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Effect of Plant Growth Regulators and Plant Growth Promoting Rhizobacteria on Physio-chemical properties of Mungbean under Drought Stress

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ABSTRACT: Among the different abiotic stress, drought is one of the most significant abiotic factors that have a negative impact on crop growth and production. In Telangana, post-rainy season grown mungbean frequently experiences drought at different growth stages and are altered pigment synthesis and metabolic processes. The present investigation was formulated to find out the potential role of plant growth regulators and plant growth promoting bacteria in improving physio-chemical properties of mungbean under drought stress conditions. The whole study was carried out at the Indian Institute of Oil Research (IIOR), Rajendranagar, Hyderabad, during the Kharif season, 2021–22. The study was conducted by arranging pots in a split-plot design with three replications and experimental material comprised two varieties of mungbean cultivars, WGG42 and MGG385. Various combinations of plant growth regulators (salicylic acid at 100 ppm and paclobutrazol at 150 ppm) and plant growth promoting bacteria (*Bacillus subtilis, Bacillus thuringiensis, and Bacillus megaterium*) were given as treatment to the crop. The plant growth regulators (PGRs) were given to the crop at 20 and 35 days after sowing (five days before flowering and five days after flowering), whereas the plant growth promoting bacteria (PGPRs) were applied as a seed treatment. Different physio-biochemical parameters were recorded during the experiment after subjecting the plants to irrigated and stressed conditions. The results indicated that drought stress conditions caused a reduction in SPAD chlorophyll meter readings, membrane stability index, and protein content, whereas increased proline content and antioxidant enzymes at all three growth stages. Furthermore, the combined application of all PGRs and PGPRs (seeds inoculated with Biotilis, Lipel, and P Sol B at 10 g/kg of seed each, paclobutrazol at 150 ppm and salicylic acid at 100 ppm) to the mungbean cultivars was found to be most promising at all the growth stages compared to the rest of the treatments and control. Therefore, from the present study, it can be inferred that application of PGRs and PGPRs were highly effective in improving the physio-chemical properties of mungbean.

Keywords: Mungbean, drought stress, PGRs, PGPRs, physio-chemical properties.

INTRODUCTION

Legumes (Leguminosae or Fabaceae) are the second only to cereals, accounts for 33% of the world's protein needs and 27% of primary crop production. Green gram (*Vigna radiate* L.) is one of the major summertime legume crops and mostly cultivated in dry and semi-arid regions of India, particularly in the *kharif* season. Due to their profound nature of biological nitrogen fixation, legume crops aid in restoring soil fertility. Green gram accounts for a share almost 15% among the total pulses production. In addition, crop is an excellent source of protein (23%) with low levels of oligosaccharides and high digestibility. It provides 1-3% fat, 55–65% carbohydrate, 3.5–4.5% fiber, and 5.5% ash. The amounts of calcium and phosphorus in every 100 gram of seed are 132.0 and 367.0 mg, respectively (Ihsan *et al*., 2013).

The crop is cultivated as a major crop in India, Burma, Sri Lanka, Pakistan, China, Fiji, Queensland and Africa. In India, the crop is cultivated over an area. It is grown in area about 51.30 lakh hectares with the total production of about 30.85 lakh tonnes with a productivity of 601 kg ha^{-1} (Indiastat, 2022). The important green gram growing States in India is Orissa, Maharashtra, Telangana, Madhya Pradesh, Gujarat, Rajasthan and Bihar. In Telangana, green gram is cultivated in an area of about 0.75 lakh hectares with the production of 0.38 lakh tones (Indiastat, 2022).

Drought is one of the most significant abiotic factors that have a negative impact on crop growth and production. In Telangana, post-rainy season grown mungbean frequently experiences drought at different growth stages (Yadav *et al.,* 2010). Drought stress not only altered morphological growth but also physiochemical properties of crop such as cell membrane stability, metabolic processes, including recued photosynthesis, decreased photosynthetic pigment synthesis and ultimately overall growth (Lemanski and Scheu 2014; Malla *et al*., 2014; Sravanthi *et al.*, 2021; Pandey *et al*., 2021).

In the recent past, the use of plant growth promoting rhizobacteria (PGPR) has become an emerging approach for sustainable agriculture and their significant role in improving the growth and yield of crops has been proven at global levels (Yadegari and Asadi 2010; Mansour *et al*., 2021; Khan *et al.,* 2020). The PGPRs are a group of bacteria that actively colonize plant roots and enhance plant growth and yield (Upadhyay *et al.,* 2012; Barnawal *et al.*, 2013; Hashem *et al*., 2015). In addition to promoting plant growth, the application of PGPRs enhances nutrient availability and increases nutrient use efficiency (Asia *et al.,* 2011; Upadhyay *et al.,* 2012). The beneficial effects of PGPRs such as asymbiotic rhizobacteria (Bhattacharya and Jha 2012), symbiotic rhizobia (Peix *et al.,* 2015), and phosphate solubilizers (Nosrati *et al.,* 2014) on plant growth and development have been proven in various crops (Mohite, 2013; Viruel *et al.,* 2014), including legumes (Noreen *et al.,* 2014).

Hormones and plant growth regulators (PGRs) are chemical compounds that have a significant impact on the development of plant cells, tissues, and organs. They serve as chemical messengers for cellular communication, controlling growth or other physiological functions at a site remote from production sites and active in minute amounts (Fishel, 2006). The roles of PGRs in promoting the plant's tolerance to different abiotic stresses have been well established. However, only a few studies have been carried out to explore the potential role of exogenously applied PGRs under water stress situations, particularly in green gram (Shyam and Aery 2012; Ismaeil, 2016; Danir *et al.,* 2019; Mujahid *et al.,* 2022).

Both PGPRs and PGRs have promising effects on plant growth when applied alone, and also combined applications are far more successful in mitigating the negative effects of drought stress. Furthermore, the application of PGRs to PGPRs inoculated plants helps in osmoregulation, reduces oxidative stress, promotes the synthesis of new proteins, and increases sugar and chlorophyll content in the leaves. When PGRs and PGPRs were applied together, it caused decreased lipid peroxidation and increased leaf area in plants. In the combined treatment of PGPRs and PGRs, the relative water content in leaves and roots, fresh and dry weight, were also increased. It is well established from earlier research that PGPRs and PGRs work in a co-operative manner to enhance plant growth in conditions such as water and nutrient deficiency (Khan *et al.*, 2017; Khan *et al.*, 2018; Ferrareze *et al.*, 2019).

Since, green gram is one of the most important grain legumes, it is an absolute need of hour to improve productivity under drought stress to meet the intensifying demand for pulses from an ever-increasing population. However, there is a dearth of information on the response of green gram to the combined application of PGRRs and PGRs in the field. Therefore, keeping in view the aforementioned facts, the current study was formulated with the following hypothesis and objectives to study the influence of PGPRs and PGRs on physio-chemical properties of mungbean under drought stress conditions.

MATERIAL AND METHODS

The pot study was carried out at Indian Institute of Oil Research (IIOR), Rajendranagar, Hyderabad, during the Kharif season, 2021–22. The experiment was laid out following the split-plot design with three replications and experimental material includes two green gram varieties, *viz*., WGG-42 and MGG-385. The physio-chemical traits, *viz*., SPAD chlorophyll meter readings (SCMR), membrane stability index (MSI), protein content, proline content, antioxidant enzymes (catalase, peroxidase, and superoxide dismutase), were recorded after the imposition of drought stress in both stressed and irrigated plots at three different stages of crop growth: flowering, pod filling, and pod maturation. The different treatments, i.e., T_1- Inoculation of seeds with Biotilis (MCC0067) @ 10g kg^{-1} seed, T_2- Inoculation of seeds with Lipel (MCC0089) @ 10g kg^{-1} seed, T_3- Seed Inoculation with P Sol B (MCC0053) @ 10 g seed T_4- Seeds inoculated with 10 g kg^{-1}Biotilis (MCC0067), Lipel (MCC0089), and P Sol B (MCC0053) T_5-Plants treated with salicylic acid at a concentration of 100 ppm as a foliar spray during flowering. T_6-Plants were treated with paclobutrazol at 150 ppm, applied as a foliar spray at flowering; T_7-Plants were treated with salicylic acid at 100 ppm and paclobutrazol at 150 ppm (both treatments were applied as a foliar spray during flowering). T_8-a combination of all three PGPRs (seeds inoculated with Biotilis (MCC0067), Lipel (MCC0089), and P Sol B (MCC0053) at 10 g/kg of seed each, and two PGRs applied as a foliar spray during flowering (paclobutrazol at 150 ppm and salicylic acid at 100 ppm), and T_9: untreated (control). The PGRs were applied to the crop at 20 and 35 days after sowing (five days prior to flowering and five days after flowering) and PGPRs were applied as seed treatment. The drought stress conditions were subjected to the crop from pre-flowering stage and maintained up to physiological maturity stage. The moisture levels in drought stressed plots were decreased to 45-50% soil moisture and maintained by withheld the irrigation.

RESULTS AND DISCUSSION

The data recorded on SPAD values revealed significant differences at flowering, pod filling and maturity stage. The mean performances of both varieties under each treatment are depicted in 1.1.

A. SPAD chlorophyll meter readings

At flowering stage, mean data indicated that SPAD values in variety WGG 42 varied from 41.02 to 57.47 (pod filling) and 39.76 to 45.53 (pod maturation) under irrigated conditions; while under drought stress conditions, SPAD values were varied from 37.42 to 45.35 (flowering), 48.39 to 55.52 (pod filling) and 35.32 to 42.38 (pod maturation). Likewise, in variety MGG 385 the range of variation was from 37.85 to 49.38 (flowering), 43.0 to 59.37 (pod filling) and 36.1 to 46.48 (pod maturation) under irrigated conditions; whereas under drought stress conditions, SPAD values were ranged from 27.13 to 47.55 (flowering), 36.00 to 57.42 (pod filling), 24.23 to 44.47 (pod maturation).Furthermore, it was also reported that under drought stress conditions, cultivar MGG 485 performed better and secured higher SPAD values compared to WGG 42.Among the treatments, the combined application of all PGPRs ((Biotilis, Lipel, and P Sol B at 10 g/kg to seed) and PGRs (paclobutrazol at 150 ppm and salicylic acid at 100 ppm) resulted in maximum SPAD compared to rest of treatments and control under both irrigated and drought stress conditions (Fig 1). These results are well in accordance with reports by Saritha *et al*. (2021) in mungbean, Mansour *et al*. (2021) in broad bean, Khan *et al*. (2020) in chickpea, and Heidari *et al*. (2019) in mungbean.

For photosynthesis, chlorophyll is one of the most crucial chloroplastic components because it captures light energy and produces reducing power. PBZ has been shown to increase chlorophyll and carotenoids content as well as chloroplast thickness (Gopi *et al.*, 2009; Youssef *et al.*, 2013; Ismaeil, 2016). Increased chlorophyll synthesis is linked to the higher levels of cytokinin (Fletcher *et al.*, 2000). In addition, PBZ appears to have delayed the onset of senescence, as represented by the rate of chlorophyll degradation in attached mung bean leaves. Similar to this, SA is thought to enhance the level of chlorophyll in the mungbean plant (Heidari *et al*., 2019). Moreover, drought inhibits pigment synthesis and reduces photosynthesis, while Bacillus spp. Stress stimulates the synthesis of chlorophyll a, b and carotenoids in stressed plants, which increases photosynthesis (Hashem *et al.*, 2015).

B. Membrane Stability Index (MSI)

The data on membrane stability index (MSI) were recorded and was found to significantly at flowering, pod filling and maturity stage (Fig. 2). The mean data indicated that MSI values in variety WGG 42 was varied from 73.33 to 88.33 (flowering), 76.5 to 92.5 (pod filling) and 70.83 to 86.83 (pod maturation) under irrigated conditions; while under drought stress conditions, MSI values were varied from 65.33 to 84.83 (flowering), 69 to 88.5 (pod filling) and 59.33 to 81.83 (pod maturation). Likewise, in variety MGG 385 the range of variation was from 75.17 to 90.83 (flowering), 78.33 to 94.83 (pod filling) and 71.83 to 88.83 (pod maturation) under irrigated conditions; whereas under drought stress conditions, MSI values were ranged from 67.83 to 86.83 (flowering), 71.83 to 90.83 (pod filling), 65.83 to 84.83 (pod maturation). The mean performance showed that drought stress conditions significantly reduced the membrane stability index in both cultivars (WGG 42 and MGG 385) of mungbean. On the other hand, the application of both PGRs and PGPRs (either alone or in combination) was found to promising in improving the MSI particularly under water limited conditions. The most promising results were obtained when a combined application of all PGPRs (Biotilis, Lipel, and P Sol B at 10 g/kg toseed, and two PGRs as foliar spray (paclobutrazol at 150 ppm and salicylic acid at 100 ppm) were given to crop. These results are well in accordance with reports by Khan *et al*. (2021) in chickpea, Mansour *et al*. (2021) in broad bean Hemantaranjan *et al*. (2016) in mungbean.

C. Protein content

The mean data indicated that protein content in variety WGG 42 was significantly varied from 1.57 to 3.28 (flowering), 2.1 to 3.67 (pod filling) and 1.37 to 2.9 (pod maturation) under irrigated conditions; while under drought stress conditions, Protein values were varied from 1.15 to 2.88 (flowering), 1.70 to 3.27 (pod filling) and 1.02 to 2.71 (pod maturation). Likewise, in variety MGG 385 the range of variation was from 1.73 to 3.86 (flowering), 2.12 to 3.88 (pod filling) and 1.58 to 3.09 (pod maturation) under irrigated conditions; whereas under drought stress conditions, Protein values were ranged from 1.37 to 2.98 (flowering), 1.99 to 3.49 (pod filling), 1.19 to 2.72 (pod maturation). In addition, per se performance also indicated that the drought stress conditions significantly reduced the protein content in both cultivars (WGG 42 and MGG 385) of mungbean. The application of both PGRs and PGPRs (either alone or in combination) was found to promotive in enhancing the protein content in mungbean cultivars particularly under water limited conditions. The combined application of all PGPRs (Biotilis, Lipel, and P Sol B at 10 g/kg to seed, and two PGRs as foliar spray (paclobutrazol at 150 ppm and salicylic acid at 100 ppm) to crop was found best and secured higher protein content under drought stress conditions compared to control (Fig. 3).

Plants are able to deal with various abiotic stress conditions due to the inoculation of seeds with both PGR and PGPR, which regulates osmo-regulation and promotes the synthesis of new proteins. Stress proteins that are water soluble are crucial for plants to survive stress (Wahid and Close 2007). Plants produce proteins under various biotic and abiotic stresses that are induced by some phytohormones such as salicylic acid (Davis, 2005). A key aspect of plant defense is an increase in protein content (Chen *et al.*, 2009). PGR and PGPR used together more efficiently reduced lipid peroxidation and increased protein content (Khan *et al*., 2018). Similar to this, the results of the present investigation on protein content showed that, in both mungbean cultivars, protein content decreased under drought-stress conditions. Mean performance, however, shown that the application of PGRs and PGPRs (either separately or in combination) significantly increases the protein content. When PGRs and PGPRs were used together, the highest protein content was observed. Furthermore, these results are well supported by the reports of Khan *et al.* (2020) in chickpea, Abd El-Aal and Eid (2017) in soybean and Thomson *et al*. (2017) in pea.

D. Proline content

Recorded data on the Proline values revealed the significant differences at flowering, pod filling and maturity stage (Fig. 4). The mean data indicated that Proline values in variety WGG 42 was varied from 0.92 to 1.83 (flowering), 1.12 to 2.13 (pod filling) and 1.55 to 2.47 (pod maturation) under irrigated conditions; while under drought stress conditions, Proline content were varied from 1.13 to 2.33 (flowering), 1.43 to 3.22 (pod filling) and 1.73 to 3.47 (pod maturation). Likewise, in variety MGG 385 the range of variation was from 0.73 to 1.63 (flowering), 1.12 to 1.93 (pod filling) and 1.35 to 2.32 (pod maturation) under irrigated conditions; whereas under drought stress conditions, Proline content ranged from 1.23 to 2.92 (flowering), 1.56 to 3.38 (pod filling), 1.56 to 3.38 (pod maturation). Moreover, mean performance revealed that drought stress conditions significantly enhance the proline content among the mungbean cultivars. In additions, application of PGRs and PGPRs to the crop further improves the proline content when applied either alone or in combination. However, a combined application of all PGPRs ((Biotilis, Lipel, and P Sol B at 10 g/kg) and PGRs (paclobutrazol at 150 ppm and salicylic acid at 100 ppm) gave best results compared to rest of treatments and control.

The results showed that proline content significantly varied under both irrigated and water stress conditions. These results are found in corroboration with the findings of Mansour *et al*. (2021) in broad bean, Khan *et al*. (2019; 2020) in chickpea, Saikia *et al*. (2018) in pea and Razmi *et al*. (2017) in soybean. Stresses including heat and drought are linked to proline accumulation (Ashraf and Foolad 2007). Proline is an AOS (activated oxygen species) scavenger (Datta and Kulkarni 2014) and higher levels of proline enabled the plant to maintain a low water potential. The accumulation of suitable osmolytes involved in osmoregulation lowers water potentials, enabling the organism to absorb more water from the environment and reducing the immediate impact of water shortages (Ambikapathy *et al*., 2002; Pandhare *et al*., 2009). Proline can also counteract hydroxyl radicals and stabilize the structure and performance of macromolecules including DNA and proteins as well as their interactions with membranes (Simaei *et al.*, 2011).

E. Antioxidant content

(i) Catalase. The mean data indicated that catalase content significantly varied from 0.14 to 0.35 with mean 0.30 at flowering, 0.24 to 0.57 with mean of 0.46 at pod filling and 0.11 to 0.42 with mean of 0.24 at pod maturation stage under irrigated conditions; while under drought stress conditions from 0.23 to 0.56 with mean of 0.46 at flowering, 0.25 to 0.83 with mean of 0.58 at pod filling and 0.13 to 0.52 with mean of 0.35 at pod maturation stage in cultivar WGG 42. Likewise, it ranged from 0.12 to 0.47 with mean of 0.28 at flowering, 0.23 to 0.62 with mean of 0.44 at pod filling and 0.04 to 0.24 with mean of 0.15 at pod maturation under irrigated conditions; whereas from 0.22 to 0.42 with mean of 0.30 at flowering, 0.15 to 0.52 with mean of 0.35 atpod filling, 0.05 to 0.23 with mean of 0.16 at pod maturation in cultivar WGG 42. The results revealed that the application of both PGRs and PGPRs significantly improves the catalase activity under both irrigated and drought stress treatment (Fig. 5). The highest catalase activity was recorded with combined application of all PGRs and PGPRs compared to control under irrigated as well as drought stress conditions.

(ii) Peroxidase. The mean performance showed that the peroxidase values in variety WGG 42 was varied from 0.46 to 1.44 with mean of 0.95, 0.64 to 1.80 with mean of 1.18, and 0.23 to 1.33 with mean of 0.76 at flowering, pod filling and pod maturation stage respectively under irrigated conditions; while from 0.65 to 2.16 with mean of 1.31, 0.85 to 2.36 with mean of 1.54, and 0.46 to 1.95 with mean of 1.14 at flowering, pod maturation, and pod filling stage respectively under drought stress conditions. Likewise, in variety MGG 385 the range of variation was from 0.29 to 1.26 with mean of 0.76, 0.45 to 1.44 with mean of 0.95, and 0.16 to 1.06 with mean of 0.58 at flowering, pod filling and pod maturation respectively under irrigated conditions; whereas from 0.48 to 1.98 with mean of 1.15, 0.65 to 2.19 with mean of 1.35, 0.25 to 1.74 with mean of 0.95 at flowering, pod filling and pod maturation stage respectively under drought stress conditions. The results showed the application of both PGRs and PGPRs significantly improves the peroxidase values under both irrigated and draught stress treatments. Furthermore, a combine application of all PGRs and PGPRs gave highest Peroxidase values in both the cultivars *viz.*, WGG 42 and MGG 385 under irrigated and drought stress conditions compared to control (Fig 6).

(iii) Super Oxide Dismutase. The mean data indicated that under irrigated conditions, SOD values was varied from 0.33 to 0.89 at flowering, 0.53 to 1.19 at pod filling and 0.14 to 0.71 at pod maturation in WGG 42; whereas from 0.24 to 0.77 at flowering, 0.45 to 0.97 at pod filling and 0.12 to 0.66 at pod maturation stage in variety MGG 385 under irrigated conditions. On the other hand under drought stress conditions, it varied from 0.43 to 1.50 at flowering, 0.63 to 2.53 at pod filling and 0.20 to 1.27 at pod maturation stage in cultivar WGG 42; while from 0.33 to 1.27 at flowering, 0.55 to 1.5 at pod filling, and 0.13 to 1.16 at pod maturation stage in cultivar MGG 385.The results showed the treatment with either PGRs(SA and PBZ) or

PGPRs (Biotilis, Lipel, and P Sol B at 10 g/kg) significantly improves the SOD values under both irrigated and drought stress treatment and most superior results were obtain with combined application of all PGRs and PGPRs compared to control (Fig. 7).

During the study, a number of antioxidant enzymes including catalase, peroxidase, and superoxide dismutase were measured. The findings showed that the treatment of PGRs (SA and PBZ) and PGPRs (*Bacillus subtilis*, *Bacillus thuringiensis*, and *Bacillus megaterium*) under both irrigated and drought stress conditions caused significant variations in antioxidant enzymes under both conditions. The results also showed that under both cultivars of mungbean (WGG 42 and MGG 385), drought stress conditions resulted to an increase in antioxidant enzymes (catalase, peroxidase, and superoxide dismutase) compared to irrigated conditions. Additionally, it was observed that PGR and PGPR treatment decreased the antioxidant content in both mungbean cultivars. Similar to our reports the findings of Khan *et al*. (2020) in chickpea, and Razmi *et al*. (2017) in soybean.

The higher activity of antioxidant enzymes in the stress control is an indication of oxidative stress encountered by the crop (Almeselmani *et al*., 2006). The observed reduction of antioxidant enzymes by the PGPR treatment may be attributed to the fact that PGPR reduced the occurrence of stress induced oxidative stress in plants subsequently the antioxidant enzymes were lesser in PGPR/PGR treated plants (Khan *et al.*, 2019; 2020; Saritha *et al*., 2021). Khan *et al*. (2017) reported that the combined application of PGPR lead to significant decrease in CAT, POD and SOD activities in the leaves of chickpea grown under stress condition. Reduction in antioxidant enzymes activity by PGPR or PGR had been reported previously in legume (Upadhyay *et al*., 2012). In addition, salicylic acid controls the activity of antioxidant enzymes and acts against different abiotic stresses (Keykha *et al*., 2014; Khan *et al.*, 2021; Schmit *et al.*, 2021). At low concentrations, salicylic acid enhances the plant's antioxidant capacity (Hara *et al.*, 2012). In conclusion, combined application of PGRs to PGPRs helps in reduces oxidative stress caused indirectly due to various abiotic stresses.

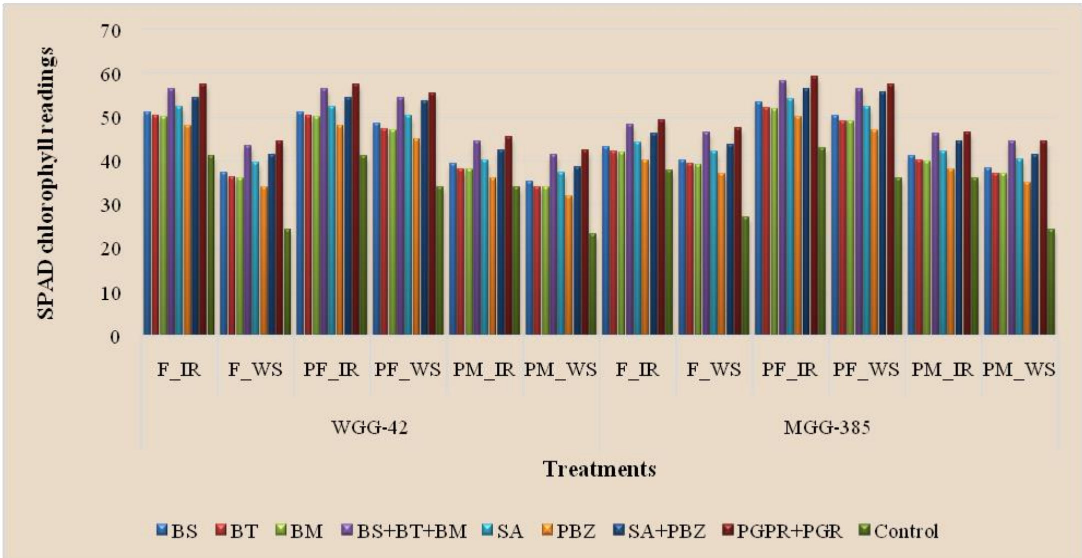

Fig. 1. Effect of PGRs and PGPRs on SPAD chlorophyll meter readings of green gram under irrigated and drought conditions.

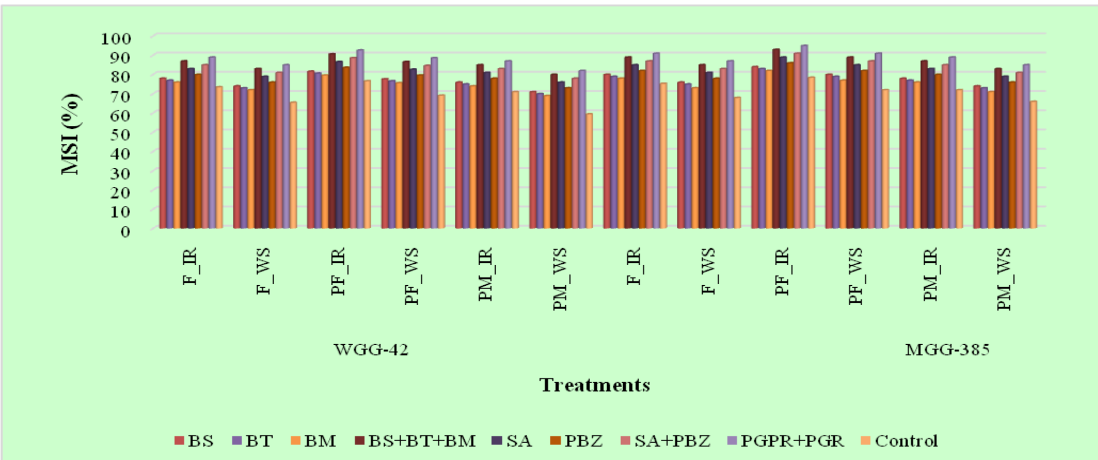

Fig. 2. Effect of PGRs and PGPRs on Membrane Stability Index (MSI) of green gram under irrigated and drought conditions.

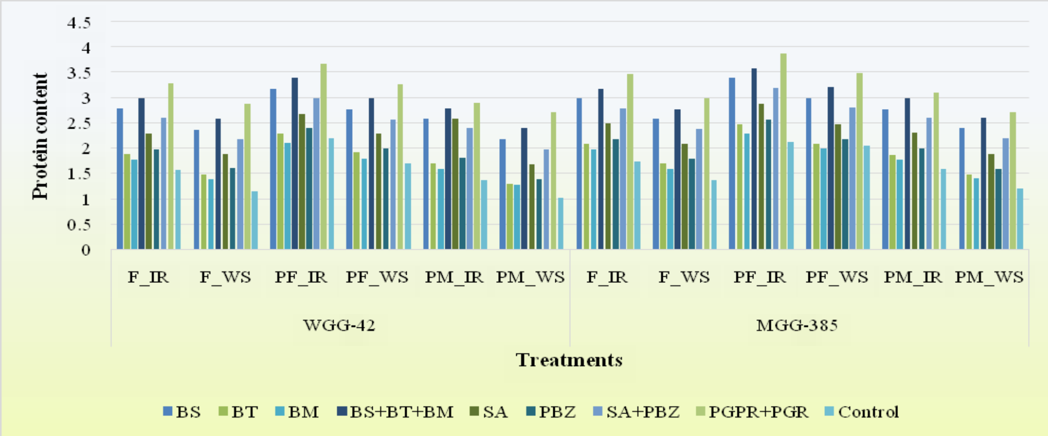

Fig. 3. Effect of PGRs and PGPRs on protein content of green gram under irrigated and drought conditions.

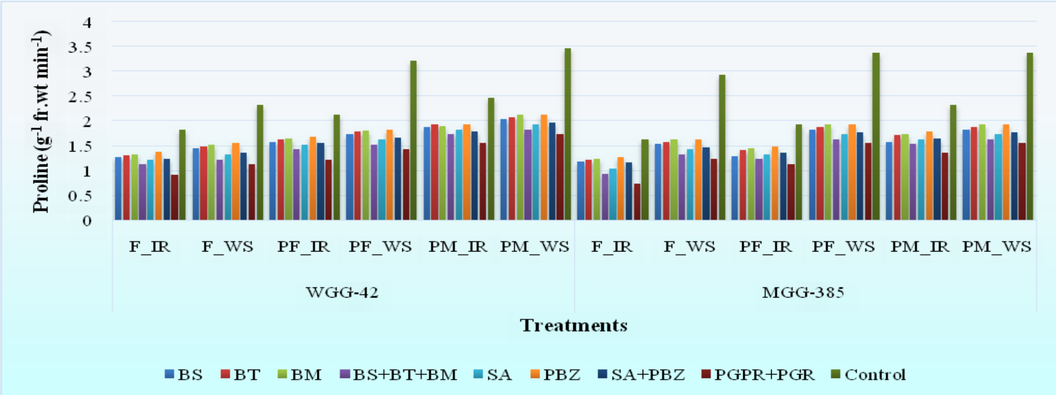

Fig. 4. Effect of PGRs and PGPRs on proline content of green gram under irrigated and drought conditions.

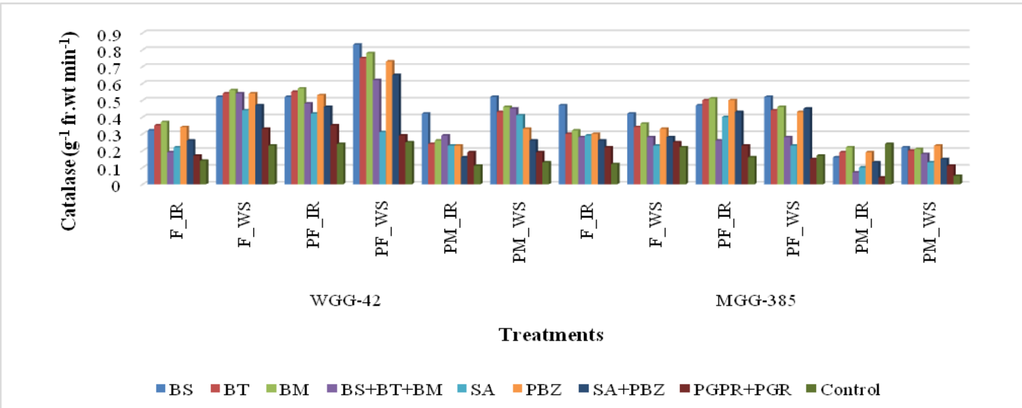

Fig. 5. Effect of PGRs and PGPRs on catalase activity in green gram under irrigated and drought conditions.

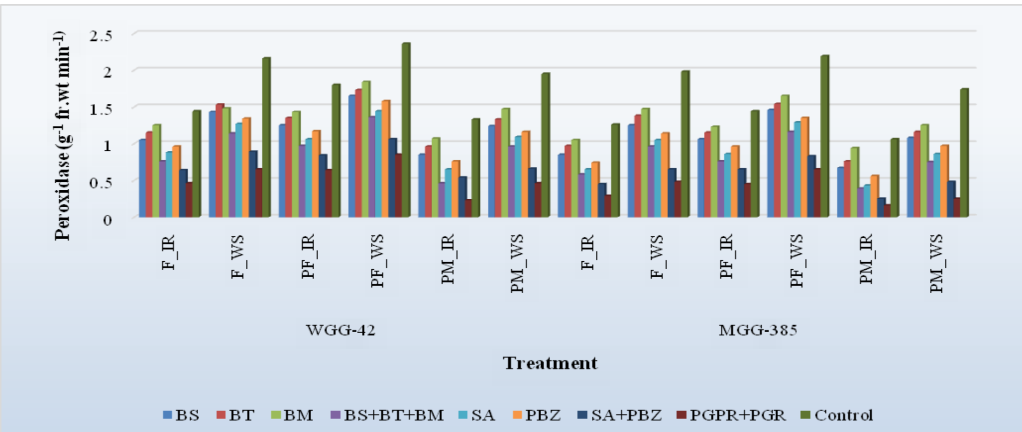

Fig. 6. Effect of PGRs and PGPRs on peroxidase activity in green gram under irrigated and drought conditions.

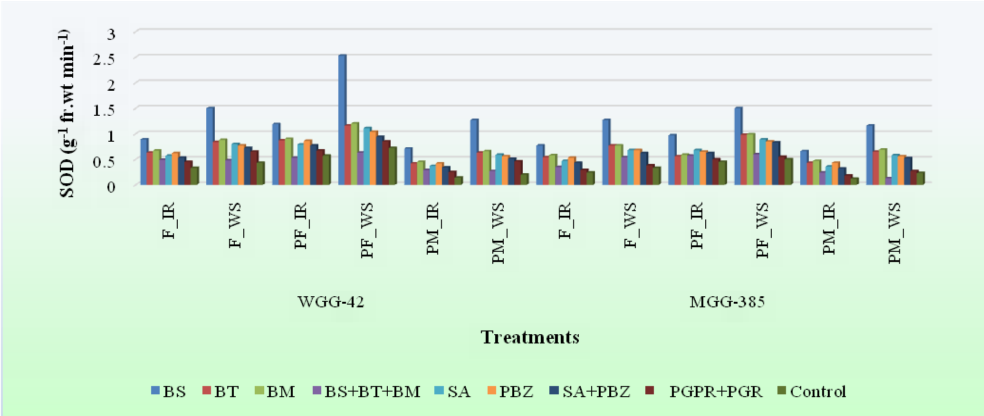

Fig. 7. Effect of PGRs and PGPRs on Super Oxide Dismutase (SOD) activity in green gram under irrigated and drought conditions.

CONCLUSIONS

The world's population is growing rapidly and is expected to reach 9 billion by 2050, raising concerns about food security. Furthermore, the changing climate scenario threatens food production both in terms of quantity and quality. Drought is one of the most significant abiotic factors that have a negative impact on crop growth and production. In present study, the physio-biochemical parameters of mungbean were recorded under the pot culture experiment after subjecting the plants to both irrigated and stressed conditions. The physio-chemical traits, *viz.*, SPAD chlorophyll meter readings (SCMR), membrane stability index (MSI), protein content, proline content, antioxidant enzymes (catalase, peroxidase, and superoxide dismutase), were recorded after the application of treatments at three different stages of crop growth: flowering, pod filling, and pod maturation. The experimental findings indicated all the physio-chemical traits were significantly varied. The imposition of drought stress conditions caused an overall significant reduction in SCMR (8.8 to 27.0%), membrane stability index (5.0 to 6.8%), and protein content (11.9 to 19.3%). On the other hand, water-limited conditions significantly enhanced the proline content (13.8 to 40.0%) and antioxidant enzymes (20.0 to 54.0%) at all three growth stages in both cultivars compared to irrigated conditions. Also, it was observed that negative effect of drought stress was more pronounced in WGG 42 compared to MGG 385. Among the cultivars, MGG 385 recorded higher SCMR, MSI, and protein content, while cultivar WGG 42 performed superiorly in terms of proline content and antioxidant enzymes under both irrigated and drought-stress conditions. Furthermore, application of PGRs and PGPRs (either alone or in combination) significantly improved the drought stress tolerance and improved the physio-chemical traits of mungbean cultivars. In conclusion, both PGRs and PGPRs in combination were found effective in mitigating the harmful effects of drought stress conditions by way of improving the physio-chemical properties of mungbean cultivars. In addition, the identified concentration of PGRs (salicylic acid and paclobutrazol) and PGPRs (*Bacillus subtilis, Bacillus thuringiensis, and Bacillus megaterium*) could be also used in other legumes as well as field crops.

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Conflict of Interest. None.

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