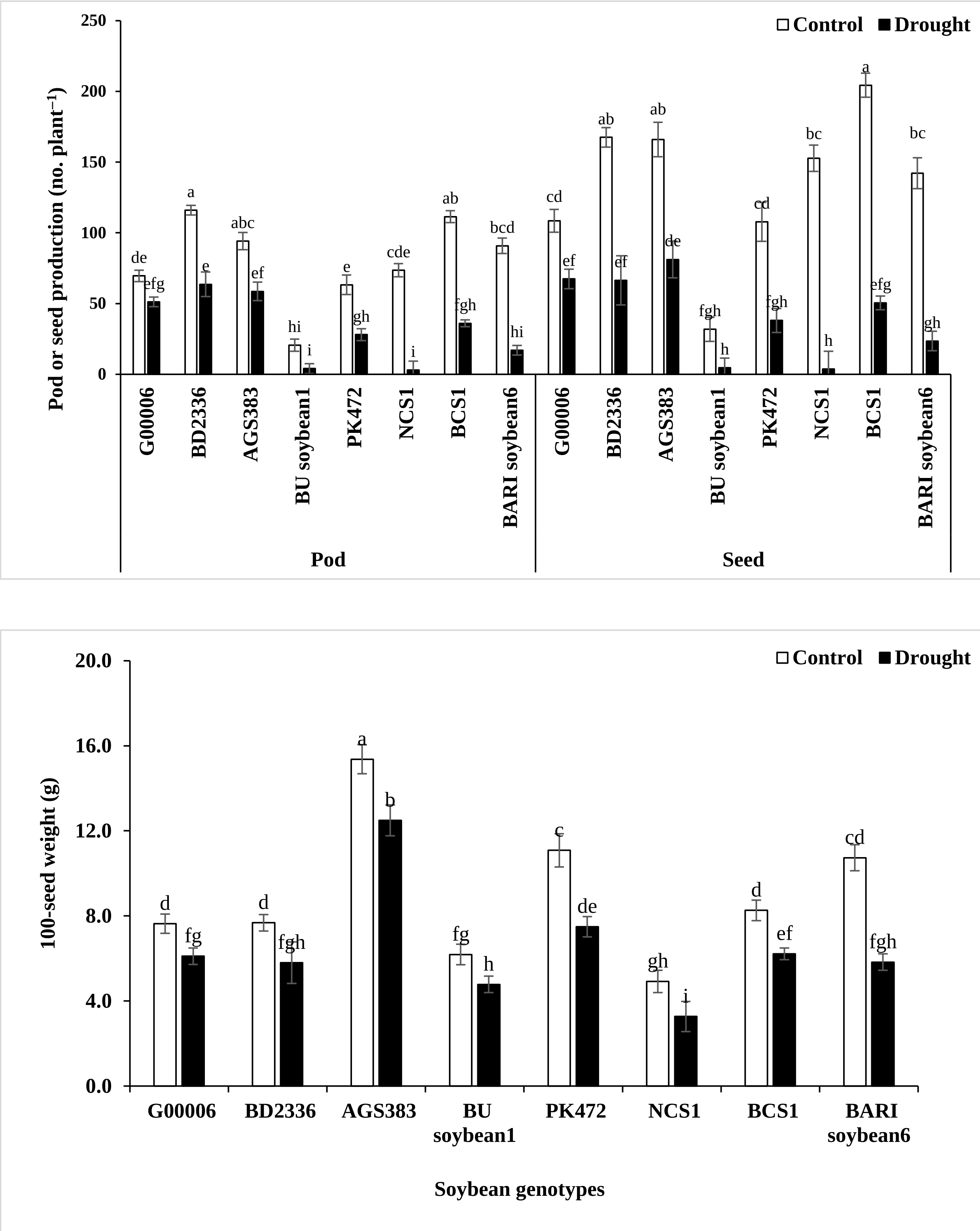


Fig. 7. Pod and seed production of soybean genotypes under drought and control.

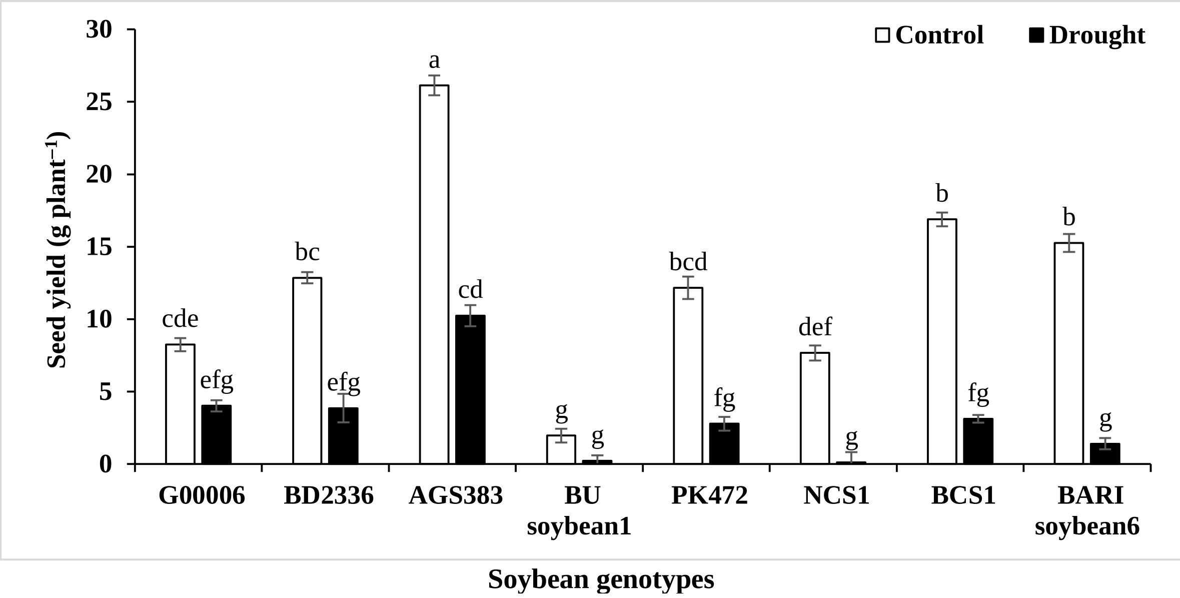


Fig. 8. Seed yield of soybean genotypes under drought and control

The photosynthetic efficiency of plants decreased under drought due to reduced number of leaves per plant which cause lower crop yield (Kramer, 1983). Similarly, the yield components like number of pods plant^{-1} and individual seed weight were also decreased, which induced lower grain yield of crop. In the present study, the lower yield under water stress condition due to decreased leaf area, lower photosynthetic rate, poor performance of yield components. These findings are supported by the previous findings of Taiz and Zeiger (2002), Liu et al. (2003) and Fatema et al. (2023). Low photosynthesis, decreased assimilates translocation, and flowers and pods abortion are the possible causes of lower yield under drought condition (Kukubun et al., 2001; Tera'n and Singh, 2002; Liu et al., 2003 and 2004;).

Drought tolerant soybean genotypes

Selection of drought tolerant soybean genotypes was done considering drought tolerance indexes in relation to genotypic performance on different agronomic parameters like height of plant; number of leaves, pods and seeds; 100-seed weight and seed yield (Table 3). AGS383, PK472 and BARI Soybean6 showed the best performance in case of plant height. In case of leaf production BU Soybean1 performed better than other genotypes. BD2336 performed better in pod production. AGS383 showed the best performance in case of total number of seeds, 100-seed weight and seed yield. In case of seeds per pod the genotype BCS1 performed better than other genotypes. Considering all the above-mentioned agronomic parameters, especially related to yield response, the genotype AGS383 performed better under drought stress than others. Based on agronomic parameters, AGS383 ranked 1 in all the parameters with the rank sum 7 (Table 4). BD2336 and PK472 ranked 2nd and 3rd positions, respectively in genotype ranking with rank sum 12 and 13. So in this experiment AGS383 perform better than all other genotypes under drought condition. The cluster analysis showed that the genotypes tended to group into two groups with 5 and 3 genotypes, respectively (Fig. 9). In this analysis, the second group performed better and was thus considered to be the most desirable cluster for both the growing conditions.

Table 3. Drought tolerance indexes based on agronomic parameters of the soybean genotypes

Soybean genotypes	Plant height	Leaf production	Pod production	Total seeds	Seeds per pod	100-seed weight	Seed yield
G00006	0.90	0.58	0.64	0.50	0.77	0.68	0.32
BD2336	0.84	0.96	0.80	0.49	0.62	0.65	0.31
AGS383	0.99	0.76	0.73	0.60	0.81	0.99	0.81
BU Soybean1	0.88	0.99	0.05	0.03	0.68	0.53	0.02
PK472	0.99	0.60	0.35	0.28	0.80	0.83	0.22
NCS1	0.90	0.78	0.04	0.03	0.73	0.36	0.01
BCS1	0.84	0.83	0.45	0.37	0.84	0.69	0.25
BARI Soybean6	0.99	0.81	0.21	0.17	0.82	0.65	0.11

Table 4. Ranking of soybean genotypes for their relative drought tolerance

Soybean genotypes	Cluster group ranking							Rank sum	Genotype ranking
	Plant height	Leaf number	Pod number	Total seeds	Seeds per pod	100-seed weight	Seed yield		
G00006	3	3	1	1	3	2	2	15	4
BD2336	2	2	1	1	2	2	2	12	2
AGS383	1	1	1	1	1	1	1	7	1
PK472	1	3	2	2	1	1	3	13	3
BCS1	2	4	2	2	1	2	3	16	5
BARI Soybean6	1	4	4	4	1	2	4	20	6
NCS1	3	1	3	3	3	4	4	21	7
BU Soybean1	4	2	3	3	4	3	4	23	8

Rescaled Distance Cluster Combine

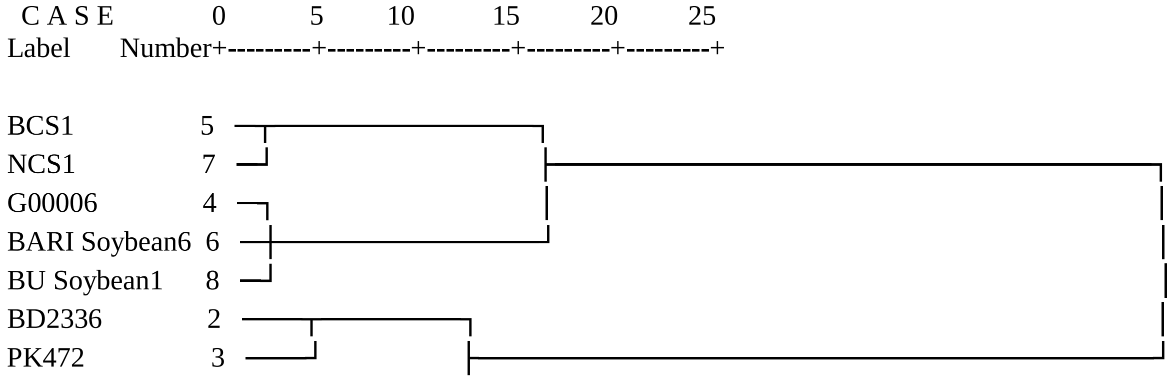


Fig. 9. Dendrogram of tested soybean genotypes using Ward's method

Conclusions

Morpho-physiological, yield and yield contributing characters of all soybean genotypes were reduced, while leaf temperature increased under drought condition. The genotype AGS383 produced heavier grains and gave improved grain yield under both growing conditions. A minimum yield reduction was occurred in AGS383 due to drought. A ranking of soybean genotypes based on relative drought tolerance index showed that AGS383 ranked 1st among all studied soybean genotypes. Due to high grain yielding ability of AGS383, it could be cultivated drought prone environment.

Author's contributions

Md. Abdullah Al Mamun contributed to the conceptualization, supervision, data analysis and manuscript drafting, Md. Karimul Ahsan carried out the field experiment and collect data, Toton Kumar Ghosh and M. Abdul Karim contributed in editing the manuscript.

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Conflicting interest

The authors have no potential conflicts of interest regarding the publication of this article.

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