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Rhizospheric Addition of Hydrogel Polymer and Zeolite Plus Glutathione Mitigate the Hazard Effects of Water Deficiency On Common Bean Plants Through Enhancing the Defensive Antioxidants

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Abstract

Currently, the world is facing many troubles in crop production and the irrigation water deficit is the most harmful among them. Saving irrigation water is the main target for all countries of the world, especially in arid areas. Field trial was executed aiming to assess the influence of irrigation regimes (100, 80 and 60% of irrigation requirements, IR (IR_{100}, IR_{80} and IR_{60}, respectively), water-absorbent substances (control, hydrogel polymer and zeolite as soil addition) and foliar application of glutathione (GSH) [with GSH or without] on the performance of common bean plants. Findings clarified that plant fresh weight obtained with the combination of IR_{80} × zeolite × GSH had no significant differences with the superior combination of IR_{100} × hydrogel polymer or zeolite × GSH. Hydrogel polymer plus GSH supply showed distinctive enhancements for N, P and K accumulation in common bean leaves. Application of zeolite plus GSH reduced the accumulation of POX and CAT by 21.8 and 15.5% under IR_{80} and 16.1 and 7.6% under IR_{60}, respectively. Spraying of GSH × hydrogel polymer under $IR_{100,}$ IR_{80} and IR_{60} significantly increased the value of pods yield by 26.5%, 25.23% and 32.80, respectively, as compared to corresponding control treatment. the interaction of IR_{100} and hydrogel polymer whether with or without GSH showed the highest significant values of N, P, protein, fiber, carbohydrates percentages and TDS. Briefly, it can be concluded that water holding amendments i.e., polymer and zeolite as well as low-molecular-weight antioxidants i.e., glutathione can mitigate the hazard impacts of elevated reactive oxygen species production under drought. Practically, common bean growers are advised to treat the soil with available soil amendment (hydrogel polymer, 0.24 t ha^{-1} or zeolite, 1.20 t ha^{-1}) and spraying common bean plants by glutathione, 1.0 mM to sustain the crop productivity and quality under shortage water conditions

Keywords Deficit irrigation · Enzymatic antioxidants · Nutrient content · Phaseolus vlugaris · Soil amendments

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Introduction

Certainly, the adverse ecological conditions such as drought, salinity and heat are the distinctive abiotic stresses which can affect plant growth and productivity (Lasheen et al. 2023), threating the cultivable land areas (Alsamadany et al. 2022; EL-Bauome et al. 2022; El-Yazied et al. 2022). By 2050, it is anticipated that drought stress will cause serious plant growth problems for more than 50% of the arable lands (Vinocur and Altman 2005). Water shortage is one of the most restrictive factors on the cultivation and productivity of plants worldwide; thus, it affects the world's food security (Tapia et al. 2022). Drought is the most threatening issue which resulted from climate change due to the reduction of rainfalls and water scarcity (Ahanger et al. 2021).

At plant cellular level, drought is associating with accumulation of reactive oxygen species (ROS), which reduce the electron transport chain activity (Hasanuzzaman et al. 2020). Different stresses are accompanied to excess ROS formation (Souri et al. 2019; Hatamian et al. 2020; Hadid et al. 2023). The hazard effects of ROS depend on deterioration of proteins, nucleic acids, membrane lipids and photosynthetic pigments (Zulfiqar and Ashraf 2021). Naturally, plants can defend themselves via enzymatic and non-enzymatic antioxidants by detoxifying ROS to alleviate stress impacts (El-Bially et al. 2018, 2022a; El-Metwally et al. 2021; Zulfiqar and Ashraf 2021; El-Mageed et al. 2022; Shahin et al. 2023). As a response to ROS stress, several osmo-regulators such as glycine betaine and proline are accumulated in plant cells (Shemi et al. 2021; El-Metwally et al. 2022a; Ramadan et al. 2023). However, suppression in photosynthetic pigments is proportionally linked to the potentiality of photosynthesis affecting crop productivity (El-Metwally et al. 2022b). Hence, water deficit reduced yield and quality (Abd–Elrahman et al. 2022; El-Bially et al. 2022b). As well, since drought causes stomata close, declines in photosynthesis assimilates and water–use efficiency were observed (Anjum et al. 2011; El-Metwally and Saudy 2021; Makhlouf et al. 2022). Moreover, the issues of drought could be ascribed to low availability of nutrients in soil while disturbance uptake and utilization by plant (Saudy and El–Metwally 2019; Mubarak et al. 2021; Salem et al. 2021). The negative impacts of abiotic stresses were reported in almost crop plant species such as faba bean (Ramadan et al. 2023), peanut (Saudy et al. 2020), sugar beet (Makhlouf et al. 2022), lettuce (Abd–Elrahman et al. 2022), sunflower (Saudy et al. 2021a, 2023a), canola (Shaaban et al. 2023a), and cereals (Saudy and Mubarak 2015; Salem et al. 2022; Saudy et al. 2023b; Saudy and El-Metwally 2023). Many strategies and approaches can be used to alleviate the drought stress on plants such as developing drought tolerant genotypes (Sprenger et al. 2016) and using soil amendments that enhance the soil water holding, i.e. hydrogel polymer and zeolite (Ozbahce et al. 2015; Čechmánková et al. 2021). Additionally, using exogenous antioxidants such as glutathione could be enhancer for the plant's tolerance to drought stress (Maslennikova and Shakirova 2021).

It has been proved that manipulating the edaphic factors in favor of crop growth regarded as the crucial practice for boosting crop yield and quality (Saudy et al. 2021b, c, 2022; El-Metwally et al. 2022c; Ali et al. 2023; El-Bially et al. 2023). In this concern, hydrogel polymer, which can be made from synthetic or biological materials (Rico-García et al. 2020), has many uses for industrial purposes, pharmacy, cosmetics, medicine and agriculture. As for agricultural purposes, hydrogel polymer is categorized as a hydrophilic substance that can absorb and hold water for about 400-time of its dry weight, therefore, it can secure moisture into the soil to supply the plant roots with water. Thus, it can improve the soil properties by increasing the soil water retention, delaying the wilting point for the growing plants (Palanivelu et al. 2022; Turioni et al. 2021; Shankarappa et al. 2020), while decreasing the nutrients loss by leaching (Čechmánková et al. 2021). Moreover, it is characterized by the imbibition ability and swelling of its granules, capability of rewetting and nontoxicity (Turioni et al. 2021; Oladosu et al. 2022; Elshafie and Camele 2021).

Zeolite is an aluminosilicate mineral that is found naturally or synthesized using other minerals as raw sources (Belviso et al. 2017). Zeolite can absorb and hold water, without any conversion or change in its crystalline structure. Accordingly, zeolite can improve the soil properties by increasing the soil water holding capacity, cation exchange capacity and leakage rates (Mondal et al. 2021). Also, it can be utilized in agriculture production, since it acts as a chelating agent or slow-release fertilizer enhancing plant growth and productivity (Mondal et al. 2021; Hazrati et al. 2017; Sepaskhah and Barzegar 2010; Belviso et al. 2022).

Regarding glutathione, it is a non-enzymatic antioxidant that helps the plant to mitigate abiotic stress such as drought or salinity; because of its participation in detoxifying or scavenging ROS and reactive nitrogen species (RNS) (Hasanuzzaman et al. 2017). Glutathione consists of three amino acids; glutamine, cysteine and glycine. It enhances the osmoregulation and water status in plant cells, the photosynthesis process, and the plant's physiological performance. Besides, glutathione shares with ascorbate, ascorbate peroxidase, monodehydroascorbate reductase, dehydroascorbate reductase and glutathione reductase at the ascorbate glutathione pathway in plants (Hasanuzzaman et al. 2019). This cycle comprises several enzymatic antioxidants that work on scavenging the ROS. Accordingly, the exogenous application of glutathione to plants grown under abiotic stress is a novel approach to alleviate the drought stress on the plants (El-Beltagi et al. 2020; Koramutla et al. 2021).

Little studies related to the interactional effect of hydrogel polymer, zeolite and glutathione on common bean growth and antioxidant enzymes under water shortage conditions are available. Based on their advantages, the current work hypothesized that water-holding materials and glutathione could effectively interact for mitigating the hazards of drought against common bean. Therefore, this study aimed to assess the influence of water-holding materials (hydrogel polymer and zeolite) in combination with glutathione supply on physiological status, growth and productivity of common bean plants grown under water deficit stress.

Materials and Methods

Plant Material and Experimental Site

A field experiment was implemented during summer season of 2021 at a farm located in Markaz Badr, El-Beheira governorate, Egypt (30°37′52.7″ N and 30°31′15.2″ E, 22 m above sea level). The experimental soil was sandy in texture with 90.32, 3.38 and 6.30% sand, silt and clay, respectively. Soil samples were taken at depth of 0–30 cm and soil physical and chemical analyses were done according to Warrick and Es, (2002). The soil characterized by EC of 0.64 dS m^{-1}, pH of 7.90; available N, P and K of 15.5, 7.20 and 39.52 mg kg^{-1} soil, respectively. Soil contained 0.23% organic matter as well as 0.60, 0.43, 0.52, 0.48 and 0.44 meq L^{-1} Ca^{++}, Mg^{++}, Na^{+}, Cl^{-} and HCO_3^{-}, respectively.

The study aimed to investigate the influence of three factors (irrigation regimes, water holding amendments and foliar spraying of glutathione) on the performance of common bean. Three irrigation regimes were applied at 100%, 80% and 60% of irrigation requirements (IR) which denoted as IR_{100}, IR_{80} and IR_{60}, representing well-watered, moderately water-stressed and severely water-stressed, respectively. Water holding amendments (without soil addition as control, hydrogel polymer at rate of 0.24 t ha^{-1} and zeolite at rate of 1.2 t ha^{-1}) were added to the soil. Two levels of glutathione (GSH) foliar spray (0.0 and 1.0 mM) were applied.

Seeds of common bean (*Phaseolus vlugaris* L.) cv. Giza-4 were obtained from the Agricultural Research Center and were sown on February 28th at a rate of 108 Kg ha^{-1}. One hour before sowing, seeds were inoculated with *Rhizobium leguminosarum* bv. phaseoli in the form of a commercial bio-fertilizer inoculant named “Okadin” that was obtained from the bio-fertilizer production unit affiliate to MASR. Seeds were treated at a rate of 480 g ha^{-1} of rhizobium inoculant carried on peat moss using sugar solution as a sticking agent. Other fertilization processes (chemical and organic) and all traditional agricultural practices for common bean production were performed.

The water-holding amendments were added to the soil before sowing immediately. Foliar GSH at 1.0 mM was applied two times two-week interval starting after 21 days from sowing at rate of 960 L ha^{-1}. The irrigation was done through drip irrigation. Irrigation water quantities were defined depending on the discharge rate of the water from the pump by using gauges.

Regarding the irrigation water requirement for common bean plants, it was calculated by determining the daily reference evapotranspiration (ETo) developed by FAO using FAO Penman–Monteith equation as described by Allen et al. (1998). Moreover, the crop evapotranspiration (ETc) was calculated from ETo using the following Eq. 1 according to Doorenbos and Pruitt (1977):

$$ET_c = ETo \times Kc \tag{1}$$

Where ETc = Crop evapotranspiration (mm/day), ETo = Reference evapotranspiration (mm/day), and Kc = Crop coefficient (0.5–1.05).

Then by using Eq. 2 according to Vermeirer and Jopling (1984) to estimate the irrigation requirements.

$$IR = ET_c xLRx10/Ea \tag{2}$$

Where IR = Irrigation requirement (m^3 ha^{-1}), LR = Leaching requirement (%) = 15%, Ea = Water application efficiency (90% for drip irrigation).

Experimental Design

The experiment was designed and established within strip split-plots in a randomized complete block arrangement in three replicates. Irrigation levels were arranged in the vertical plots and the water holding amendments were allocated in the horizontal plots, while the GSH foliar spraying was arranged in the sub plots. The experimental unit area (sub plot) was 10.5 m^2 (3.0 m × 3.5 m), and there was a boarder of 3.0 m among the three main irrigation strips. Planting distance was 15 cm apart on one side of the ridge.

Water Holding Amendments and GSH Preparation

Polyacrylamide (acrylamide, polymers; acrylamidehomopolymer; americancyanamidkpam; americancyanamidp-250; aminogenpa;ap273; CPAM; pam1800) was the hydrogel polymer which obtained from Chemical Engineering and Pilot Plant Dep., National Center of Research (NCR), Egypt, where it has high swelling ability (190 g g^{-1}). GSH was obtained from NCR, while zeolite was obtained from Alex Zeolite Company having CEC (163.00 cmol kg^{-1}), EC value of 2.50 dSm^{-1}, P_2O_5 (1.15%), FeO (5.9%), SiO_2 (64.75%), AlO_3 (12.4%), Na_2O (1.60%) and CaO (8.0%) and K_2O (6.20%).

Before the addition of water holding materials to soil, hydrogel polymer (as powder) was put in an amount of distilled water with stirring with a wooden stick, where it had good cohesive properties, then was mixed with an amount of experimental soil, while zeolite was mixed only with an amount of experimental soil. While, GSH was dissolved in distilled water to obtain the solution, its concentration was 1.0 mM.

Data Recorded

Vegetative Growth Characteristics

Samples of five plants were chosen randomly at 45 days after sowing from each plot to measure plant height and plant fresh weight. Afterwards, the plant dry weight was recorded by drying the plant samples in oven at 70 °C until constant weight.

Leaf Chlorophyll Content

The leaf greenness of the plants was measured by a portable chlorophyll meter (SPAD–502, Konica Minolta Sensing, Inc., Japan). SPAD-502 chlorophyll meter is a non-destructive method, which can be used to estimate amounts of total chlorophyll in plant leaves (Neufeld et al. 2006). For each plant, the youngest fully expanded leaves of randomly five plants per replicate were selected, readings were taken at four locations on the leaf; two on each side of the midrib, and then averaged (Xiong et al. 2015).

Leaves Mineral Content

After drying the plant leaves at 70 C° until constant weight, the dried samples were ground to fine powder to pass a 1 mm sieve. Afterwards, 0.1 g of the dried samples was taken and wet digested as described by Thomas et al. (1967), by using a mixture of sulphuric acid (H_2SO_4 98%) and hydrogen peroxide (H_2O_2 30%). The mineral content of leaves was assayed in the digested solutions. Total nitrogen was determined using Kjeldahl method as described by Fixen and Grove (1990). Colorimetrically, phosphorus content was determined by using spectrophotometer using the ascorbic acid method as described by AOAC (2005). Also, potassium was determined by flame photometer as described by Knudsen et al. (1983).

Antioxidant Enzymes Assay

A fresh leaves sample (0.2 g) were ground in 4 mL of 0.1 M ice-cold sodium phosphate buffer (pH 7.0) containing 1% (w/v) polyvinylpyrrolidon (PVP) and 0.1 mM EDTA, then centrifuged at 10.000 × g at 4 C° for 20 min. Afterwards, the antioxidant enzymes activity was assayed at the supernatant. The catalase (CAT; EC 1.11.1.6) activity was assayed by monitoring the decrease in absorbance of H_2O_2 at 240 nm (Cakmak et al. 1993), while the peroxidase activity (POX) was assayed as described by (Dias and Costa 1983), hence the assay depends on the ability of peroxidase to catalyze the dehydrogenation of numerous organic compounds such as guaiacol (guaiacol peroxidase (G-POX; EC1.11.1.7)) and examining the enhance in absorbance at 470 nm to determine its capacity to transform guaiacol into tetraguaiacol.

Pods Yield and Quality

By reaching a proper maturity stage, pods were harvested to assess yield attributes, involving pods number $plant^{-1}$, pod length, pod diameter and pods yield. yield quality attributes expressed in mineral content in pods such as nitrogen, phosphorus and potassium percentages were assayed according to AOAC (2005). Furthermore, pods crude protein content was estimated by multiplying nitrogen percentage in pods samples by conversion factor of 6.25. Carbohydrate content, pods fiber content and total dissolved solids (TDS) were measured (AOAC 2005).

Statistical Analysis

Data were subjected to statistical analysis of variance (ANOVA) using the CoStat package program (Microcomputer Program Analysis, Version 6.303; CoHort Software, CA, USA). Duncan's multiple range test, at 5% level of probability, was employed to compare the significant differences among means of the treatments (Waller and Duncan 1969).

Results

Growth Criteria and Chlorophyll Content

Undoubtedly, the well-watered plants show the highest significant values of the growth attributes and SPAD as compared to the moderately-watered and severely stressed plants. Moreover, the addition of soil amendments (zeolite and hydrogel polymer) significantly enhanced the growth attributes and SPAD as compared with untreated soil treatment. Also, spraying GSH significantly enhanced the

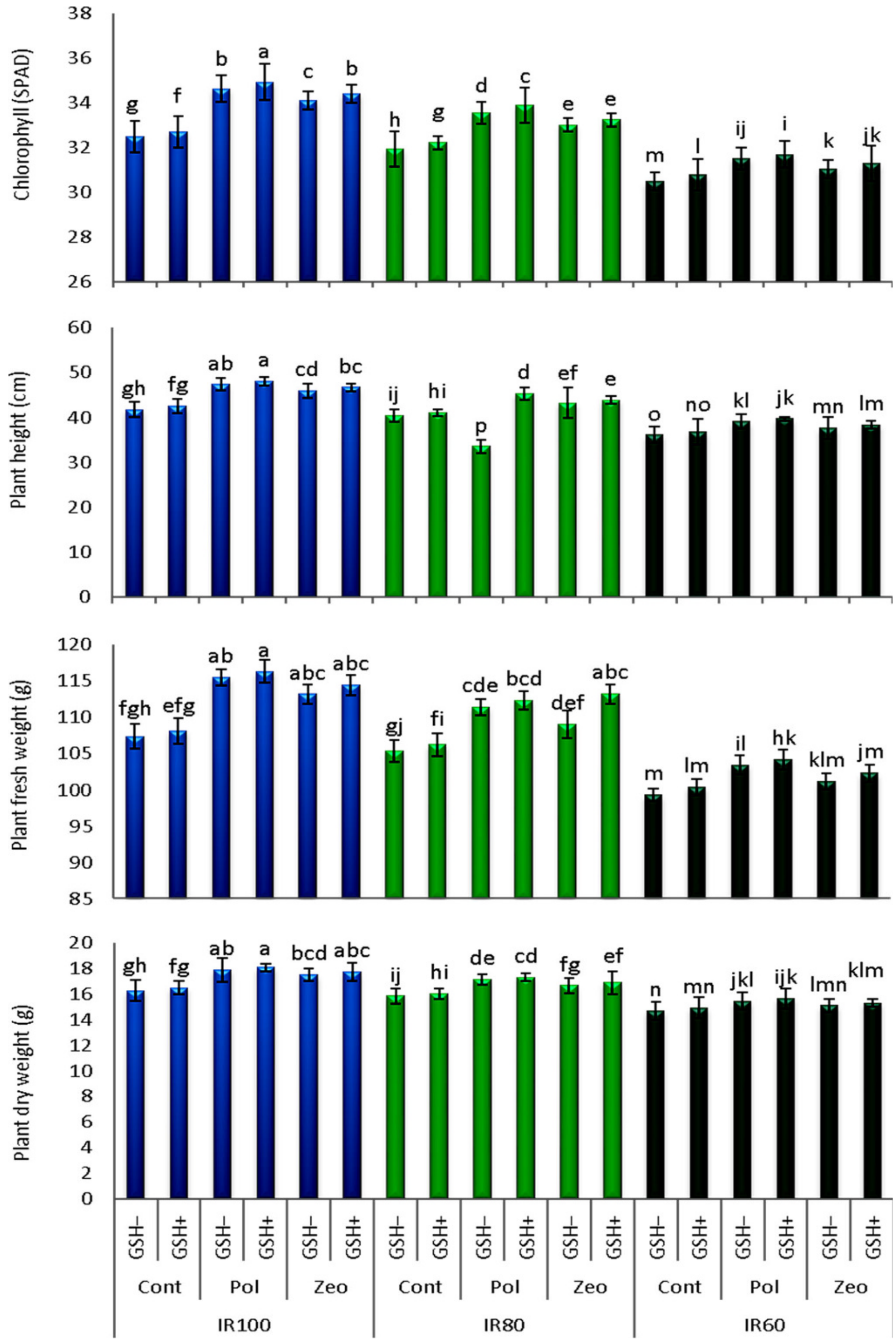

Fig. 1 Combination effect of water holding amendments and glutathione on plant height, chlorophyll, fresh weight and dry weight of common bean plants grown under different irrigation regimes. *Cont* control treatment, *Pol* hydrogel polymer, *Zeo* zeolite; *GSH– and GSH+* without and with glutathione spraying, respectively; *IR100, IR80 and IR60* 100, 80 and 60% of irrigation requirements, respectively. Bars indicates standard error (SE) of the means ($n = 3$). Significant differences between the treatments are indicated by different letters according to Duncan's multiple range test ($p \leq 0.05$)

vegetative growth attributes and SPAD values as compared with control.

It is obvious from Fig. 1 that the combination of IR_{100} with hydrogel polymer and GSH foliar spraying showed the highest significant values of chlorophyll expressed in SPAD reading. Also the combination of IR_{100} with hydrogel polymer whether with or without GSH showed the maximum significant values of plant height. While for the fresh and dry weights of plants, it is clear that the combination of IR_{100} and hydrogel polymer or zeolite whether with or without GSH showed the highest significant values. In addition, the combination of IR_{80} and zeolite in conjunction with GSH had no significant differences with the superior combinations (IR_{100} and hydrogel polymer or zeolite whether with or without GSH), hence it revealed the highest significant value of plant fresh weight.

Mineral Content in Leaves

It is clear that the combination of IR_{100} and hydrogel polymer plus GSH revealed the maximum significant contents of N, P and K percentages in common bean leaves as compared to other treatments (Fig. 2). Under each IR_{80} and IR_{60} conditions, the application of soil amendments and GSH significantly promoted the mineral contents in common bean leaves as compared to control treatment (without soil amendment and without GSH) under each irrigation regime. In this respect, compared to the corresponding control treatment, hydrogel polymer plus GSH supply showed distinctive enhancements for N, P and K accumulation in common bean leaves.

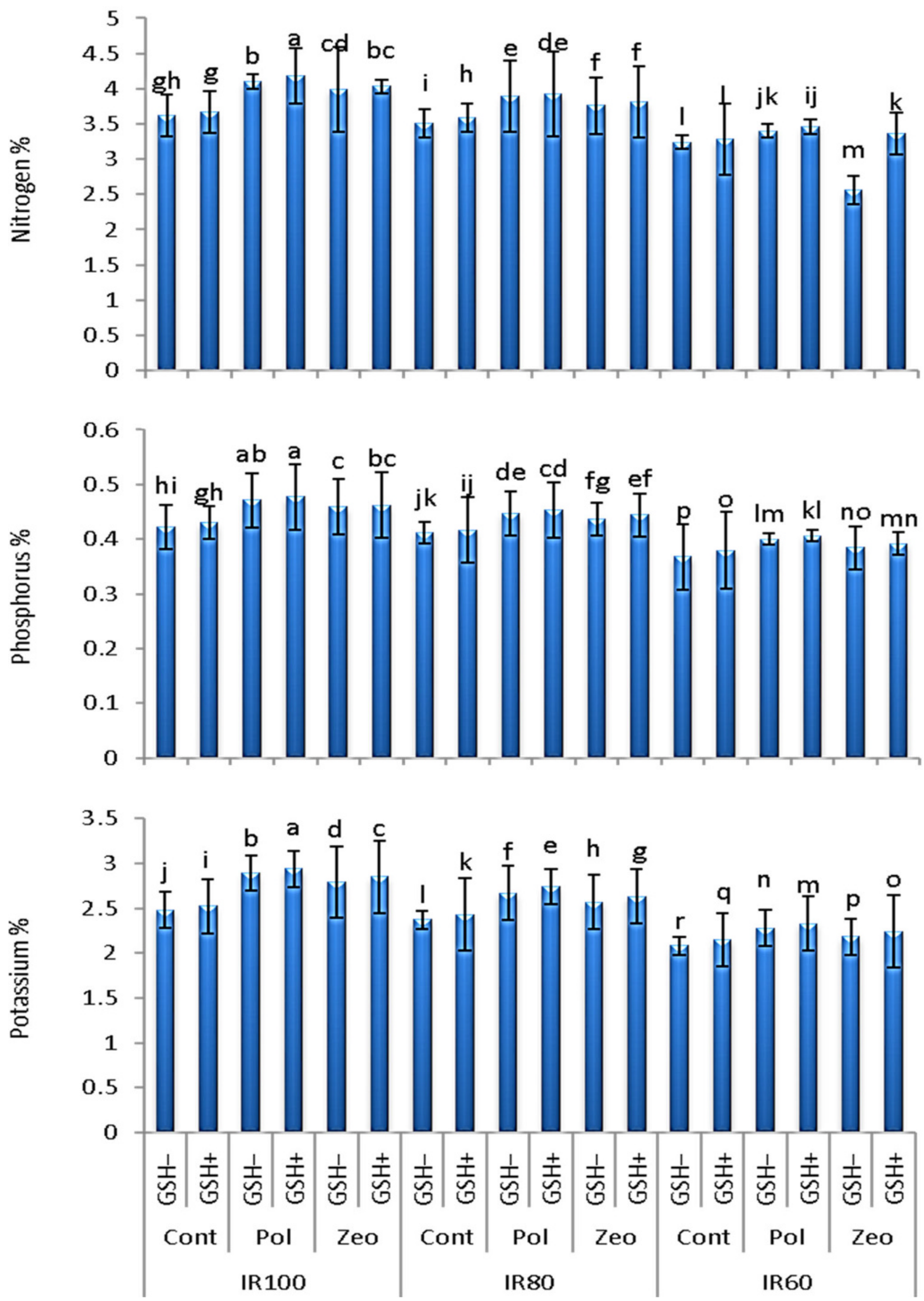

Fig. 2 Combination effect of water holding amendments and glutathione on leaves nitrogen, phosphorus and potassium percentages of common bean plants grown under different irrigation regimes. *Cont* control treatment, *Pol* hydrogel polymer, *Zeo* zeolite; *GSH– and GSH+* without and with glutathione spraying, respectively; *IR100, IR80 and IR60* 100, 80 and 60% of irrigation requirements, respectively. Bars indicates standard error (SE) of the means ($n=3$). Significant differences between the treatments are indicated by different letters according to Duncan's multiple range test ($p \leq 0.05$)

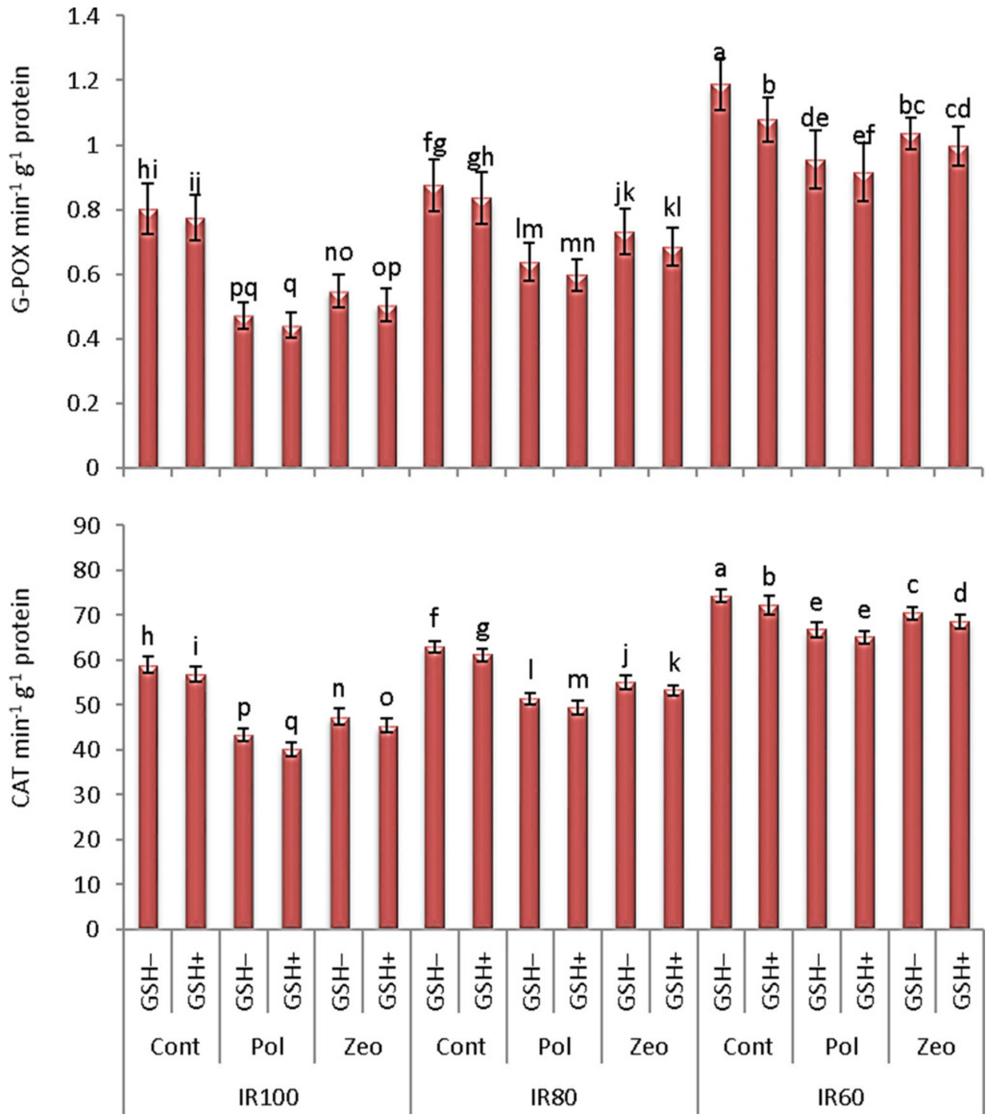

Fig. 3 Combination effect of water holding amendments and glutathione on guaiacol peroxidase (G-POX) and peroxidase (CAT) activity of common bean plants grown under different irrigation regimes. *Cont* control treatment, *Pol* hydrogel polymer, *Zeo* zeolite; *GSH– and GSH+* without and with glutathione spraying, respectively; *IR100, IR80 and IR60* 100, 80 and 60% of irrigation requirements, respectively. Bars indicates standard error (SE) of the means ($n=3$). Significant differences between the treatments are indicated by different letters according to Duncan's multiple range test ($p \leq 0.05$)

Antioxidants

Regarding the performance of common bean plants to self-production antioxidants enzymes, i.e., guaiacol peroxidase (G-POX) and catalase (CAT), Fig. 3 clearly shows that the combination of IR_{60} without soil amendments and without GSH showed the highest significant values. Without providing soil amendments and without GSH, the increases due to application of IR_{60} amounted to 1.35 and 1.47 times in POX as well as 1.17 and 1.26 times in CAT greater than IR_{80} and IR_{100}, respectively. It is interesting to note that application of zeiolite plus GSH reduced the accumulation of POX and CAT by 21.8 and 15.5% under IR_{80} and 16.1 and 7.6% IR_{60}, respectively, compared to the corresponding control treatment.

Pod Yield Attributes

All yield attributes of common bean markedly responded to the combination irrigation regime, soil amendment, and GSH foliar application (Fig. 4). As expected, the values of pods number plant^{-1}, pod length, pod diameter and pods yield significantly declined as the irrigation level decreased (IR_{80} and IR_{60}) as compared with the IR_{100} under different soil amenedements plus GSH treatments. In this respect, the combination of IR_{100} in conjunction with hydrogel polymer whether with or without GSH showed the highest significant values of pod length and pod diameter, however only the combination of IR_{100} in conjunction with hydrogel polymer with GSH application revealed the highest significant values of pods number plant^{-1} and pods yield. Concerning the pods yield under each of the irrigation regimes, it has been found that the application of GSH with hydrogel polymer under $IR_{100,}$ IR_{80} and IR_{60} significantly increased

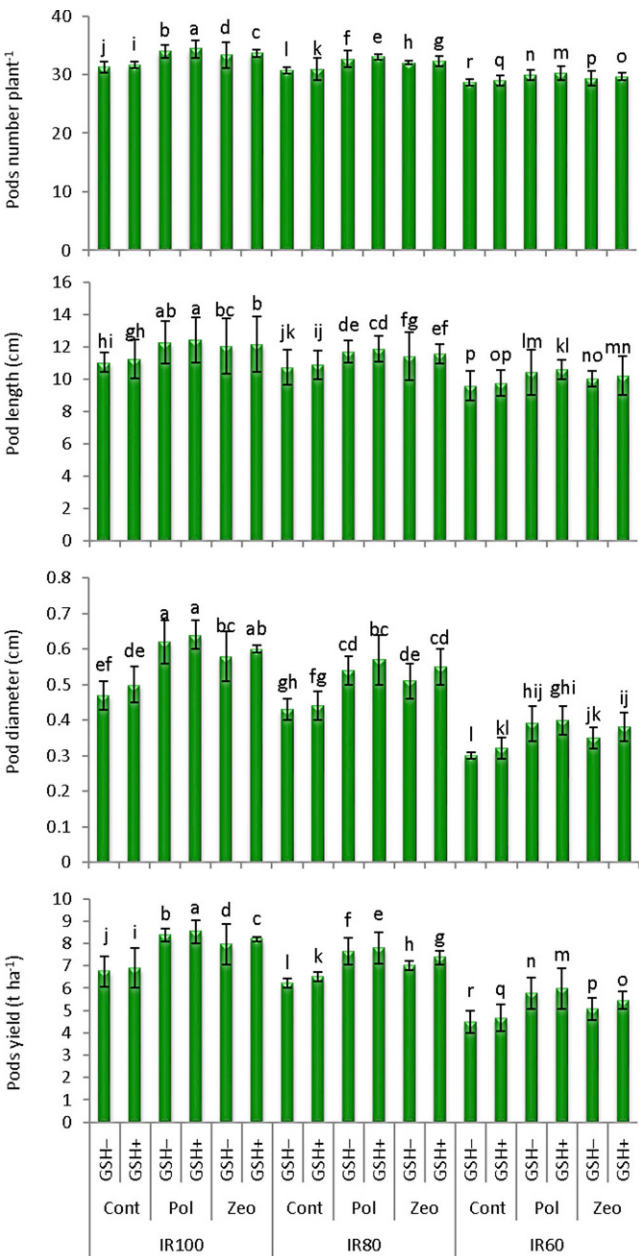

Fig. 4 Combination effect of water holding amendments and glutathione on pods number, pod length, pod diameter and pods yield of common bean plants grown under different irrigation regimes. *Cont* control treatment, *Pol* hydrogel polymer, *Zeo* zeolite; *GSH– and GSH+* without and with glutathione spraying, respectively; *IR100, IR80 and IR60* 100, 80 and 60% of irrigation requirements, respectively. Bars indicates standard error (SE) of the means ($n=3$). Significant differences between the treatments are indicated by different letters according to Duncan's multiple range test ($p \leq 0.05$)

the value of pods yield by 26.5%, 25.23% and 32.80, respectively, as compared to corresponding control treatment (without GSH and without soil amendment).

Pod Quality Attributes

Concerning the yield quality and mineral content in pods, it is obvious that there is a significant decline ($p \leq 0.05$) in N, P and K contents of common bean pods (Fig. 5) and pods crude protein, carbohydrates, fiber and TDS % (Fig. 6) at IR_{80} and IR_{60} treatments under various soil amendements plus GSH treatments. Accordingly, the lowest significant values of the yield quality and mineral content of pods were recorded at the combination of IR_{60} without soil amendments and without GSH. Otherwise, the interaction of IR_{100} and hydrogel polymer whether with or without GSH showed the highest significant values of N, P, protein, fiber, carbohydrates percentages and TDS. Also, the combination of IR_{100} and hydrogel polymer with GSH showed the highest significant values of K % in common bean pods.

Discussion

Obviously, water deficit had negative effects on vegetative growth, chlorophyll content, yield and quality attributes and the mineral content of common bean plants. Previous studies pointed out similar trend in various vegetable crops such as cauliflower and potato (Ahanger et al. 2021; EL-Bauome et al. 2022; El-Yazied et al. 2022; Tapia et al. 2022). While both soil amendements and spraying of GSH, significantly increased the vegetative growth attributes and SPAD values, yield and quality attributes, the mineral content of leaves and pods as compared with control. The findings of the beneficial role of GSH agree with those reported by Zhang et al. (2022) on mulberry, El-Beltagi et al. (2020) on chickpea, Maslennikova and Shakirova (2021) on wheat. Also, the obtained results of soil amendments are in good accordance with previous researches implemented under drought stress on various crops including common bean (Ozbahce et al. 2015), green pea (Youssef et al. 2018), Aloe vera L. (Hazrati et al. 2017), tomato (Ju et al. 2022), olive (Lopes et al. 2022) and rice (Sepaskhah and Barzegar 2010).

Drought is one of the most significant environmental factors leading to dramtical declines in commercial crop production worldwide. Lack of water can affect crop development features, photosynthetic parameters, nutrient absorption, and yield production (Shaaban et al. 2023b). Drought stress affects various processes in the plant; sincxe it decreases the transpiration rate; consequently, the nutrients transport from the roots to the aerial parts of the plant (Griffiths and Parry 2002). Also, drought conditions significantly reduced the water potential of leaf and relative water content of the plant tissues (Sprenger et al. 2016; Diaz-Valencia et al. 2021; Seleiman et al. 2021), thereby causing toxicity to plant cells at severe drought conditions (Meher et al. 2018). Furthermore, drought conditions make osmotic

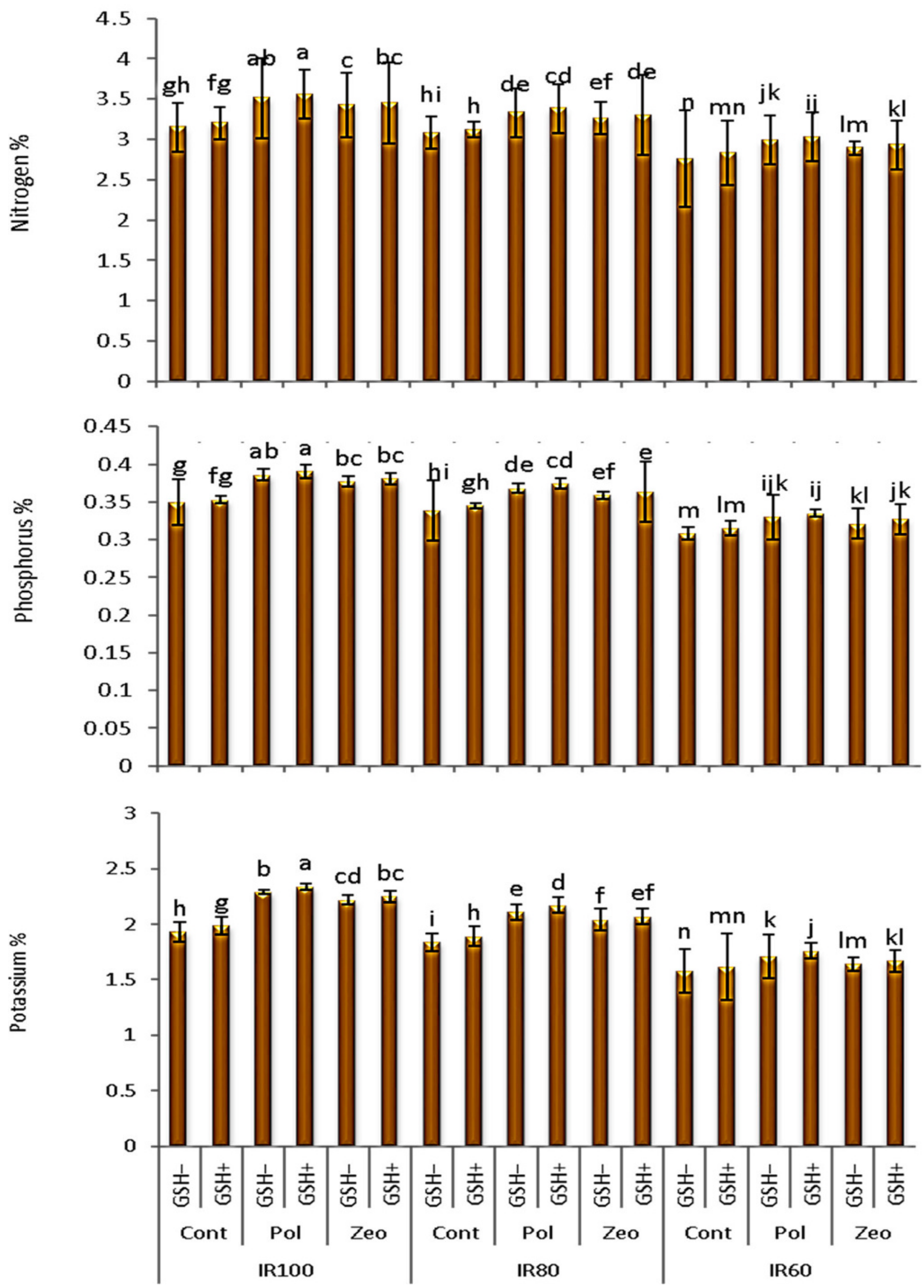

Fig. 5 Combination effect of water holding amendments and glutathione on pods nitrogen, phosphorus and potassium percentages of common bean plants grown under different irrigation regimes. *Cont* control treatment, *Pol* hydrogel polymer, *Zeo* zeolite; *GSH– and GSH+* without and with glutathione spraying, respectively; *IR100, IR80 and IR60* 100, 80 and 60% of irrigation requirements, respectively. Bars indicates standard error (SE) of the means ($n = 3$). Significant differences between the treatments are indicated by different letters according to Duncan's multiple range test ($p \leq 0.05$)

imbalance in plant cells, exposing the plant to stress that increase the ROS, which increase the oxidative damage of the chloroplast, in turn, ATP synthesis obstructed (Ullah et al. 2017). This imbalance also leads to a decline in stomatal conductance that obstclate CO_2 intake causing increment in photorespiration and decrement in carbohydrates accumulation (Hasanuzzaman et al. 2017; Cornic 2000). Also, the excessive accumulation of ROS and RNS which is due to electron leakage from complex I and IV of the electron transport chain in the mitochondria resulting in disturbance in the mitochondrial respiration (Turk and Genisel 2020; Zhao et al. 2019). Hence, accumulation of ROS severely resulting in cell lipid peroxidation and damage the plant cell membranes and components (Ibrahim et al. 2020; Tiwari et al. 2021; Chaves et al. 2003; Anjum et al. 2017). Accordingly, the plant growth, development and productivity were negatively influenced by water deficit.

Concerning the soil amendments, the hydrogel polymers have roles at increasing soil water and nutrient retention, hydraulic conductance and water availability in rhizosphere

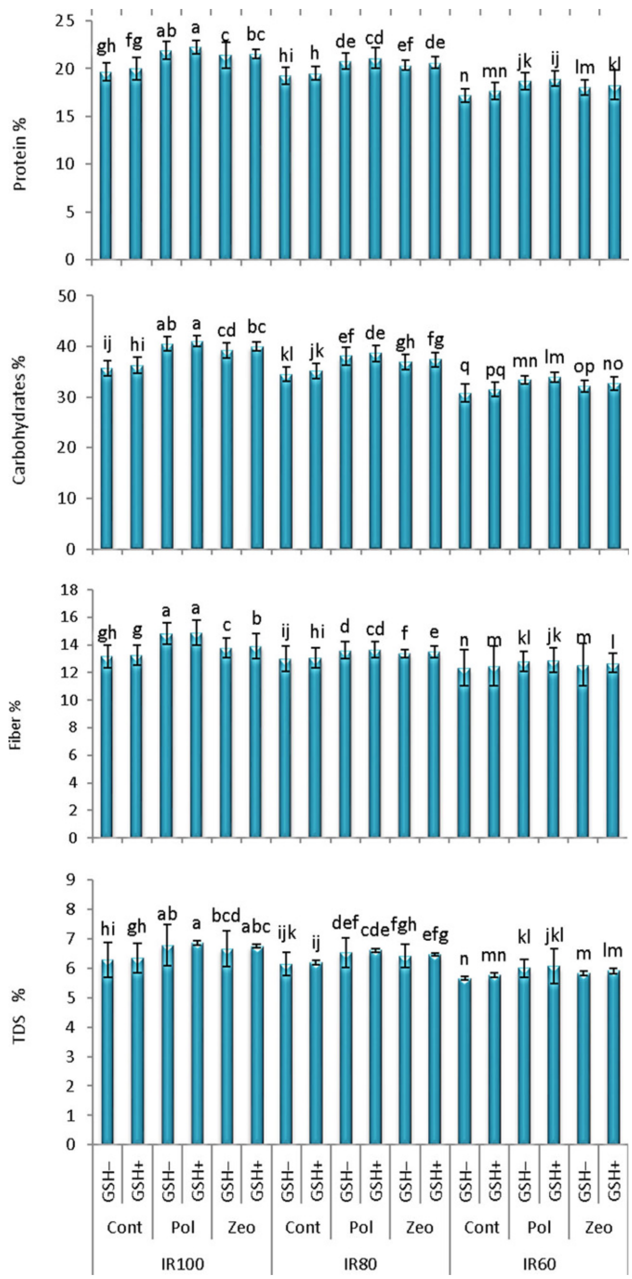

Fig. 6 Combination effect of water holding amendments and glutathione on pods protein, carbohydrates, fiber and total disolved solids (TDS) percentages of common bean plants grown under different irrigation regimes. *Cont* control treatment, *Pol* hydrogel polymer, *Zeo* zeolite; *GSH– and GSH+* without and with glutathione spraying, respectively; *IR100, IR80 and IR60* 100, 80 and 60% of irrigation requirements, respectively. Bars indicates standard error (SE) of the means ($n = 3$). Significant differences between the treatments are indicated by different letters according to Duncan's multiple range test ($p \leq 0.05$)

to plants (Seleiman et al. 2021). Also, the evaporation from hydrogel treated soil decreased as compared with hydrogel non-treated soils (Saha et al. 2020). Further, hydrogel polymers improve the fertilizers performance in soil (Elshafie and Camele 2021). Consequently, the vegetative characters were enhanced mainly number of leaves and leaf area, leaf relative water content, and leaf dry weight (Tomášková et al. 2020), leading to enhancement of photosynthetic rate and nutritional status of plants as a result of increasing the uptake of micro and macro elements (Oladosu et al. 2022; M'barki et al. 2019). Subsequently, the yield attributes were enhanced by applying hydrogel polymer to soil (Fig. 4), and the yield quality (Fig. 5 and 6). Furthermore, it has been found that the hydrogel application increased the proline content at different drought sensitive and tolerant tree species under water shortage conditions, that acts as antioxidant which alleviates the drought stress on plants (Tomášková et al. 2020).

As for zeolite, it has been found that zeolite ameliorates the water retention and the water availability for plants (Hazrati et al. 2017). Also, it is considered to be a chelating agent since it acts as chemical sieve that blocks some ions while allows passing for others (Gholamhoseini et al. 2012). According to its physical and chemical properties, it enhances the cation exchange capacity of soil, decreases the nutrients leaching (Gholamhoseini et al. 2012) and supplies the plants with nutrients, i.e., potassium (Szatanik-Kloc et al. 2021; Chatzistathis et al. 2022). Thus, the beneficial effect of zeolite for alleviating drought stress on plants had been reported (Mondal et al. 2021; Ibrahim and Alghamdi 2021). The vegetative growth (Hazrati et al. 2017; Ju et al. 2022) and photosynthesis process (Lopes et al. 2022) of plants were enhanced as treated by zeolite. As a result of the enhancement of vegetative growth attributes and chlorophyll content, the yield characters and quality attributes were significantly enhanced.

Regarding glutathione foliar spraying, it is clear from results that the application of GSH significantly enhanced the vegetative growth characters, SPAD values, yield and yield quality under all irrigation levels. These increments associated GSH supply under drought might be attributed to its protective action as an antioxidant, while enhancing the osmoregulation and water status in plant cells and regulating various metabolic functions (Nahar et al. 2015; Chen et al. 2022). Not only GSH regulates the genes expression and encoding transcription but also regulates the signaling pathways by modifying the protein components via S-glutathionylation and/or S-nitrosoglutathione-mediated protein S-nitrosylation (Koramutla et al. 2021; Koh et al. 2021). Hence under drought stress, the expression of DREB1 (dehydration-responsive element binding) was upregulated as well as P5CS ({Delta} 1-Pyrroline-5-Carboxylate Synthetase) gene expression which is responsible for proline production, whereas the DHN5 and WZY2 (dehydrin) genes are correlated to dehydrins production in wheat plants (Vuković et al. 2022). Glutathione works as substrate at glutathione peroxidase (GPX) and glutathione S-transferase (GST), hence GPX works at ROS detoxification, whereas GST is responsible for xenobiotic detoxification (Hasanuzzaman et al. 2017). Also, S-nitrosoglutathione (GSNO) plays an important role in nitric oxide signaling. While the glyoxalase system comprises glyoxalase I (Gly I) and glyoxalase II (Gly II) enzymes, this system is responsible for detoxifying of cytotoxic and oxidative stress creator methylglyoxal (MG), where Gly I uses GSH at MG detoxification and signaling (Hasanuzzaman et al. 2019; Laxa et al. 2019). MG at high levels is a toxic compound that suppresses plant growth, development, and metabolic processes; seed germination, photosynthesis, increasing ROS in plant cells indirectly by reducing the available glutathione (GSH) concentrations which is a strong non-enzymatic antioxidant and impairing the function of antioxidant enzymes (Hasanuzzaman et al. 2017; Hoque et al. 2016). In addition, glutathione participates at the ascorbate-glutathione pathway which plays role at ROS detoxifying (Maslennikova and Shakirova 2021). Moreover, the increments in the vegetative characters and yield owing to GSH application could be ascribed to improved nutritional status of plants, since GSH stimulates the mineral content at the plant under all irrigation regimes by its role of ROS detoxifying. Accordingly, the application of glutathione enhanced common bean growth, yield and quality, nutritional status of plants grown under drought conditions.

Commonly, findings of the current work could introduce a significant approach which can be adopted to induce drought stress tolerance in common bean plants using soil amendments that enhance the soil water holding, i.e., hydrogel polymer and zeolite, in addition to foliar application of glutathione as an antioxidant defender.

Conclusions

The findings of this current research could be clearly elucidate the significance of using soil amendments (hydrogel polymer and zeolite) and glutathione under different irrigation regimes for enhancing vegetative growth characteristics, plant pigments, yield and yield quality attributes. Briefly, the combination of hydrogel polymer and glutathione under well-water exhibited the highest significant values of the vegetative growth, leaf greenness, yield and its quality, mineral content of leaves and pods, while the lowest significant values of antioxidant enzymes activity were noticed. The superior influence of combination between glutathione and soil amendments specially the hydrogel polymer was crystal clear, not only under the well-watered condition but also under the moderately water-stressed and severely water-stressed conditions. Therefore, common bean growers are advised to apply hydrogel polymer plus glutathione whether with water abundance or water deficiency to secure high yield and quality. However, further investigations using the advice molecular techniques are needed for understanding accuretly the role of soil amendments plus glutathione in increasing the yield and inducing varied signaling pathways in common bean plants under water shortage conditions.

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