Research Article

Different Soybean Varieties are Effected by Irrigation in Mardan Khyber Pakhtunkhwa Pakistan

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Abstract | Water stress severely affected soybean growth, development, and production in semi-arid regions. Developing new soybean cultivars with high efficiency and ability to drought resistance is very important. The field experiment was conducted to investigate the impact of irrigation regimes at different growth stages (Full irrigation, irrigation regimes at vegetable growth, flowering, and pod full stages) on yield and yield components of two soybean varieties (1448 and Egyptian) under semi-arid regions. The results indicated that irrigation regime applications had a significant effect on most of the traits except the weight of the plant. The pod full stage is more affected by the drought than other stages on most of the parameters tested. Irrigation regimes at pod full stage reduced the number of pods plant^{-1} by 38.4% and 26.0%, the weight of pods plant^{-1} by 23.7% and 53.6%, the number of seeds plant^{-1} by 29.0% and 28.8%, seeds weight plant^{-1} by 17.2% and 38.8%, 100-seeds weight by 35.3% and 38.1% for 1488, respectively. Irrigation regimes at the flowering stage decreased the weight of the plant by 57.5% and seed yield by 24.4% and 31.2% for 1448 respectively as compared with the same variety at full irrigation. Varieties had significant differences in plant weight, number of pods per plant, number of seeds per plant, harvest index, and seed yield. In this study, the soybean cultivars exhibited high sensitivity to water stress. Based on the study, the 448 cultivar is recommended due to its higher seed yield and yield components under the given conditions.

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Introduction

Abiotic stresses such as salinity and drought stress remain one of the most significant constraints to crop production worldwide (Ali *et al*., 2019, 2020). Drought stress is one of the most important limiting factors for the growth and yield of crops, which affects 40 to 60 % of the world's agricultural lands (Ardestani *et al*., 2011). Abiotic stresses such as drought, salinity, heat, cold, light intensity, inadequate nutrients, and soil acidity have been reported to cause a decrease in crop yield ranging from 54% to 82% (Ali *et al*., 2021). Drought stress can also lead to decreased water uptake and nutrient absorption by plants, as well as increased production of reactive oxygen species, which can cause oxidative damage to cellular components (Farooq *et al*., 2009). Additionally, drought stress can affect hormone regulation in plants, leading to altered plant growth and development (Sehgal *et al*., 2017). In response to drought stress, plants may also change gene expression and metabolic pathways to cope with the stress (Mondal *et al*., 2011). These changes can include the activation of stress-responsive genes and the accumulation of osmolytes, which help plants maintain cellular turgor and protect cellular structures from damage (Sehgal *et al*., 2017). Drought stress in legumes elevates abscisic acid levels and causes pollen sterility by impairing the ability of reproductive sinks to use starch and sucrose resulting in ovary abortion and poor pollen grain development, leading to fewer grains and reduced grain yield (Farooq *et al*., 2020).

Soybean (*Glycine max* L.) is one of the most important crops in the world. It has high nutritional qualities due to its high protein content of 40% by weight, 32% carbohydrate, 20% fat, 5% minerals 3% fiber, and other trace substances (Singh, 2010; Comlekcioglu and Simsek, 2011). It is richer than cow's milk, egg, moderately fatty beef, bean, and lentil in terms of nutrient content, phospholipids, vitamins and diet fiber which are used for both human and animal consumption as well as for industrial purposes (Mentreddy *et al*., 2002; Singh, 2010). During the early vegetative stages, drought stress can lead to reduced plant growth and development, as well as decreased root and shoot biomass. This can result in fewer nodes and branches, ultimately leading to a reduction in the number of pods and seeds produced (Ali *et al*., 2009). Drought stress occurring during this period increases the rate of pod abortion, leads to a smaller number of pods per plant, and ultimately decreases seed yield (Kokubun *et al*., 2001).

The final seed yield of soybean is highly affected by drought stress, particularly when the stress is occurring during flowering and early pod expansion. The yield loss is due mainly to an increased rate of pod abortion resulting in a smaller number of seeds per unit area. All the physiological processes of plant are directly or indirectly influenced by water status of plant (Ali *et al*., 2009). Soybeans respond well to irrigation during later growth stages, where water stress may reduce yield. Thus, timely and proper irrigation management is crucial to enhance yield potential and water use efficiency (Ali *et al*., 2009). The yield of soybean is highly affected by many factors among the soil water availability, cultivars and irrigation being the most important ones. Similarly, various soybean cultivars show varying sensitivity to drought at their different developmental stages (Ali *et al*., 2009). The irrigation management plays an important role because water has direct relationship with crop yield (Kobraee and Shamsi, 2011). Drought stress or drought badly affects the yield of different crops. It has been suggested that in many crops differences in sensitivity to drought stress occur at different growth stages (Kirda, 2002; Abayomi, 2008). The most important times for soybean plants to have adequate water are during pod development and seed fill. These are the stages when water stress can lead to a significant decrease in yield (Abd El-Mohsen *et al*., 2013). Moisture stress in soybean reduced the number of pods per plant, pod weight, number of seeds per pod and seed weight (Farooq *et al*., 2009). Irrigation increased seed yield, 100 - seed weight and seed weight per plant. Water stress imposed during pre-flowering and flowering stage reduced yield of soybean by 28% and 24% respectively (Liu, 2004; Ali *et al*., 2009). The best yield and most efficient water use are generally obtained when the available soil water in the root zone is not depleted by more than 50-60%. Thus, sufficient water supply, especially during the early reproductive stages is essential for soybean production under water-limited conditions (Liu, 2004; Ali *et al*., 2009; Ullah *et al*., 2023). Keeping in view all these aspects, the objectives of this study was to investigate the impact of four different irrigation regimes on yield and yield component traits of two soybean cultivars at different growth stages under north Khartoum conditions. Also, to determine relationship between yield and yield components by using different statistical methods to help soybean breeders how to determine the effect of yield components and what yield components could be efficiently used in breeding program. Because until now no one apply these verities to abiotic stress. From the current result we can hypnotized that water most effect the growth and yield of soyabean varieties.

Materials and Methods

Experimental site and experimental design

A field study was carried out on the Experimental Farm of Mardan Abdul Wali khan university (32.35"E, 15.31"N, within the semi-desert region)

(Adam, 2002), in the soybean growing seasons of 2019 and 2020. The soil of the site is described by (Abdel-Hafeez, 2001) as loam clay it is characterized by a deep cracking, moderately alkaline clays, and low nitrogen content and pH 7.5–8, and high exchangeable sodium percentage (ESP) in subsoil. The climate of this area is semi-arid and with low relative humidity, the annual rainfall is about 151.8 mm. This field experiment was conducted as split plot arrangement in a randomized complete block design (RCBD) with four replications. Main plots included four irrigation regimes (Full irrigation, irrigation regimes at vegetable growth, flowering, and pod full stages), and subplots included two varieties (1448 and Egyptian). The two season experiments were sown on first June for 2019 and 2020 seasons.

Seeds varieties and sowing data

Pure quality seeds of two varieties including Egyptian and 1448 were obtained from Agricultural Research center Nowshera Tranaform was used in this study. Seeds within a variety were selected for uniform size, shape, and color. All seeds were less than five months old and were previously stored in paper bags under laboratory conditions (RH 40-60% at 15-20 °C) to maintain good germination ability. Before planting, seeds were sterilized using sodium hypochlorite solution (1%) for 3 min, washed with distilled water three times, and then air-dried. Seeds rate was four seeds per hole spaced at 30 cm between holes. Sowing was carried out on the Jun 21th, 2022. Thinning was carried out three weeks after sowing to raise two plants per hill. Weeding was done twice using hand hoeing. These seeds were planted carefully by following the methodology generally recommended for the region.

Experimental treatments

The crops during the growing seasons received full irrigations (control) every 10 days, including planting irrigation (D0). Irrigation regimes treatments were applied by skipping two irrigations at three critical stages: vegetable growth (D1), flowering (D2), and pod filling stages (D3). Four treatments were defined by the water irrigation at three different growth stages. For this purpose, the life cycle of soybean was divided into three stages, namely vegetative, flowering, and pod filling, according to the classification of developmental stages of soybean (Farooq *et al.*, 2009).

Sampling and data collection

Yield components parameters: At maturity stage, for assessing the relationship between yield and its components, according to (Farooq *et al.*, 2020) the yield components were recorded at the time of harvest. Five plants were randomly selected from each experimental unit, and average values were calculated for traits such as fresh plant weight, number of pods per plant, number of seeds per plant, and seed weight per plant. This was calculated using the number of pods and seeds per plant.

$$\text{Number of seeds per pod} = \frac{\text{Number of seeds per plant}}{\text{Number of pods per plant}}$$

100-seed weight (g)

A sample of 100 seeds was randomly taken from the yield of each plot, and then weighed to determine the 100-seed weight for each treatment.

Seeds yield (kg/ha)

Plants on the one-meter length from middle of each plot of each treatment were harvested, sun-dried, weighed to obtain the biological yield. The pods of the harvested plants were threshed, and seeds were collected. The seed yield per unit area was converted into kg ha^{-1} at 14 % moisture content.

Harvest index

It was estimated using the data of grain yield and biological yield as follows:

$$\text{Harvest index} = \frac{\text{Final Seed Yield weight}}{\text{Biological Yield}} \times 100$$

Statistical analysis

Analysis of variance was performed using MSTAT-C Statistical Package software with season and replication as random and irrigation regimes and varieties as field effects (Abdelgadir, 2010). Dependent variables included plant weight, number of pods plant^{-1}, weight of pods plant^{-1}, number of seeds plant^{-1}, weight of seeds plant^{-1}, 100 seeds weight, seeds yield, and harvest index, and were analyzed across the 2 seasons. The procedure of analysis of variance and mean separation were followed according to the description of (Kirda, 2002). When F values were significant, each parameter's means were compared by the LSD test ($P \leq 0.05$).

Results and Discussion

Effects of variables of season (Y) and irrigation regimes (D) on number of pods plant^{-1}, weight of pods plant^{-1}, number of seeds plant^{-1}, weight of seeds plant^{-1}, 100 seeds, seeds yield, and harvest index were analyzed for significance at the $P < 0.05$, $P < 0.01$ or $P < 0.001$ levels. Significant effects of Y and V were each observed on all parameters except number of seeds plant^{-1} and harvest index, while only D exerted not significant effects on plant weight. However, no significant effects were exerted by varieties (V) on either number of pods plant^{-1}, weight of pods plant^{-1}, weight of seeds plant^{-1}, 100 seeds, and harvest index. Significant effects of V on plant weight, number of seeds plant^{-1} and seeds yield. The interaction of Y × V revealed significant effects on plant weight, number of pods plant^{-1} and seeds yield ($P < 0.05$), while the D × V interaction exerted significant effects on all parameters ($P < 0.05$). Significant effects of the Y × V × N interaction had a significant effect ($p < 0.05$) on all traits except number of pods plant^{-1} and harvest index.

Weight of plant (g per plant)

The results indicated that, the weight of plant had a significant change during the seasons of study and the highest weight of plant was observed in the second season (41.5 g per plant). The mean comparison of the interaction between seasons and varieties revealed that the both varieties in the second season of study had the highest value of weight of plant (45.7 g per plant for Egyptian and 37.3 g per plant for 1448 variety). The flowering stage higher affected by the drought stress than pod full and vegetative growth stages. Therefore, as a result of the interaction between irrigation regimes with varieties, variety 1448 at pod full stage was more affected by the other stages, it was decreased by 37.7% as compared with same variety at full irrigation. While, Egyptian variety at the flowering stage was more affected, it was reduced by 57.5% as compared with same variety at full irrigation (Figure 1A).

Number of pods per plant

As a result of the interaction between varieties with drought stress, both varieties at flowering and pod full stages was more affected than vegetable growth stage, and the Egyptian variety was sensitive to drought stress than 1448. As comparison with 1448 variety at full irrigation, the number of pods per plant reduced by 20.8% and 38.4% at the flowering and pod full stages respectively, but increased by 5.0% at the vegetative growth stage (Figure 1B). In addition, the number of pods per plant was increased at vegetative growth

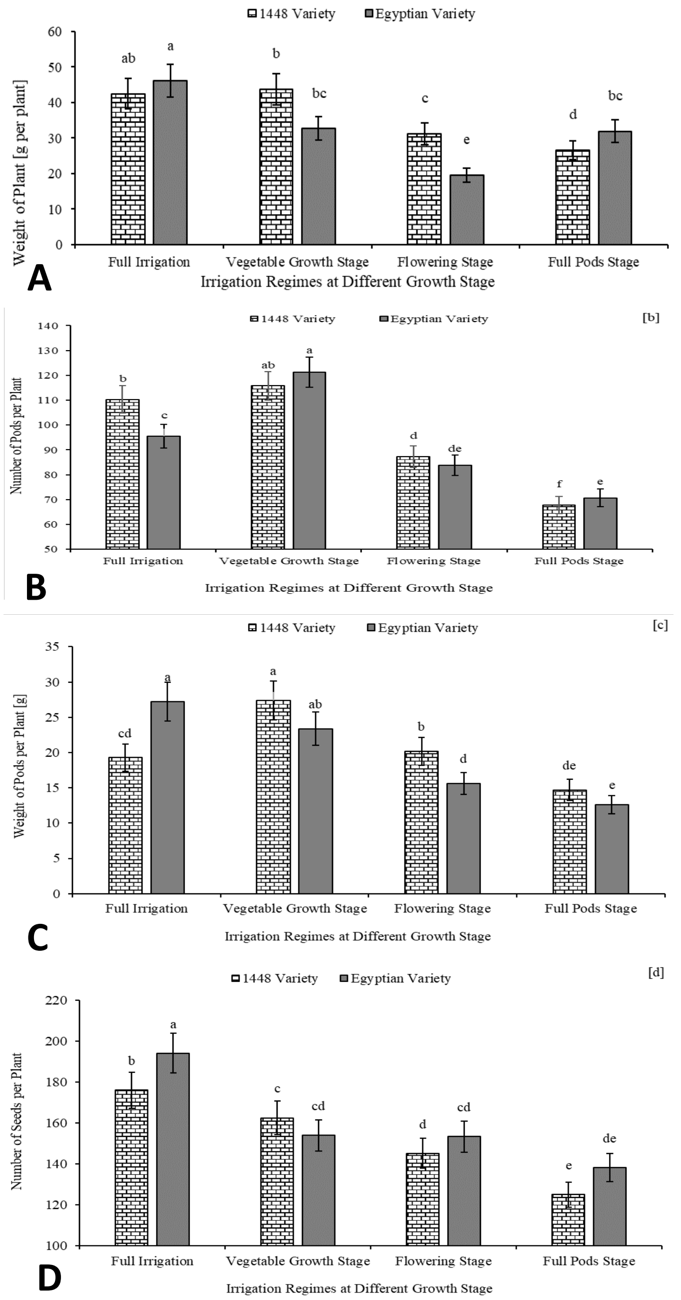

Figure 1: *Plant weight (A), number of pods per plant (B), weight of pods per plant (C) and number of seeds per plant (D) of two soybean varieties 1448 and Egyptian variety as influenced by the combination between varieties and irrigation regimes at different stages. Bars with different letters are significantly different at the 0.05 probability. Means were separated by the LSD test.*

stage by 26.9%, and reduced by 12.2% and 26.0% at the flowering and pod full stages respectively for the Egyptian variety as comparison with the same variety at full irrigation (Figure 1B). The mean comparison of the seasons and irrigation regimes interaction revealed that the vegetative growth stage in both seasons was not impacted by the drought stress than other stages. As compared with full irrigation at first and second season, the number of pods per plant increased by

26.3% and 37.0% respectively, over the control, but drought stress at the flowering and pods full stages decreased by 19.1% and 20.6% respectively, for the first season, and 28.0% and 18.8% respectively for the second season.

Weight of pods per plant (g per plant)

The results indicated that, the weight of pods per plant had a significant change during the seasons of study, and the highest weight of pods per plant was observed in the first season. The mean comparison of the weight of pods per plant affected by the interaction between irrigation regimes and seasons showed that, as compared with control at the same season, irrigation regimes at the vegetative growth, flowering and pods full stages were decreased by 30.5%, 37.3% and 56.1% respectively, for first season and were reduced by 33.3%, 39.1% and 37.1% respectively, for second season. Therefore, in the interaction between irrigation regimes with varieties, both varieties at pod full stage was more affected by the other sages. Variety 1448 did not affected by the irrigation regimes at the vegetative growth and flowering stages, it was increased by 42.0% and 4.6%, while reduced by 23.7% at the pods full stage as compared with same variety with full irrigation, while, variety Egyptian was affected by the irrigation regimes at all stages, as compared with variety 1448 with full irrigation, the weight of pods per plant decreased by 14.1%, 42.6% and 53.6% at the vegetative growth, flowering and pods full stages respectively (Figure 1C).

Number of seeds per plant

In the interaction between irrigation regimes with varieties, both varieties were affected by the irrigation regimes at all stages. The pod full stage was more affected by the other stages, and the variety Egyptian was more affected by irrigation regimes than 1448. As comparison with 1448 variety at full irrigation, the number of seeds per plant were reduced by 7.7%, 17.5% and 29.0% at the vegetable growth, flowering and pod full stages, respectively (Figure 1D). However, the number of seeds per plant were reduced at the same stages by 20.7%, 21.0% and 28.8%, respectively, for the Egyptian variety as compared with the same variety at full irrigation (Figure 1D). In the interaction between season and irrigation regimes revealed that the number of seeds per plant at the first season higher than second season. Meanwhile, as compared with full irrigation at first and second season, the number of seeds per plant at the vegetable growth stage were decreased by 7.3% and 6.7%, respectively, at the flowering stage were reduced by 10.0% and 26.2% respectively, and at the pod full stage decreased by 19.6% and 13.7% respectively.

Weight of seeds per plant

Averaged across the seasons and irrigation regimes, in both seasons, irrigation regimes at flowering stage and pods full stage decreased the weight of seeds per plant by 24.7% and 39.8%, respectively for first season, and reduced by 14.8 and 12.6%, respectively, for second season. While, soybean plant supplied to irrigation regimes at the vegetable growth stage was not affected, it was increased by 8.2% and 30.1% for first and second season respectively as compared with full irrigation at the same seasons. Averaged across all the irrigation regimes and both varieties, irrigation regimes exhibited weight of seeds per plant at different plant growth stage except vegetative growth stage. Variety 1448 recoded the high number of seeds per plant at all drought stress than variety Egyptian (Figure 2A). Irrigation regimes decreased the seeds weight per plant for 1488 and Egyptian varieties at flowering stage by 10.9% and 30.8% respectively, and decreased by 17.2% and 38.8% respectively at pods full stage, while, at the vegetative growth stage, 1448 and Egyptian varieties were increased the seeds weight per plant by 39.2% and 9.5% respectively, as compared with the same varieties at the full irrigation (Figure 2A).

100 seeds weight

The 100 seeds weight values averaged of two soybean varieties exhibited and decreasing with irrigation regimes at the different plant growth stage at both seasons. Regarding the interaction between irrigation regimes and seasons, irrigation regimes exhibited 100 seeds weight at different plant growth stage. The 100 seeds weight was decreased by 10.5% and 55.6% for first season and reduced by 15.5% and 3.3% for second season for vegetative growth and pods full stages as compared with same variety at full irrigation. In the interaction between irrigation regimes and varieties, the annual average of 100 seeds weight value at the vegetative growth and pod full stages, 1448 variety were slightly increased by 4.2% and 9.2% respectively, relative to Egyptian variety at the same irrigation regime, while at the flowering stage Egyptian variety was increased by 19.9 relative to 1448 (Figure 2B).

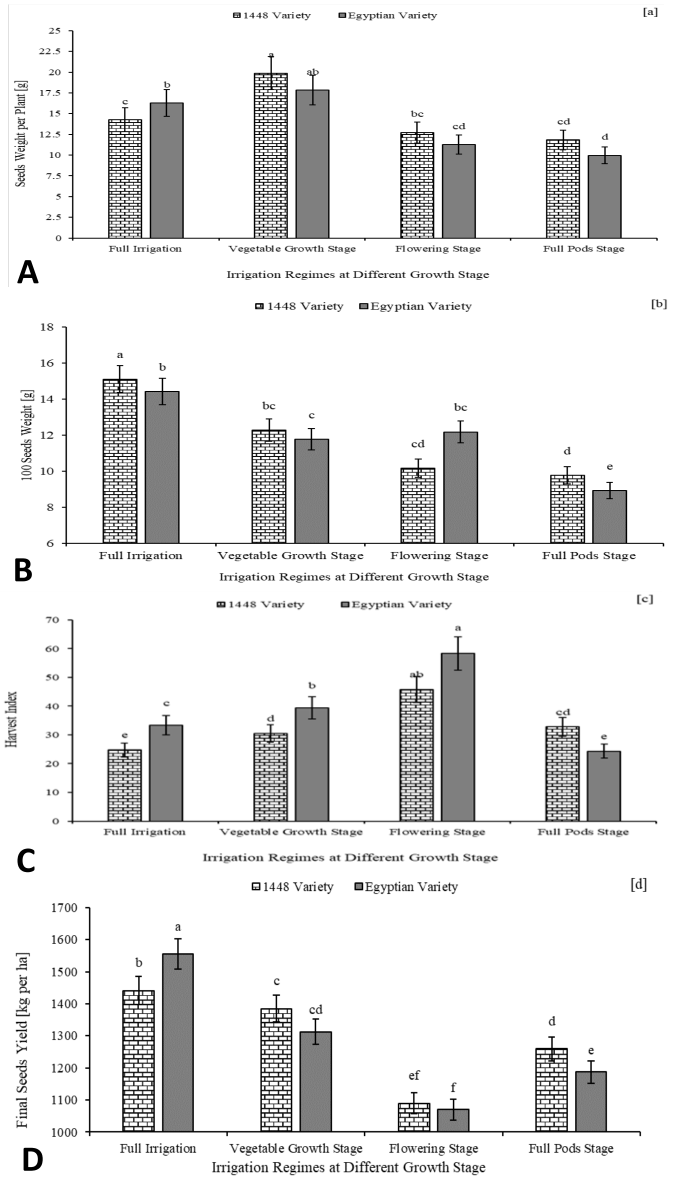

Figure 2: *The weight of seeds per plant (A), 100 seeds weight (B), harvest index (C) and final seeds yield (D) of two soybean varieties 1448 and Egyptian variety as influenced by the combination between varieties and irrigation regimes at different stages. Bars with different letters are significantly different at the 0.05 probability. Means were separated by the LSD test.*

Harvest index

For each soybean varieties and within each season, variety 1448 was observed the highest value for harvest index with the increased by 53.5% and 56.3% for first and second season respectively, as compared with Egyptian variety at the same season. Irrigation regimes increased the harvest index at all growth stages, the highest value at the first and second seasons recorded at the flowering stage (51.3 ± 25.3 and 38.8 ± 15.4, respectively), following the vegetative growth and pod full stages. Variety Egyptian was more tolerance to drought stress than 1448 variety. In the interaction between irrigation regimes and varieties, at the vegetative growth, flowering, and pods full stages, the harvest index increased by 29.4%, 27.4% and 35.0% respectively, for Egyptian variety relative to 1448 variety at the same irrigation regime (Figure 2C).

Final seeds weight (kg per ha^{-1})

The results indicated that, the final seeds weight had a significant change during the seasons of study and the highest value was observed in the second season (1273.4 g per ha^{-1}). The mean comparison of the final seeds weight was affected by the irrigation regimes and seasons. At the first and second season, irrigation regimes reduced the final seeds weight. As compared with full irrigation at the same season, irrigation regimes at the vegetative growth, flowering and pods full stages were decreased by 0.3%, 2.06% and 2.4% respectively, for first season and were decreased by 33.9%, 40.6% and 35.4% respectively for second season. Therefore, as a result of the interaction between irrigation regimes with varieties, both varieties at flowering stage was more affected by the other sages, it was decreased by 24.4% and 31.2% for 1448 and Egyptian variety as compared with same variety at full irrigation (Figure 2D). Variety 1448 recoded the highest value of final seed yield at all irrigation regimes that means 1448 variety was more tolerance to irrigation regimes (Figure 2D).

Among abiotic factors, drought stress is probably the most limiting for crop quality and productivity. Drought stress is a multidimensional stress affecting plants at various levels of their organization (Farooq *et al*., 2020, 2006). Thus, the effects of drought stress are often manifested at morphological, physiological, biochemical and molecular level, such as inhibition of growth, accumulation of compatible organic solutes, changes in plant hormones endogenous contents (Aimar *et al*., 2011). The number of pods per plant is an important variable for determining seed yield crops performance in leguminous plants (Kobraee *et al*., 2011; Mirzaei *et al*., 2013; Ullah *et al*., 2023). In this study, irrigation regimes at flowering and seed development stages caused reducing in number of pods per plant, but water stress at vegetable growth stage was did not effected on this trait, the highest number of pods per plant were observed in vegetable growth stage following by full irrigation (Arshad *et al*., 2006). The reduction in number of pods per plant is the result of water deficiency which has adverse effect on the development of reproductive parts of plants. Stress at vegetative stage results in less development of fruit bearing branches, which ultimately affect the number of pods per plant (Farooq *et al*., 2020). The water stress nearer to flowering stage; its effect was increased on number of pods and finally the seed yield, it is concluded that drought stress had most effect on non-inoculation flowers and their falling. Increasing water irrigation caused to fertile flowers and finally growing pods this led to increasing the number of pods per plant and seed yield (Abd El-Mohsen *et al*., 2013). The drought stress had little effect on the seed growth and yield of the tested varieties during the vegetative growth and stem elongation stages. The number of seeds per pod was remarkably affected by the water stress at any stage of soybean plant resulted in decreased. This fact reflects the environmental changes and genetic effects on the studied trait. In this study, the higher value of number of seeds per plant recorded at the full irrigation (Ma *et al*., 2006). We pointed out the increase in number of seeds per plant under water shortage during the vegetable growth, flowering and pods formation stages. By increasing the assimilate production, the stress can cause a decrease in seed yields through seed and pod shattering (Masoud, 2007; Mirzaei *et al*., 2013; Ullah *et al*., 2023). In addition, these findings are indicated that drought stress during any stage of soybean crop influenced significantly the number of seeds, and reported the higher number of seeds per plant and number of pods per plant at higher irrigation frequencies. Drought stress caused decreasing of photosynthesis and consuming of photosynthesis matters by growing leaves and decrease the phloem photosynthesis materials (Mirzaei *et al*., 2013). However, water stress by decreasing the number of pods per plant and number of seed per pod reduced the rapeseed yield during the pollination and seed filling stages. Weight of seeds per plant and number of seeds per plant is an important factor for determining the yield of leguminous crops. Seed weight per plant had directly impact on the final yield of any crop. Severe drought stress seed forming stage results in significant reduction of weight of seed and pods per plant. In this study we found that drought stress decreased the weight of seeds per plant (Aimar *et al*., 2011; Mohsen *et al*., 2013). The reduction in seed weight per plant during drought stress might be due to less development of seeds under stress conditions, and a reduction indirectly of the photosynthesis and consumption of photosynthesis matters by increased the growing of the leaves compared with growing of seeds and pods (Mirzaei *et al*., 2013; Abd-Alla and Orman, 2022). Our finding indicated that during water stress at flowering stage, the final grain yield reduces due to decreasing the seed weight, resulted from harmful effect of drought on producing biomass and drought stress caused to reducing seed weight. Final yield is the combined effect of various yield components under irrigation regimes (Aimar *et al*., 2011). Thus, any variation in them is liable to bring about variation in seed yield. Water deficits have been shown to increase seed abortion, and the duration of the maturation period has been reduced by water stress during seed filling, leading to accelerated senescence, and decreased seed yield and yield components (Rosadi *et al*., 2007; Shakir *et al*., 2023). Cultivars had different response at different levels drought stress on yield component and seed yield. The results showed that Egyptian cultivar had highest seed yield using full irrigation and lowest seed yield obtained at flowering stag at same cultivar. High seed yield in Egyptian cultivar can attribute to high numbers of pods per plant, number of seeds per pod and 1000-seeds weight that fresh pod yield of ten vegetable soybean cultivars ranged from 11 to 15 t ha^{-1}. At last, we can say that possible reasons for such difference could be associated with their work which was conducted in different environmental conditions with other maturity groups of soybeans.

Conclusions and Recommendations

Our study examined the effects of water stress on the yield and yield components of two soybean varieties. Water stress at any stage of the soybean plant significantly reduced plant weight, the number and weight of pods per plant, the number and weight of seeds per plant, the weight of 100 seeds, and overall seed yield. Importantly, the highest seed yield was achieved with full irrigation, followed by stress during the vegetative growth stage, while the lowest seed yield occurred with water stress during flowering and pod filling stages. This study concludes that the varieties showed a wide range of variability for most traits and demonstrated a high yield variation among soybean cultivars. The results indicate that variety 1448 performed the best for traits under different irrigation regimes and is therefore recommended as the most suitable commercial soybean variety under the study conditions.

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Novelty Statement

Water stress significantly affects soybean growth, development, and production in semi-arid regions. This research emphasizes the importance of water management at different growth stages for optimizing soybean production in semi-arid regions and provides insights into the specific impacts on different varieties.

Author's Contribution

Shakir Ullah: Supervision. Lubna Shakir: Methodology. Ghani Subhan: Writing review and editing. Mohammad Sohail: Methodology, writing - original draft.

Conflict of interest

The authors have declared no conflict of interest.

References

Abayomi, Y., 2008. Comparative growth and grain yield responses of early and late soybean maturity groups to induced soil moisture stress at different growth stages. World J. Agric. Sci., 4: 71–78.

Abdel-Gadir, S., 2010. Another look at the determinants of foreign direct investment in MENA countries: an empirical investigation. J. Econ. Dev., 12 (6) 134-567.

Abd-Alla, A. and M. Omran. 2022. Response of four soybean genotypes to nitrogen fertilization levels and plant population. Ann. Agric. Sci. Moshtohor., 40: 93–105.

Abd-El-Mohsen, A.A., G.O. Mahmoud and S.A. Safina. 2013. Agronomical evaluation of six soybean cultivars using correlation and regression analysis under different irrigation regime conditions. J. Plant Breed. Crop Sci., 5(5): 91–102. https://doi.org/10.5897/JPBCS2013.0389

Abdel-Hafeez, M., 2001. Effect of partially acidulate phosphate rocks and triple superphosphate and their combinations on growth, mineral composition and yield of wheat. D thesis, Sudan University of Science and Technology.

Adam, H., 2002. The agricultural climate second edition.

Aimar, D., M. Calafat, A. Andrade, L. Carassay, G. Abdala and Molas, ML. 2011. Drought tolerance and stress hormones: From model organisms to forage crops. Plants Environ., 10(6): 137–164.

Ali, A., M. Tahir, M.A. Nadeem, A. Tanveer, M. Asif, Wasaya, A. and Rehman, J. 2009. Effect of different irrigation management strategies on growth and yield of soybean. Pak. J. Life Soc. Sci., 7(2): 181–184.

Ali, A.Y.A., M.E.H. Ibrahim, G. Zhou, N.E.A. Nimir, A.M.I. Elsiddig, MI., Jiao, X and Elradi, SBM. 2021. Gibberellic acid and nitrogen efficiently protect early seedlings growth stage from salt stress damage in Sorghum. Sci. Rep., 11(1): 1–11. https://doi.org/10.1038/s41598-021-84713-9

Ali, A.Y.A., M.E.H. Ibrahim, G. Zhou, N.E.A. Nimir, X. Jiao, Zhu, G., Elsiddig, AMI., Zhi, W., Chen, X. and Lu, H. 2019. Ameliorative effects of jasmonic acid and humic acid on antioxidant enzymes and salt tolerance of forage sorghum under salinity conditions. Agron. J., 111(6): 3099–3108. https://doi.org/10.2134/agronj2019.05.0347

Ali, A.Y.A., M.E.H. Ibrahim, G. Zhou, N.E.A. Nimir, X. Jiao, Zhu, G., Elsiddig, AMI., Suliman, MSE., Elradi, SBM. and Yue, W. 2020. Exogenous jasmonic acid and humic acid increased salinity tolerance of sorghum. Agron. J., 112(2): 871–884. https://doi.org/10.1002/agj2.20072

Ardestani, GH and Rad, A. HS. 2011. Impact of regulated deficit irrigation on the physiological characteristics of two rapeseed varieties as affected by different potassium rates. Afr. J. Biotechnol., 11(24): 6510-6519.

Arshad, M., N. Ali, and A. Ghafoor. 2006. Character correlation and path coefficient in soybean *Glycine max* (L.) Merrill. Pak. J. Bot., 38(1): 121.

Comlekcioglu, N. and M. Simsek. 2011. Effects of deficit irrigation on yield and yield components of vegetable soybean (*Glycine max* L. (Merr.)) in semi-arid conditions. Afr. J. Biotechnol., 10(33): 6227–6234.

Farooq, M., Barsa, SM. and Wahid, A. 2006. Priming of field-sown rice seed enhances germination, seedling establishment, allometry, and yield. Plant growth regulation, 49: 285-294.

Farooq, M., A. Wahid, N. Kobayashi, D. Fujita and S. Basra. 2009. Plant drought stress: Effects, mechanisms and management. Sustainable agriculture: pp. 153–188. https://doi.org/10.1007/978-90-481-2666-8_12

Farooq, M., L. Romdhane, M.K. Al Sulti, A. Rehman, W.M. Al-Busaidi and Lee, DJ. 2020a. Morphological, physiological and biochemical aspects of osmopriming-induced drought tolerance in lentil. J. Agron. Crop Sci., 206(2): 176–186. https://doi.org/10.1111/jac.12384

Kirda, C., 2002. Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. Food Agric. Organ. U. N., Deficit Irrig. Pract. Water Rep., 22(102).

Kobraee, S. and K. Shamsi. 2011. Effect of irrigation regimes on quantitative traits of soybean (*Glycine max* L.). Asian J. Exp. Biol. Sci., 2(3): 441–448.

Kobraee, S., K. Shamsi and B. Rasekhi. 2011. Soybean production under water deficit conditions. Ann. Biol. Res., 2(2): 423–434.

Kokubun, M., S. Shimada and M. Takahashi. 2001. Flower abortion caused by preanthesis water deficit is not attributed to impairment of pollen in soybean. Crop Sci., 41(5): 1517–1521. https://doi.org/10.2135/cropsci2001.4151517x

Liu, F., 2004. Physiological regulation of pod set in soybean (*Glycine max* L. Merr.) during drought at early reproductive stages. PhD degree at The Royal Veterinary and Agricultural University (KVL), Copenhagen, Denmark. pp. 148.

Ma, Q., S.R. Niknam and D.W. Turner. 2006. Responses of osmotic adjustment and seed yield of *Brassica napus* and *B. juncea* to soil water deficit at different growth stages. Austral. J. Agric. Res., 57(2): 221–226. https://doi.org/10.1071/AR04283

Masoud, S.M., 2007. The effects of water deficit during growth stages of canola (*Brassica napus* L.).

Mentreddy, S., A. Mohamed, N. Joshee and A. Yadav. 2002. Edamame: A nutritious vegetable crop. ASHS Press. pp. 432–438.

Mirzaei, A., R. Naseri, A. Moghadam and M. Esmailpour-Jahromi. 2013. The effects of drought stress on seed yield and some agronomic traits of canola cultivars at different growth stages. Bull. Environ. Pharmacol. Life Sci., 2: 115–121.

Mondal, M.M.A., M.S.A. Fakir, A.S. Juraimi, M. Hakim, M. Islam and Shamsuddoha, AT. 2011. Effects of flowering behavior and pod maturity synchrony on yield of mungbean (*Vigna radiata* (L.) Wilczek). Austral. J. Crop Sci., 5(8): 945.

Mohsen, AA, Mohsen, K, and Wael SG. 2013. Effect of salinity stress on Vicia faba productivity with respect to ascorbic acid treatment. 6(3) 725-736.

Rosadi, R.B., M. Senge, K. Ito and J.T. Adomako. 2007. The effect of water stress in regulated deficit irrigation on soybean yield (*Glycine max* (L.) Merr.). Paddy Water Environ., 5(3): 163–169. https://doi.org/10.1007/s10333-007-0080-z

Sehgal, A., K. Sita, J. Kumar, S. Kumar, S. Singh, Siddique, KH. and Nayyar, H. 2017. Effects of drought, heat and their interaction on the growth, yield and photosynthetic function of lentil (*Lens culinaris* Medikus) genotypes varying in heat and drought sensitivity. Front. Plant Sci., 8: 1776. https://doi.org/10.3389/fpls.2017.01776

Shakir, L., U. Shakir, S. Mohammad, U. Rihan and S. Muhammad. 2023. Phytochemical analysis, antipyretic and antifungal activities of *Solanum nigrum* L. Natl. J. Pharma. Sci., 3(2): 06-12.

Singh, G., 2010. The soybean: Botany, production and uses. CABI.

Ullah, S., A. Said, H. Ihtisham, U. Ikram, B. Rizwana, A. Asghar, K.Y. Muhammad. 2023. Ethnobotanical study of village Darangal Kambat Tehsil Samarbagh, District Dir Lower, Khyber Pakhtunkhwa, Pakistan. J. Agric. For. Res., 2: 5.

Ullah, S., L. Shakir and R. Ullah. 2023. Morphological and phytochemical study of Cirsium Arvense from District Mardan Pakistan. J. Bioinf. Biotechnol. Res., 1(1): 1-7. https://doi.org/10.61440/JBBR.2023.v1.01