Asian Journal of Soil Science and Plant Nutrition

Volume 9, Issue 1, Page 21-33, 2023; Article no.AJSSPN.96767
ISSN: 2456-9682

Enhancing Drought Tolerance of Quinoa (*Chenopodium quinoa*) Through Potassium and Boron Application

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Authors' contributions

This work was carried out in collaboration among all authors. Authors IZ, SI, and Sanaullah designed the study, performed the statistical analysis, wrote study protocol and drafted the manuscript. Authors HN, MAt, and MAf managed the analyses of the study. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJSSPN/2023/v9i1169

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/96767

Received: 14/12/2022
Accepted: 20/02/2023
Published: 25/02/2023

Original Research Article

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ABSTRACT

Aims: Pakistan is facing a severe water shortage and the situation is further aggravated due to elevated temperature, leading to drastic yield reduction of quinoa. Hence, there is a dire need to maintain or increase agricultural production by utilizing sustainable methods of production to tackle changing climate. Quinoa (*Chenopodium quinoa*) is a crop, recognized by United Nations due to its nutritional and health benefits.

Methodology: Therefore, a field study was carried out to evaluate the drought tolerance of quinoa through soil application of potassium (K) and boron (B) under Randomized Completely Block Design (RCBD) with a split-split plot arrangement and three replications. The crop was sown on November 06, 2021, using a seed rate of 8 kg ha^{-1} on 75 cm apart ridges with hand dibbling maintaining plant to plant distance of 120 cm. The experiment contained the following treatments; soil application of K at 0, 50, and 75 kg K_2O ha^{-1} and B (H_3BO_3) at 0, 6 kg ha^{-1} in well-watered and drought-induced experimental units.

Results: Data related to crop physiological response and yield attributes were recorded using standard procedures and protocols. Quinoa performance decreased under drought stress but it was improved by potassium (K) supplementation at 75 kg K_2O ha^{-1}. Supplementation of K improved the seed yield of quinoa in drought-stressed conditions up to 41% and was also found economically viable because the value of benefit cost ratio was 2.2 in drought conditions as compared to the respective control (1.65).

Conclusion: Drought is an environmental factor that negatively interferes with crop growth and yield. So application of potassium and boron can enhance drought tolerance of quinoa through soil application.

Keywords: Drought stress; quinoa; potassium; boron; climate change.

1. INTRODUCTION

Ensuring food and nutritional security is a worldwide challenge and to cope with the prevailing issue of food security, alternative food crops should be utilized. Approximately 75% of global food demand is being fulfilled by consuming only 12 species of crops and the contribution of maize, wheat, and rice is 50% to the world diet [1]. Dependency on a few crop species to meet food requirements is not a wise option because of climatic variations and more insect pest attacks on these crops [2]. Climate resilient or minor/exotic crops are getting attention due to their numerous benefits like tolerance to abiotic stresses, better profit margin, and nutritional properties [3].

Extreme climatic variations with prevailing drought and increasing temperature are key problems for sustainable agricultural production throughout the world [4]. In most parts of the world, crop production is facing the problem of water scarcity that greatly reduced crop ability to perform better in this conditions. Drought is a major environmental factor that caused a reduction in yield of up to 50% or even more throughout the world [5]. At the global level, water deficiency is the foremost restriction to plant development and the yield of crops [6]. Drought stress is a main environmental issue that limits the productivity of plants and reduces the production of food in agriculture by lowering the absorption and uptake of water and nutrient from the soil [7].

To overcome drought stress, application of different macro and micronutrients is more important [5]. Among them, potassium (K) is an important nutrient that plays a key role in osmotic adjustment, enzyme activation, and osmoregulation [6]. The K augments several physiological and biochemical process that ultimately improves plant growth and yield of quinoa under drought conditions [8]. The Boron is a micronutrient that has stimulating responses of tolerance against water stress because of improved water uptake from the soil medium due to more root hairs along mycorrhiza. The mycorrhizal association resulted in enhanced stomatal conductance and carbon assimilation via leaf expansion [9].

The B application markedly enhanced the oil quality of camelina under drought conditions [10]. The B treatment improved antioxidant activities and gene expression while decreasing malondialdehyde (MDA) contents under drought stress. The B nutrition is found effective in alleviating the negative impacts of drought stress in many field crops [11]. Because it is mandatory for many metabolic pathways which are helpful in the biosynthesis of pectin for cell wall and stability of cell wall. The B has a pivotal role in sugar translocation, phenolic metabolism, oxidative stress, and phenolic metabolism [12]. Many researchers reported that optimum B supply to plants enhances plant growth and development by increasing ant oxidative activates photosynthetic efficacy and the water status of plants under limited water conditions [13,14]. In light of the above discussion, it can be made possible to improve quinoa drought tolerance through soil application of K and B. Therefore, the current study was conducted to enhance drought tolerance in quinoa through soil-applied K and B.

2. MATERIALS AND METHODS

2.1 Study Site

In the proposed study, soil application of K (0, 50, 75 kg ha^{-1}) and B (0, 6 kg ha^{-1}) was carried out in fully irrigated and drought experimental units. The study was conducted at the research area of Muhammad Nawaz Shareef University of Agriculture Multan under a Randomized completely block design with split-plot and replicated thrice. After soil preparation, Seventy-five-centimeter part ridges were made. The variety UAF-Q7, was purchased from the department of Agronomy, University of Agriculture Faisalabad. The seed was sown on one side of the ridges using a seed-rate of 10 kg ha^{-1}. Irrigation was applied before sowing and seeds were manually sown by the chopa method on ridges at 2-3 cm depth. Fertilizer at the rate of N: P 75: 50 kg ha^{-1} was applied. The recommended dose of fertilizers N and P were applied before the preparation of ridges. Thinning of the crop was done manually at 21 Days to maintain a plant spacing of 10 cm. No herbicides were applied during the trial and two weeding were done manually at 30 days and 55 days respectively. The crop was harvested after attaining maturity stage.

2.2 Treatments

Factor A: Water stress

D 1: (Fully irrigated (4 Irrigations, 1st at 25 days after sowing, 2nd at 20 days after 1 st Irrigation, 3rd at flowering and 4th at grain formation)
D 2: (Deficit irrigation (2 Irrigations skipping last two irrigations at reproductive R 1 and R 2 stages)

Factor B: Boric acid doses

T 1: 0 kg ha -1
T 2: 6 kg ha -1

Factor C: K (potassium sulphate) doses

T 1: 0 kg ha -1
T 2: 50 kg ha -1
T 3: 75 kg ha -1

3. RESULTS AND DISCUSSION

3.1 Physiological Parameters

Three plants were tagged in each experimental unit and physiological parameters were recorded during the flowering stage (80 days of sowing).

3.2 Photosynthetic Rate

It was possible to measure the rate of photosynthesis using portable CIRAS-3. All tagged plants were surveyed and the mean value was computed. Statistically significant variations were noted in the leaf photosynthetic rate (LPR) of quinoa due to drought, potassium (K), and boron (B) levels while all interactive effects were non-significant (Fig. 1). K and B supplementation improved LPR both under drought and well-watered conditions but the more clear impact was noticed due to K application @ 75 kg K_2O ha^{-1} both under drought and well-watered conditions.

3.3 Leaf Transpiration Rate

Portable CIRAS-3 was used to measure the transpiration rate. After collecting data from tagged plants mean value was determined. Present results indicated that statistically significant differences were found in the leaf transpiration rate (TR) of quinoa due to drought and B levels as represented in ANOVA (Fig. 2).

3.4 Leaf Stomatal Conductance

Stomatal conductance (SC) of quinoa was significantly influenced due to drought while all other main and interactive effects were non-significant (Fig. 3). SC was noticed in the range of 32.33-38 (mmol H_2O m^{-2} s^{-1}) in drought-induced plots while in well-watered condition SC was found in the range 62-76 (mmol H_2O m-2 s^{-1}).

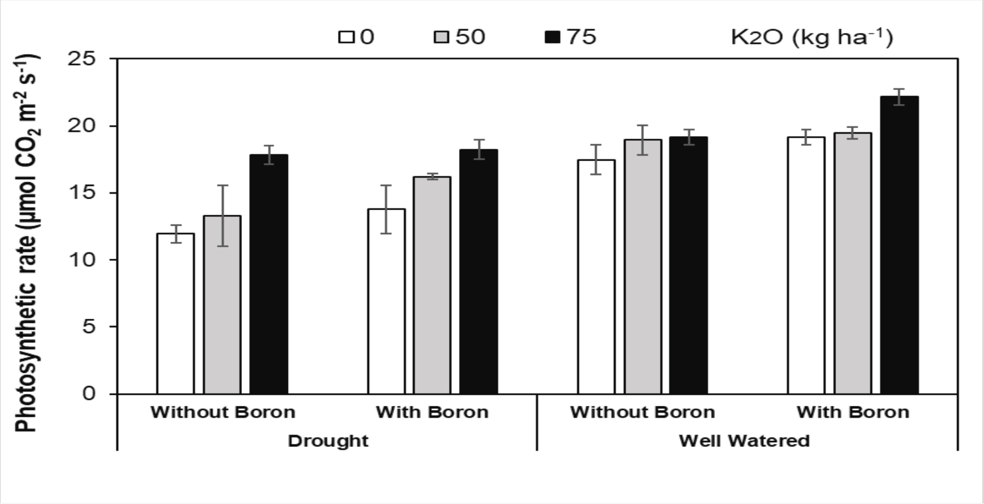

Fig 1. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on leaf photosynthetic rate of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

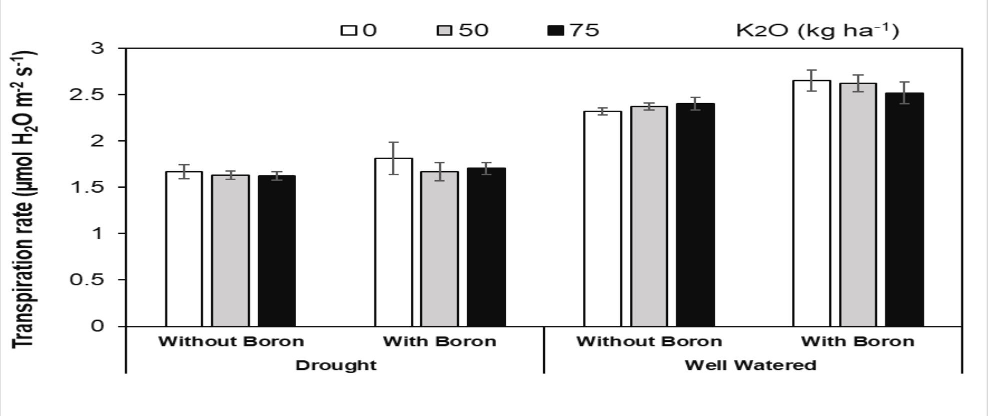

Fig. 2. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on the leaf transpiration rate of quinoa grown under drought (2 Irrigations) and well-watered conditions (4 Irrigations)

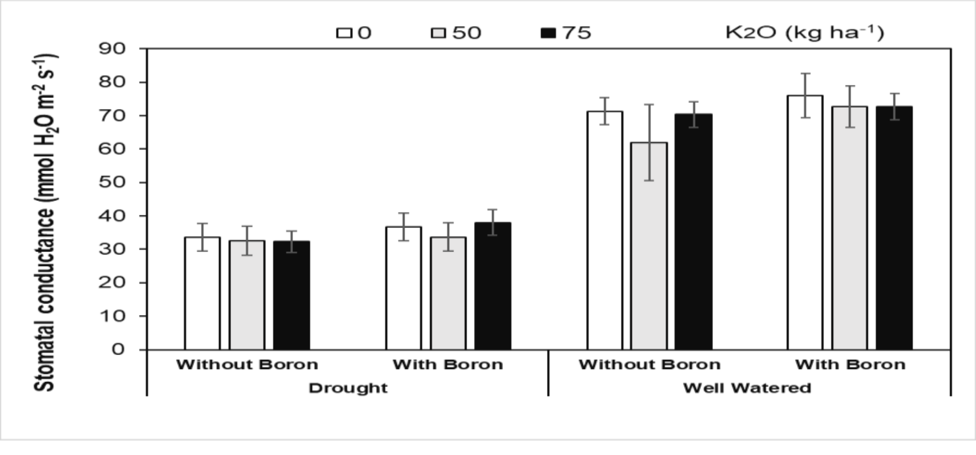

Fig. 3. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on leaf stomatal conductance of quinoa grown under drought (2 Irrigations) and well-watered conditions (4 Irrigations)

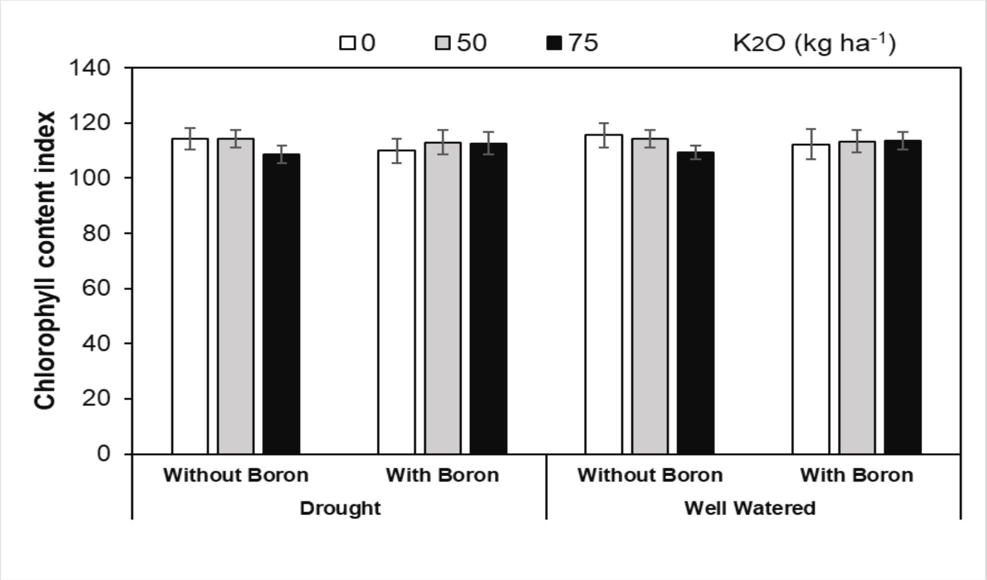

Fig. 4. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on leaf chlorophyll content index of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

3.5 Leaf Chlorophyll Content Index

It has been noticed that all main as well as interactive effects of drought, potassium, and boron levels related to leaf chlorophyll content index were non-significant. Quinoa maintained leaf chlorophyll contents even in drought condition.

3.6 Leaf Analysis

3.6.1 K contents in leaf (ppm)

Drought stress, potassium and boron supplementation significantly impacted the accumulation of Potassium (K) in leaf of quinoa. More K accumulated in leaves of quinoa sampled from drought experimental units supplemented with 75 kg K_2O ha^{-1} (Fig. 5).

3.6.2 Ca contents in leaf (ppm)

Drought stress and potassium fertilizer addition significantly affected the accumulation of calcium (Ca) in the leaf of quinoa. More Ca accumulated in leaves of quinoa sampled from drought experimental units supplemented with 75 kg K_2O ha^{-1} (Fig.6).

3.6.3 Na contents in leaf (ppm)

A statistically significant effect was found due to Boron supplementation related to sodium (Na) accumulation in leaves. Boron supplementation reduced Na accumulation in all drought-induced, well-watered and K-supplemented experimental plots (Fig. 7).

3.6.4 Leaf-relative water contents

The interactive effect of K and B supplementation related to leaf-relative water contents (RWC) was found statistically significant. K supplementation@ 75 kg K_2O ha^{-1} improved RWC in all treated experimental units (Fig. 8).

3.7 Growth Parameters

3.7.1 Plant height (cm)

Plant height was measured to estimate the effect of various treatments on plant growth. Drought stress significantly impacted the plant height of quinoa only the main effect related to drought stress was significant. Low plant heights were noticed in drought-induced plots as compared to well-watered plots. K supplementation @ 75 kg K_2O ha^{-1} also improved the plant height of plants (20-22%) in drought-induced plots (Fig. 9).

3.7.2 Stem diameter (mm)

Stem diameter was measured from three different sites, the top, the mid and the bottom end of the stem and the mean value was calculated. Drought stress significantly affected the stem diameter of quinoa; the only main effect related to drought stress was significant. Fewer values of stem diameter of plants were noticed in drought-induced plots as compared to well-watered plots. No significant effects of K and B supplementation were observed (Fig. 10).

3.8 Yield Parameters

3.8.1 Main panicle length (cm)

The panicle length of tagged plants was measured at physiological maturity using a centimeter scale and mean values were computed. The interactive effect of drought stress and K supplementation regarding the main panicle length of quinoa was found significant. K supplementation @75 kg K_2O ha^{-1} improved the main panicle length of quinoa in drought-induced experimental plots (Fig. 11).

3.8.2 Main panicle dry weight (g)

The main effects of drought and K supplementation were found significant concerning main panicle dry weight. In drought stress plots quinoa produced the main panicle with less weights however due to K supplementation main panicle dry weight increased (Fig. 12).

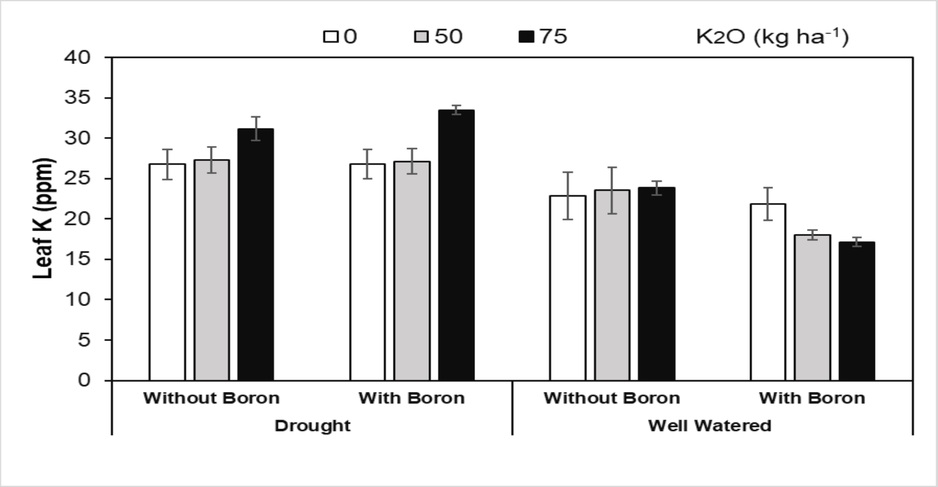

Fig. 5. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on leaf potassium contents of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

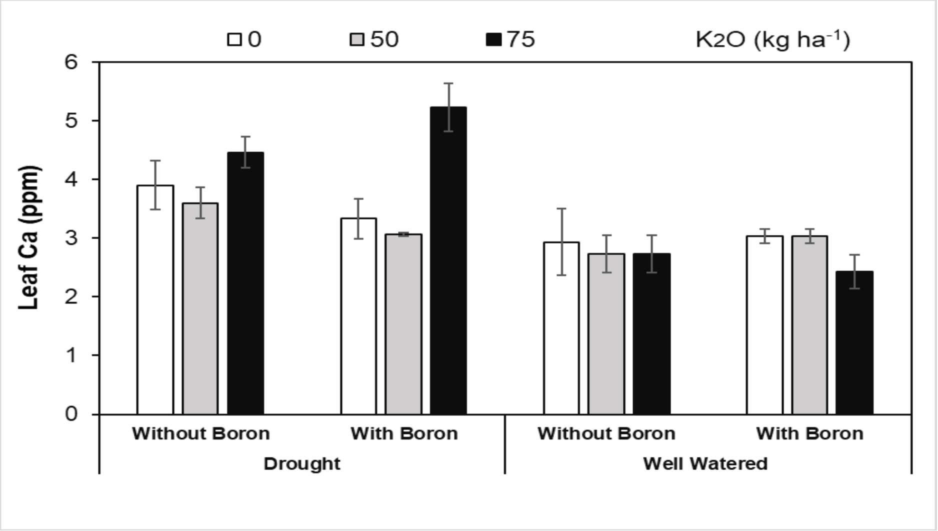

Fig. 6. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on leaf calcium contents of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

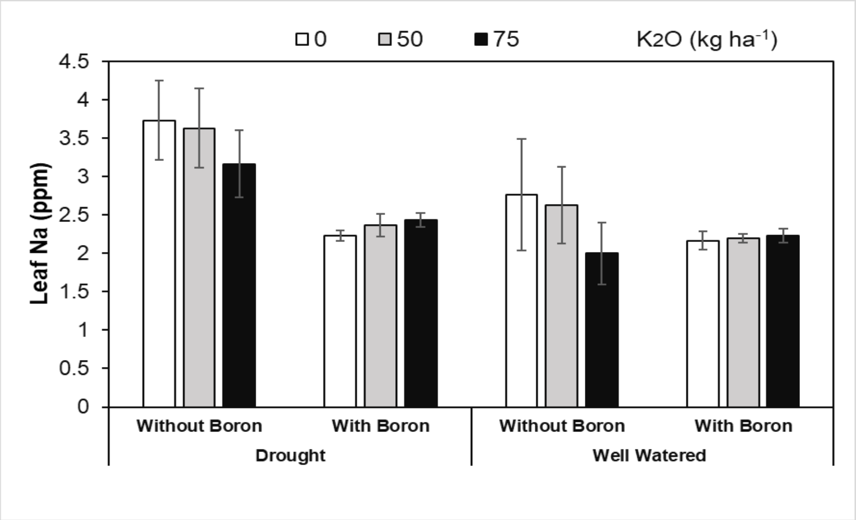

Fig. 7. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on leaf sodium contents of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

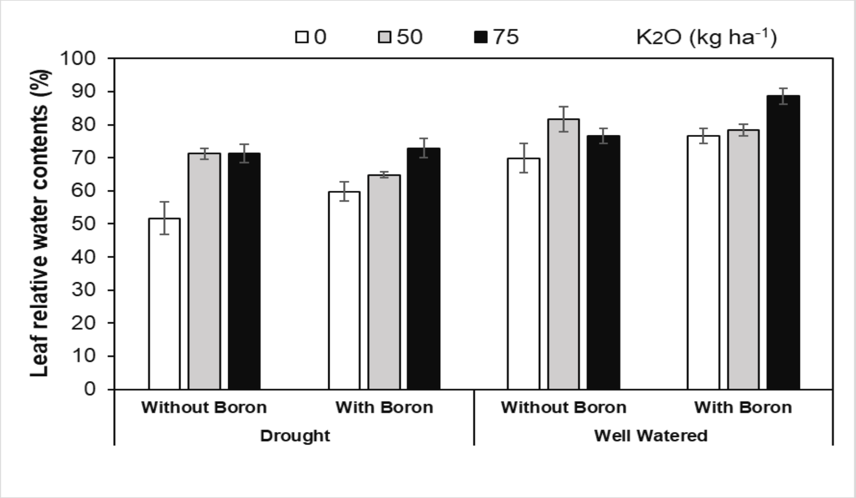

Fig. 8. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on leaf relative water contents of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

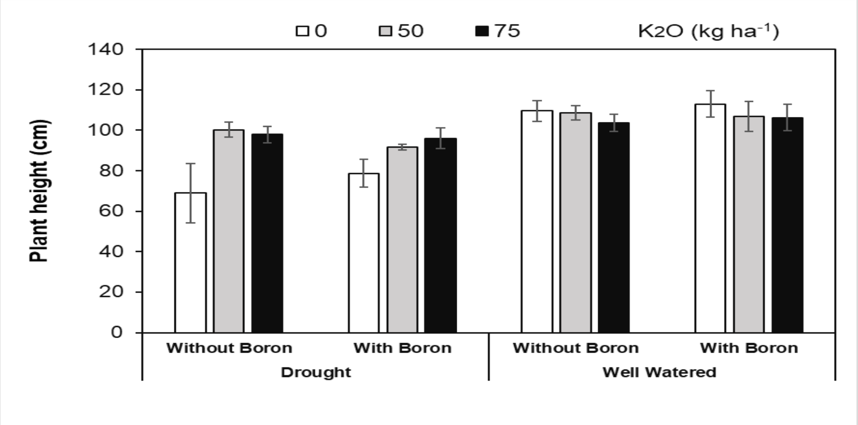

Fig. 9. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on plant height of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

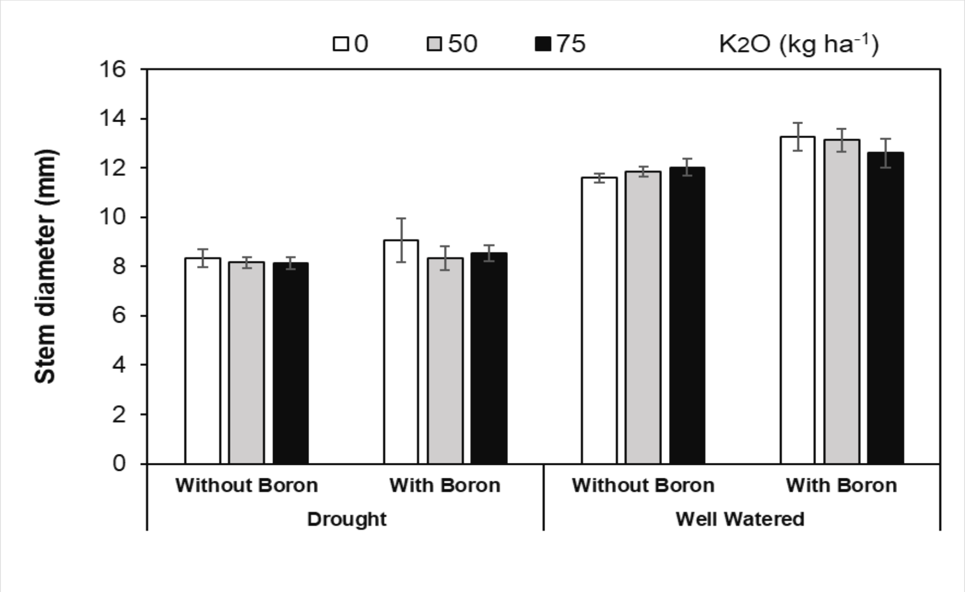

Fig. 10. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on stem diameter of quinoa grown under drought (2 Irrigations) and well-watered conditions (4 Irrigations)

3.8.3 Main panicle seed weight (g)

Main panicles were harvested manually from tagged plants and sun-dried to remove moisture content from the seed. Drought and K levels were found statistically significant regarding the main panicle seed weight of quinoa. Fewer seeds were obtained from main panicles harvested from drought-stressed plots as compared to well-watered plots (Fig. 13).

3.8.4 Number of sub panicles

The main effect of drought was found significant regarding the number of sub-panicles of quinoa. Drought stress impacted negatively and less number of sub panicles were produced in quinoa grown in drought-stressed conditions. In drought conditions, sub-panicles were up to 17 and in well-watered plots sub-panicles were found up to 23 (Fig. 14).

3.8.5 Seed yield (kg ha^{-1})

The main effects of drought and potassium were found significantly related to the seed yield of quinoa. Potassium supplementation (75 kg K_2O ha^{-1}) improved seed yield in both drought and well-watered conditions (Fig. 15).

3.8.6 Biological yield (kg ha^{-1}).

Statistically significant main effects of drought and potassium were observed concerning the biological yield of quinoa. Potassium supplementation (75 kg K_2O ha^{-1}) improved biological yield in both drought and well-watered conditions (Fig. 16).

3.9 Thousand Grain Weight

The interactive effect of drought stress and K supplementation was found statistically significant regarding the thousand-grain weight of quinoa. Thousand-grain weight (3.2 g) improved due to K (75 kg K_2O ha^{-1}) and B (6 kg H_3BO_3 ha^{-1}) supplementation when harvested from drought-stressed plots as compared to thousand-grain weight (2.6) of respective control (Fig. 17).

3.10 Seed Quality Parameters

3.10.1 Germination percentage (%)

All main and interactive effects related to the germination percentage of quinoa seeds harvested from different experimental units were noticed as non-significant. Germination percentage was found in the range of 73-77%.

3.10.2 Seed vigor index (%)

All main and interactive effects related to the seed vigor index of quinoa seeds harvested from different experimental units were noticed as non-significant. The seed vigor index was found in the range of 161-169%.

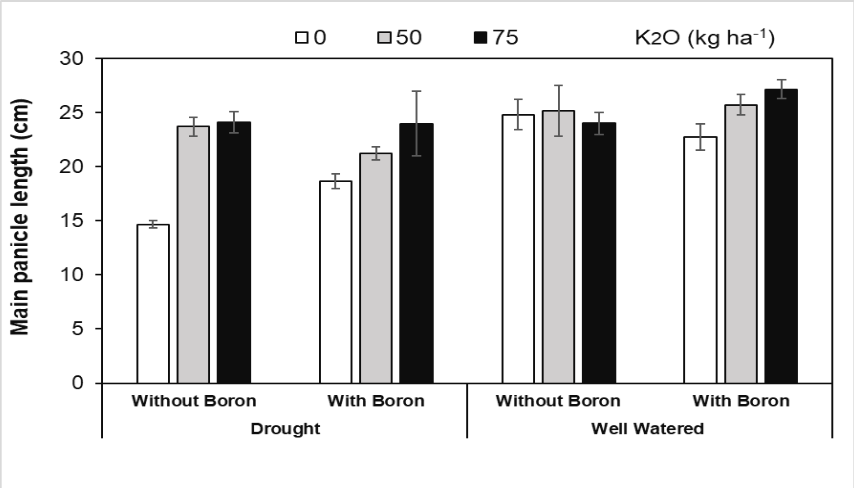

Fig. 11. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on main panicle length of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

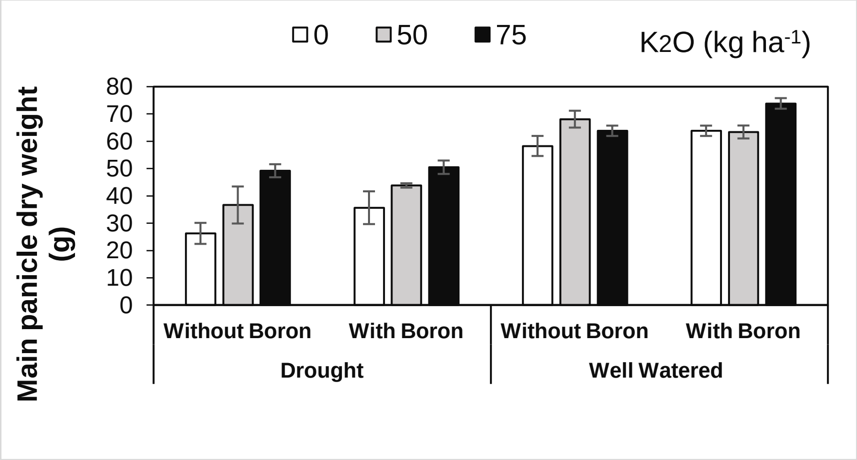

Fig. 12. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on main panicle dry weight of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

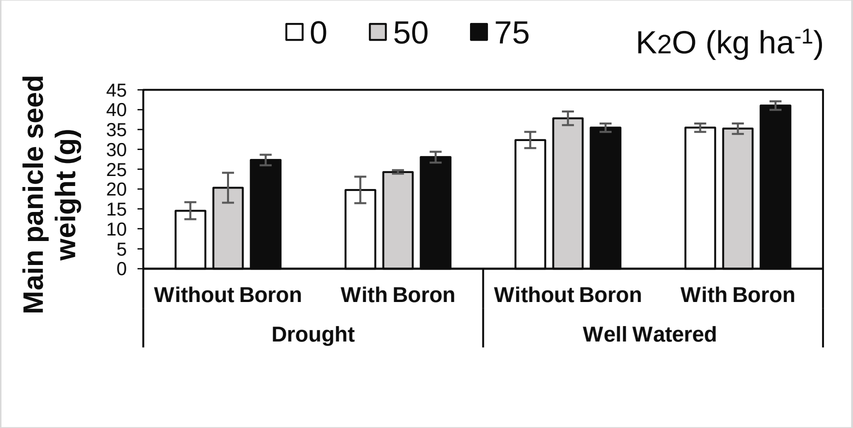

Fig. 13. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on main panicle seed weight of quinoa grown under drought (2 Irrigations) and well-watered conditions (4 Irrigations)

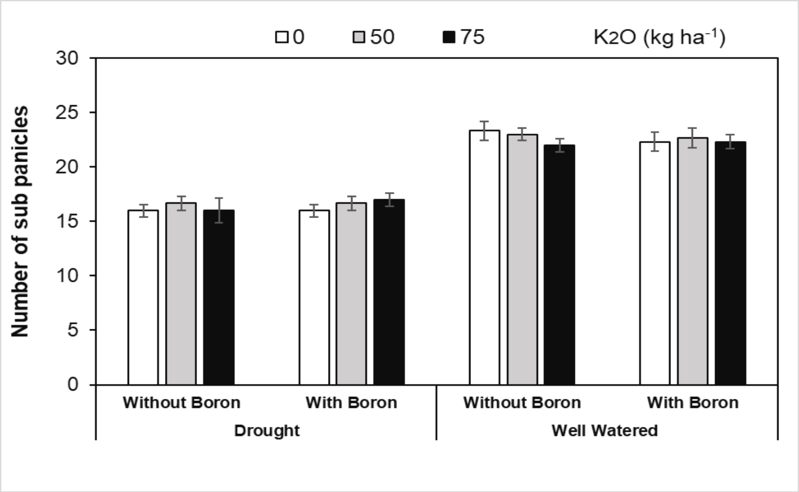

Fig. 14. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on number of sub panicles of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

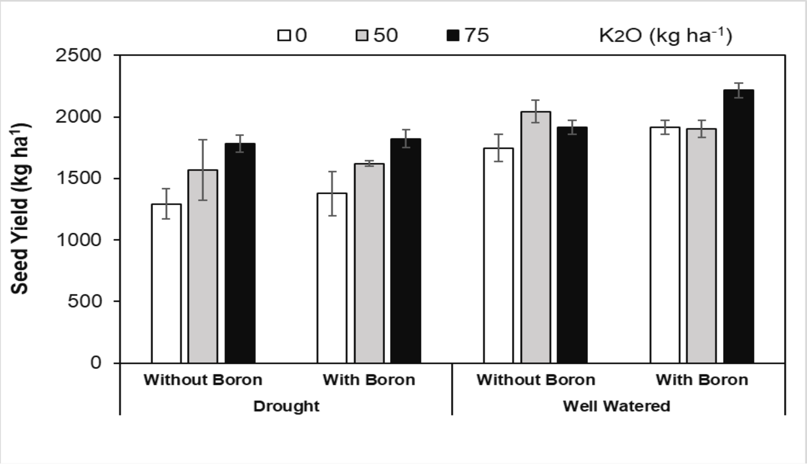

Fig. 15. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on seed yield of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

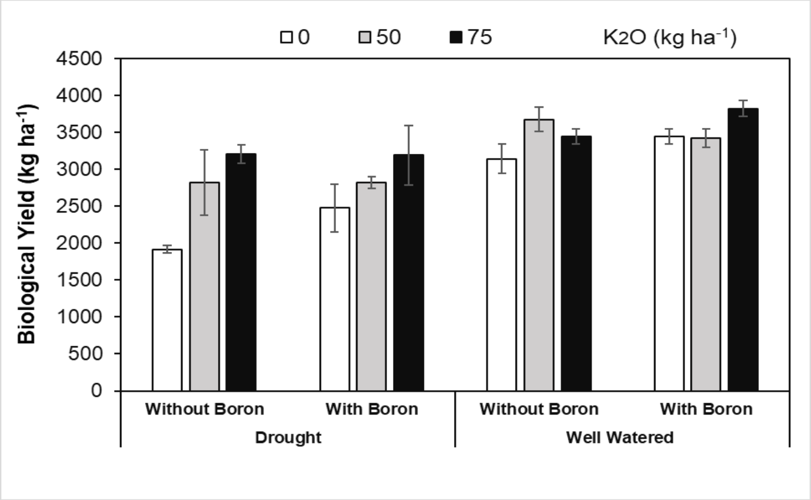

Fig. 16. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on biological yield of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

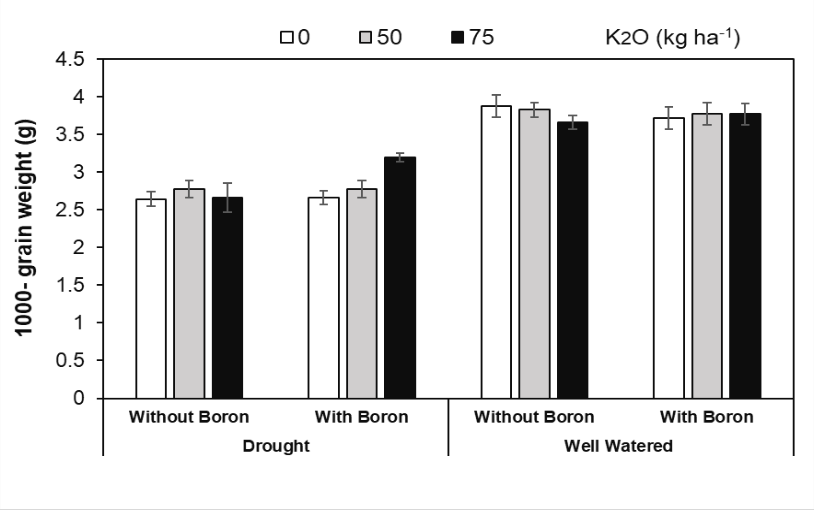

Fig. 17. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on thousand-grain weight quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

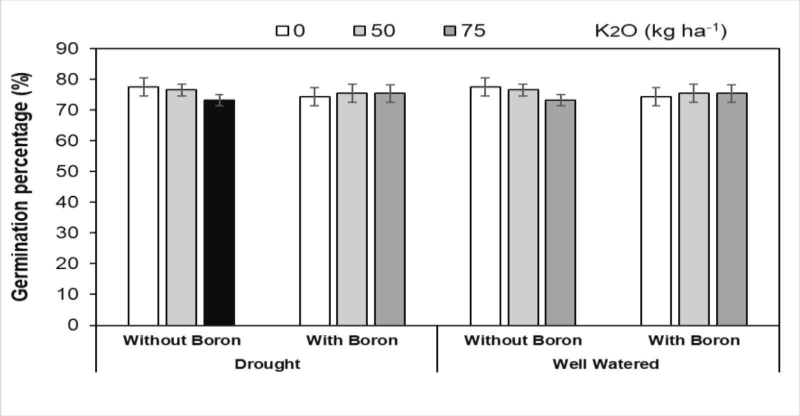

Fig. 18. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on germination percentage of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

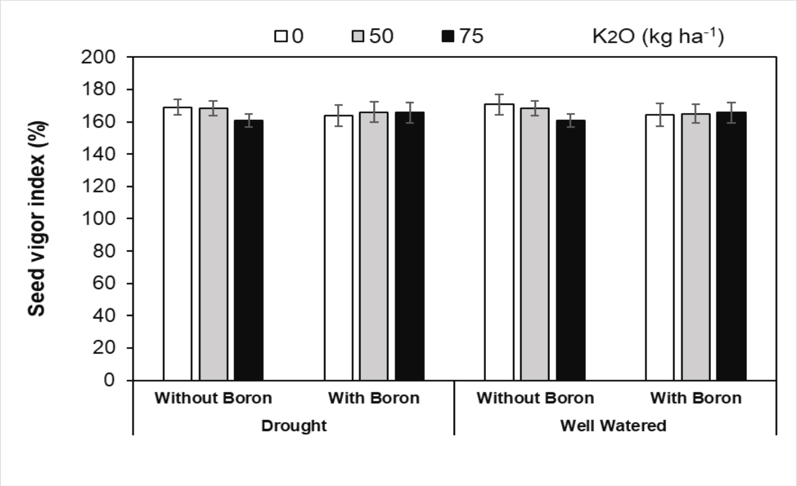

Fig. 19. Impact of Potassium and Boron (6 kg H_3BO_3 ha^{-1}) supplementation on seed vigor index of quinoa grown under drought (2 Irrigations) and well water conditions (4 Irrigations)

More than 5000 plant species are edible and most of the world's population is consuming only three crops i.e., wheat, rice, and maize leading to malnutrition, this situation is further aggravated due to climate change adversities and failure of major crops. So dire need is to diversify the food basket by utilizing Future Smart Food species like quinoa, millet, and pulses for food and nutritional security. Future Smart Food (FSF) is a term coined by FAO for those crops having 4 characters i.e., 1) Climate Resilience 2) Balanced nutritional profile 3) Locally available 4) Economically viable.

Quinoa is plant species that might ensure food and nutritional security in this century. Quinoa exhibits tolerance to abiotic stress including drought. Quinoa adopts adaptive strategies to cope with abiotic stress through modulations in physiological and morphological attributes (Saddiq et al. 2021). Therefore, this study was conducted to further enhance drought tolerance through the application of potassium and boron. Over sixty enzymes are actively hated by potassium, an essential nutrient for plant growth and development. Potassium strengthens the plant's defenses against drought, heat, and disease. Root development is enhanced, stomata conductance is controlled for higher water usage efficiency, and starches are produced by the plant body as a result of potassium (K). K plays a very vital role in osmotic adjustment. Boron has also been reported to enhance drought tolerance. The plants that were nutrient rich in boron (B) showed stimulating reactions of resistance against the effects of drought. This was due to enhanced absorption of water from the soil rhizosphere, which was achieved by producing more root hairs and mycorrhizae. Because of the availability of B, stomata conductance and carbon (C) absorption were both enhanced, with the consequence being full-sized leaf growth.

Therefore, in this study, soil application of K (0, 50, 75 kg ha^{-1}) and B (0, 6 kg ha^{-1}) was applied in fully irrigated and drought experimental units. The study was conducted at the research-area of MNSUAM. The experiment was carried out in RCBD with split-split arrangements having 3 replications. Quinoa was sown on six November 2021 with treatments detail;

Factor A: Water stress, D$_1$: (Deficit irrigation (2 Irrigations skipping last two irrigations at reproductive stages) D$_2$: (Fully irrigated (4 Irrigations, 1st at 25 days after sowing, 2nd at 20 days after 1st irrigation, 3rd at flowering and 4th at grain formation.

Factor B: Boric acid doses B$_1$: 0 kg ha^{-1}, B2: 6 kg ha^{-1}

Factor C: K (kg K$_2$O ha^{-1}) doses K1: 0 kg ha^{-1} K2: 50 kg ha^{-1} K3: 75 kg ha^{-1} using SOP fertilizer. The crop was harvested in April 2022. Data regarding physiological, growth, yield, ionic, and seed-related traits were taken using standard procedures. Data regarding different variables collected from different experimental units were compared by using Fisher's analysis of variance with 5% probability level. Economic analysis was also conducted to investigate comparative results and the benefits of different treatments.

4. CONCLUSION

According to the results it has been observed that due to drought stress, quinoa performance declined drastically as indicated by biological yield and seed yield. However, K supplementation (75 kg K$_2$O ha^{-1}) improved the performance of quinoa both in drought and well-watered conditions. Supplementation of K improved seed yield of quinoa in drought-stressed conditions by up to 41%. This dose was also found economically viable because the value of BCR was 2.2 in drought conditions as compared to the respective control (1.65). Furthermore, this improvement was linked with the better accumulation of K and Ca in leaves which helped plants to tolerate drought through osmoregulation as depicted by better leaf-relative water contents. This study showed that quinoa plants also exhibit mechanisms to avoid water loss as depicted by reduced stomatal conductance and transpiration rate in drought conditions. Quinoa seed characters did not disturb by drought or any other treatments rather little impacted by unusually high temperatures during the grain development stage.

ACKNOWLEDGEMENT

We are highly thankful to our teachers and parents for their financial, technical, and moral support.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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