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PGPR BIOSTIMULANTS AS EFFECTIVE DROUGHT MITIGATING AGENTS

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Abstract. Drought is severe environmental stress effecting the agriculture sector on a large scale. Plants under drought have shown low productivity, however, Plant growth promoting rhizobacteria (PGPR) have ability to enhance plant tolerance and maintain their water potential status. In current study highly drought tolerant exopolysaccharides (EPS) producing rhizobacteria are used and their phytostimulatory activity have been observed using Triticum aestivum. Three levels of water stress (normal, moderate and severe drought stress conditions) have been maintained firstly by increasing solute concentration in soil and secondly by varying watering intervals. Growth parameters and biochemical analysis of bacterized Triticum aestivum was carried out and compared with non-treated plants. All bacterial strains used in current studies i.e., *Pseudomonas* sp. (DS1), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (ES2) shave shown array of varying behavior. These PGPR have shown better results under stress condition provided by varying water intervals as compared to the stress provided by increasing solute concentration, though, improvement have been observed in all cases. Hence, these PGPR can be used as biostimulants in agriculture fields to improve crop quality and productivity.

Keywords. Biostimulant, drought, PGPR, exopolysaccharides, *Triticum aestivum*

1. Introduction

The Biostimulants are diverse set of biological materials that either interact directly with plant signaling or stimulate soil micro-fauna to facilitate nutrient acquisition. They also enhance stress tolerance in plants either through regulation of various hormone or by activating plant defense mechanisms. Many studies have shown that plant associated rhizobacteria have the potential to act as biostimulants. Different bacterial genera have been reported as potential biostimulants such as, *Rhizobium*, *Bacillus, Bradyrhizobium*, *Pseudomonas, Azotobacter* and *Azospirillum* [1,2]. These plant growth promoting bacteria are used to inoculate seeds and plants, where they express their growth-promoting activities after establishing an associative interaction by colonizing the plant rhizosphere. Identification of a PGPR strain showing a compatible interaction with a given plant species is a valuable strategy that can be used to develop biological inputs, such as microbial inoculants, that can be applied to produce seedlings with higher adaptive and developmental potential [3,4].

Many researchers have reported PGPR as an effective agent to ameliorate the negative effects of drought on plants [5-7]. For this, PGPR have adapted various strategies like regulation of different phytohormones, synthesis of various enzymes and volatile compounds, formation of biofilms and secretion of exopolysaccharides. Exopolysaccharides (EPS) are the extracellular polymeric matrix consisting mainly sugars and proteins and slight amount of other compounds like nucleic acids. EPS is known for its vital role to protect bacterial cell from various environmental stresses including drought. Some bacterial species have been reported for increased production of EPS under dry conditions to make nutrients and water available [8]. This has been proved quite helpful for plant growth as EPS forms soil aggregates that have capacity to hold large amount of water and nutrients as compared to rest of soil [9]. In current study effect of EPS producing plant growth promoting rhizobacteria have been analysed on growth parameters of *Triticum aestivum* under various levels of drought stress i.e., 100% field capacity (FC) (normal conditions), 60 % FC (moderate stress), 40% FC (severe stress).

2. Materials and Methods

2.1. Drought tolerance potential

Already isolated and biochemically identified fifteen rhizobacteria were used to observe their drought tolerance potential. Bacterial strains were grown in LB media supplemented with different concentrations of polyethylene glycol PEG-400 (i.e., 0, 200, 400, 600, 800 and 1000 µg/ml) and their sensitivity was recorded by measuring their optical density at 600 nm through spectrophotometer.

2.2. Experimental design

The experiment was carried out in randomized complete block design by using three replicates per treatments in Microbiology laboratory, Department of Botany, University of the Punjab, Lahore, Pakistan. Two strategies were used for the induction of drought stress of three levels i.e., 100, 60, and 40% FC, first by increasing the solute concentration in soil by adding different concentrations of polyethylene glycol i.e., 0, 400 and 800 µg/ml and second by varying watering intervals i.e., daily watering, watering after 4 and 8 days. Control set of pots with same stress conditions without bacterial treatment were used for comparative analysis of treated and non-treated plants.

2.3. Seeds procurement

Certified seeds of *Triticum aestivum* L. var FSD2008 were collected from Punjab Seed Corporation Lahore, Pakistan.

2.4. Bacterization of Triticum aestivum

To study the phytostimulatory impact on *Triticum aestivum* a pot experiment was conducted by using highly drought resistant bacteria. Seeds were surface sterilized and bacterially inoculated following Ahmed and Hasnain [10] before sowing.

2.5. Seed germination analysis

Germination of seeds were determined by recording the number of seeds germinated by total number of seeds planted.

2.6. Postharvest analysis

Various growth attributes like shoot length, root length, fresh weight and water content were recorded. Chlorophyll ‘a’, chlorophyll ‘b’ and total chlorophyll content of the bacterially treated and non-treated plants was determined following modified method of Wellburn [11] and protein content was determined by following Lowry et al. [12].

3. Results

3.1. Drought tolerance potential

Out of fifteen bacterial strains only five drought tolerant bacteria i.e., *Pseudomonas* sp. (DS1), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (ES2) were selected for further studies.

3.2. Bacterization of *Triticum aestivum*

Seeds were inoculated with bacterial strains prior to sowing. Six seeds were sown in each pot containing 186.7 g of soil. Plants were harvested after 25 days of sowing and various growth parameters were recorded and compared with the control plants which were treated with autoclaved distilled water for the same period of time.

3.3. Seed germination analysis

All the bacterially treated plants have shown increment in germination rate when compared with control. Increase of 27.2% in germination rate was recorded when seeds were treated with bacterial strain *Pseudomonas* sp. (DS1), *Pseudomonas* sp. (DS3) and *Pseudomonas aeruginosa* (DS4) when compared to non-treated seeds and in case of seeds treated with bacterial strain *Shewanella putrefaciens* (DS2) and *Pseudomonas* sp. (ES2) germination rate has been enhanced by 18.17% as compared to control ones. When the watering interval was extended to 4 days the increment in percentage was recorded as 21.2, 10 and 10% in case of treatment with bacterial strains *Pseudomonas aeruginosa* (DS4), *Pseudomonas* sp. (DS3) and *Pseudomonas* sp. (ES2) respectively, over the control plants. Similarly, when the watering interval was increased to 8 days the improvement in percentage germination was recorded as 43.4 and 14% by *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (DS1) respectively, when compared with control plants. However, when stress was applied using PEG-400 in concentration of 400µg the improvement recorded in germination percentage is 37.5 and 12.2% by treatment with bacterial strains *Pseudomonas* sp. (ES2) and *Pseudomonas* sp. (DS1) respectively, over the control one. Likewise, when the concentration of PEG-400 was increase to 800µg, 50.2, 50, 16.7, 16.2 and 33% improvement in the germination percentage of seeds treated with bacterial strains *Pseudomonas* sp. (ES2), *Pseudomonas aeruginosa* (DS4), *Pseudomonas* sp. (DS3), *Shewanella putrefaciens* (DS2) and *Pseudomonas* sp. (DS1) respectively, was recorded over the control plants (Fig. 1).

3.4. Postharvest analysis

Increase in shoot length, root length, fresh weight and water content in the bacterially treated plants have been recorded. In case of daily watering, the increment in shoot length was recorded as 21.89, 19.81, 17.49, 17.49 and 11.6% by the bacterial strains *Pseudomonas* sp. (DS1), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (ES2) respectively over the control plants. However, in case of watering after 4 and 8 days the maximum increment in shoot length was recorded in plants treated with bacterial strains *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (DS1) i.e., 23.61 and 26.33% respectively over the control plants. Whereas, increase of 21.36, 18.27, 14.17 and 7.14% was recorded in plants treated with bacterial strains *Pseudomonas* sp. (DS1), *Pseudomonas* sp. (DS3), *Shewanella putrefaciens* (DS2) and *Pseudomonas* sp. (ES2) respectively when compared with control plants when watering was skipped for 4 days. On the other hand, increase of 26.3, 25.69, 23.88 and 20.38% has been observed in the shoot length of plants treated with bacterial strains *Pseudomonas* sp. (DS1), *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (DS3) respectively, when watering is skipped for 8 days. However, when artificial stress of 400µl of PEG-400 was applied increment of 31.6, 29.3, 29.1, 22.4 and 19.7% was recorded in plants treated with bacterial strains *Shewanella putrefaciens* (DS2), *Pseudomonas aeruginosa* (DS4), *Pseudomonas* sp. (DS1), *Pseudomonas* sp. (DS3) and *Pseudomonas* sp. (ES2) respectively, when compared with non-treated plants (Fig. 2).

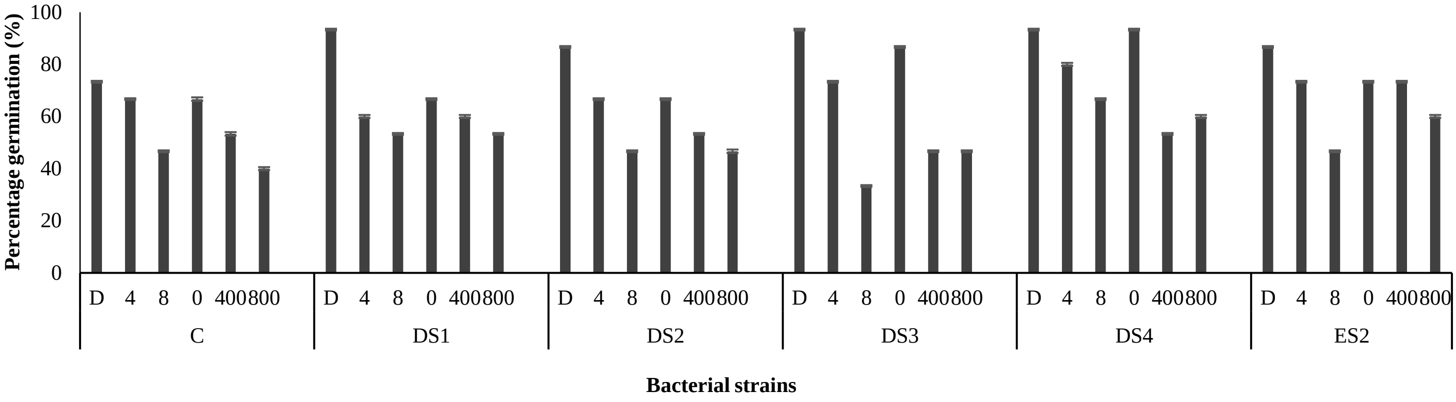

Fig. 1: Effect of bacterial inoculation with and without PEG stress (0, 400, 800µg/ml) and water interval (D-daily, 4-days, 8-days) stress on seed gemination *Triticum aestivum* [C - control; bacterial strains – *Pseudomonas* sp. (DS1), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4), *Pseudomonas* aeruiginosa (ES2)].

On the other hand, in case of stress applied by 800 µl of PEG-400, elevation of 36.09, 33.15, 30.57, 23.33 and 22.9% in the shoot length of plants treated with bacterial strains *Pseudomonas* sp. (ES2), *Pseudomonas* sp. (DS1), *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4) and *Shewanella putrefaciens* (DS2) respectively, as compared to control plants. Similarly, significant improvement in root length of bacterially treated plants was also recorded. In case of normal watering maximum increment of 74.3 % in root length was recorded in plants treated with bacterial strain *Shewanella putrefaciens* (DS2) when compared with the un-treated plants. In the same way, increase of 56.58, 49.34, 37.5 and 37.4 % was recorded in plants inoculated with bacterial strains *Pseudomonas* sp. (ES2), *Pseudomonas aeruginosa* (DS4), *Pseudomonas* sp. (DS3) and *Pseudomonas* sp. (DS1). When watering was skipped for 4 days, improvement in root length of bacterized plants were recorded as 56.75, 47.1, 46.9, 43.08 and 38.16% by bacterial strains *Pseudomonas* sp. (ES2), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (DS1), *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (DS3) respectively, when compared with non-treated plants. Furthermore, when watering interval was increased for 8 days, increase in root length of bacterially inoculated plants was recorded as 93.5, 13.08, 11.54 and 4.15% by the treatment with bacterial strains *Pseudomonas* sp. (DS1), *Pseudomonas aeruginosa* (DS4), *Pseudomonas* sp. (ES2) and *Shewanella putrefaciens* (DS2) respectively, however, no significant improvement in plants treated with *Pseudomonas* sp. (DS3) was recorded when watering gap was extended up to 8 days comparatively to the control plants. Additionally, when drought stress is applied artificially by applying PEG-400 in concentration of 400µg and 800µg increase in root growth was also recorded however, this increase is not recorded in all bacterial strains. Escalation in root growth was recorded as 20.25, 8.8 and 8.3 % when treated with bacterial strains *Pseudomonas* sp. (ES2), *Pseudomonas* sp. (DS1) and *Pseudomonas* sp. (DS3) respectively, as compared to the un-treated plants in case of PEG-400 in concentration of 400µg. In the same way when the stress is applied by using PEG-400 in concentration of 800µg rise in root length was recorded as 32.2, 24.4 and 15.6% when treated with bacterial strain *Pseudomonas* sp. (ES2), *Pseudomonas* sp. (DS1) and *Shewanella putrefaciens* (DS2) respectively, when compared with non-treated plants. However, no significant improvement in roots was observed in plants treated with bacterial strain *Pseudomonas aeruginosa* (DS4) in case of stress applied using polyethylene glycol, though, increment was recorded in normal watering conditions and when watering intervals were increase comparative to the control plants (Fig. 2).

As far as fresh weigh and water content of bacterially treated plants was measured significant improvement was noticed. Increase in fresh weight of bacterially treated plants under normal watering conditions was recorded as 42.4, 37.3, 33.8, 32.2 and 25.2% when treated with bacterial strain *Pseudomonas* sp. (ES2), *Pseudomonas* sp. (ES2), *Shewanella putrefaciens* (DS2), *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (DS3) respectively, over the control plants. However, when watering interval was increased for 4 days the increment observed was 20.5, 9.8, 8.7 and 3.9% by treating with bacterial strain *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (ES2), *Pseudomonas* sp. (DS1) and *Pseudomonas* sp. (DS3) respectively, over the control plants and when watering interval was increased to 8 days the increment observed was 26.3 and 9.7% by treating with the bacterial strain *Shewanella putrefaciens* (DS2) and *Pseudomonas* sp. (ES2) respectively when compared with the non-treated plants. Though, no significant improvement was observed when plants were treated with bacterial strain *Pseudomonas* sp. (DS1) and *Pseudomonas* sp. (DS3). Similarly, increment in fresh weigh of bacterially treated plants was recorded as 33.9, 27.2, 23.1 and 18% in case of stress provided by applying PEG-400 in concentration of 400µg with bacterial strain *Pseudomonas* sp. (DS3), *Pseudomonas* sp. (ES2), *Shewanella putrefaciens* (DS2) and *Pseudomonas* sp. (DS1) respectively, when compared to the control plants. Similarly, increment recorded under stress of 800µg of PEG-400 fresh weigh of treated plants was 60.7, 52.9, 47 and 45% with the bacterial strain *Pseudomonas* sp. (DS1), *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (ES2) respectively, over the control plants (Fig. 3).

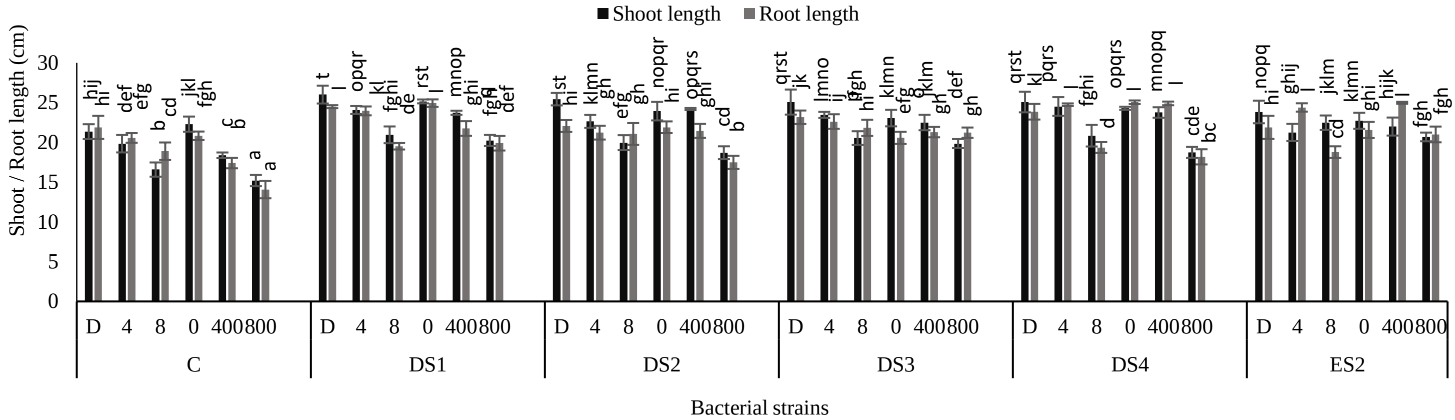

Fig. 2: Effect of bacterial inoculation with and without PEG stress (0, 400, 800µg/ml) and water interval (D-daily, 4-days, 8-days) stress on shoot and root length of *Triticum aestivum*. Different letters indicating significant differences between treatments using Duncan's multiple range test (P = 0.05) [C - control; bacterial strains – *Pseudomonas* sp. (DS1), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4), *Pseudomonas* aeruiginosa (ES2)].

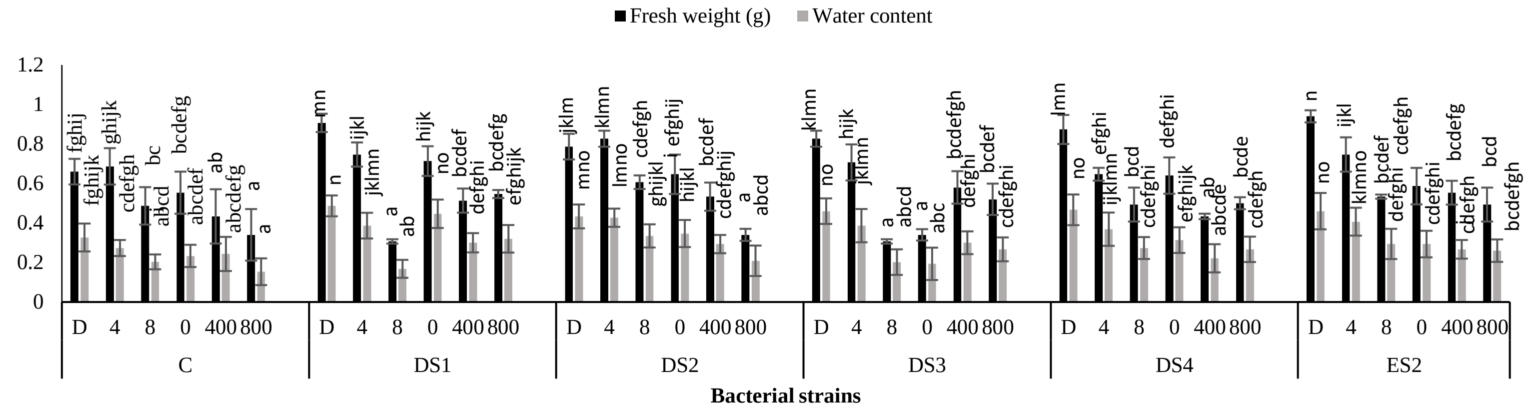

Fig. 3*:* Effect of bacterial inoculation with and without PEG stress (0, 400, 800µg/ml) and water interval (D-daily, 4-days, 8-days) stress on fresh weight and water content *Triticum aestivum*. Different letters indicating significant differences between treatments using Duncan's multiple range test (P = 0.05) [C - control; bacterial strains – *Pseudomonas* sp. (DS1), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4), *Pseudomonas aeruiginosa* (ES2)].

Likewise, the water uptake under drought stress was also improved in case of bacterially treated plants. Under normal watering conditions increase of 49.2, 43.1, 41.1, 41 and 32 % was recorded by treatment with bacterial strains *Pseudomonas* sp. (DS1), *Pseudomonas aeruginosa* (DS4), *Pseudomonas* sp. (ES2), *Pseudomonas* sp. (DS3) and *Shewanella putrefaciens* (DS2) respectively, over the control ones. In the same way increment observed in water content of bacterially treated plants in case of watering after 4 days was 56.1, 48.9, 41.6 and 41.5% when treated with bacterial strain *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (ES2), *Pseudomonas* sp. (DS3) and *Pseudomonas* sp. (DS1) respectively, over un-treated plants. When watering interval was increased for 8 days, increment in fresh weigh observed as 64.6, 44.8 and 34.6% by treatment with bacterial strain *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (ES2) and *Pseudomonas aeruginosa* (DS4) respectively, when compared with the control plants. However, when the stress is applied by using 400µg of PEG-400 the improvement recorded as 23.4, 23.3 and 20.5% when treated with bacterial strain *Pseudomonas* sp. (DS3), *Pseudomonas* sp. (DS1) and *Shewanella putrefaciens* (DS2) respectively as compared to the un-treated plants. Likewise, the increment observed under stress of 800µg of PEG-400 was recorded as 74.2, 74.1, 71 and 69% by treating with bacterial strain *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4), *Pseudomonas* sp. (DS1) and *Pseudomonas* sp. (ES2) respectively, when compared with the non-inoculated plants (Fig. 3).

Bacterially treated plants have also shown significant enhancement in biochemical parameters like chlorophyll and protein content when compared to control plants. During normal watering conditions the impact of bacterial strains *Pseudomonas* sp. (DS1), *Pseudomonas* sp. (DS3), *Shewanella putrefaciens* (DS2), *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (ES2) on the total chlorophyll, chlorophyll 'a' and 'b' content of treated plants were recorded as 50, 40, 39, 36 and 32% respectively when compare with non-treated plants. When watering interval was increased for 4 days the increment in the total chlorophyll, chlorophyll 'a' and 'b' content of treated plants were recorded as 59.48, 58.8, 55, 53.7 and 48% in plants treated with bacterial strains *Pseudomonas* sp. (DS1), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (ES2), *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (DS3) respectively when compared with control plants. In the same way, when watering interval enhanced for 8 days, increment in total chlorophyll, chlorophyll 'a' and 'b' content of treated plants were recorded as 44.9, 44.1, 43.8, 42.5 and 36.7% when treated with bacterial strain *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (ES2) and *Pseudomonas* sp. (DS1) respectively, when compared with the non-treated plants. Similarly, when stress is applied artificially by using PEG-400 in concentration of 400µg the increment observed in photosynthetic pigment of bacterially treated plants was 39, 38.3, 38, 33.8 and 25.8% when treated with bacterial strain *Pseudomonas aeruginosa* (DS4), *Pseudomonas* sp. (DS3), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (ES2) and *Pseudomonas* sp. (DS1) respectively, when compared to the control plants. Likewise, when the concentration of PEG-400 increased to 800µg the increase recorded was 46, 44, 43.8, 40.8 and 40.3 when treated with bacterial strains *Pseudomonas* sp. (DS1), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (DS3), *Pseudomonas* sp. (ES2) and *Pseudomonas aeruginosa* (DS4) respectively, over the un-treated plants (Fig. 4).

In the same, way improvement in the soluble protein content of bacterially treated was noticed when compared with un-treated plants. Under normal watering conditions bacterially treated plants showed 74.9, 56.5, 49.3, 37.5 and 37.4% improvement with bacterial strains *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (ES2), *Pseudomonas aeruginosa* (DS4), *Pseudomonas* sp. (DS3) and *Pseudomonas* sp. (DS1) respectively, over the un-treated plants. when the watering interval was increased for 4 days 56.7, 47.1, 46.9, 43 and 38.1% increment was shown by bacterial strains *Pseudomonas* sp. (ES2), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (DS1), *Pseudomonas aeruginosa* (DS4) and *Pseudomonas* sp. (DS3) respectively, over the control ones. Similarly, when the watering interval was increased to 8 days, 93.5, 13, 11.5 and 4.1% improvement in soluble protein content of plants treated with bacterial strain *Pseudomonas* sp. (DS1), *Pseudomonas aeruginosa* (DS4), *Pseudomonas* sp. (ES2) and *Shewanella putrefaciens* (DS2) was recorded respectively, when compared with the un-treated plants. However, no significant improvement in soluble protein content was observed by bacterial strain *Pseudomonas* sp. (DS3) in this condition. However, under drought stress applied by using PEG-400 in concentration of 400µg the increment recorded as 20.2, 8.8 and 8.3% with the treatment with the bacterial strains *Pseudomonas* sp. (ES2), *Pseudomonas* sp. (DS1) and *Pseudomonas* sp. (DS3) respectively, over the control plants and under stress of 800µg PEG-400 the increment shown was 32.2, 24.4 and 15.6% by bacterial strain *Pseudomonas* sp. (ES2), *Pseudomonas* sp. (DS1) and *Shewanella putrefaciens* (DS2) respectively, when compared to the non-treated plants (Fig. 5).

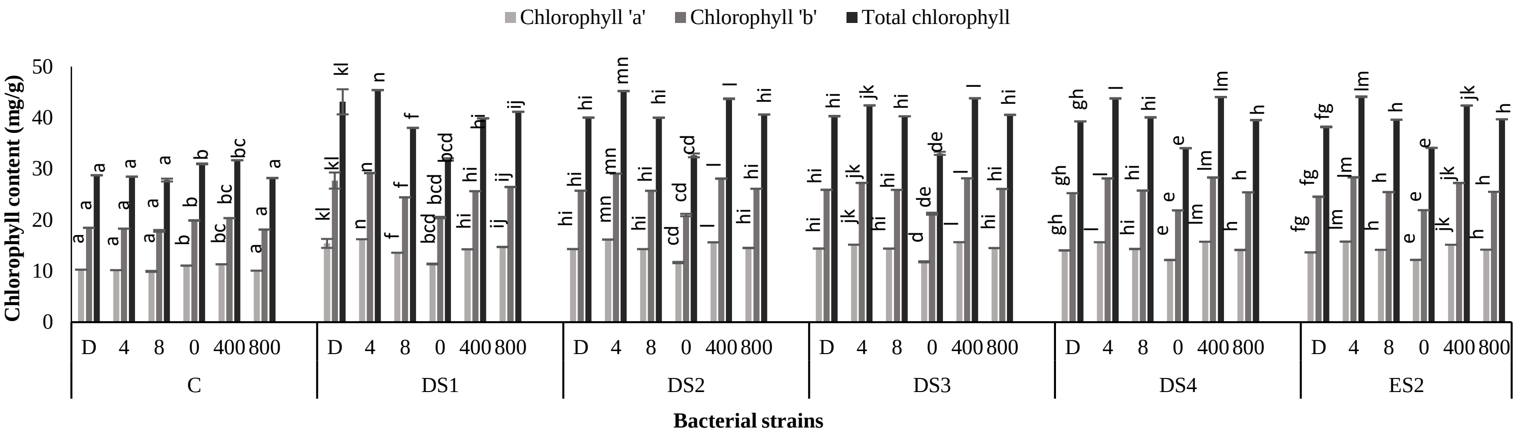

Fig. 4: Effect of bacterial inoculation with and without PEG stress (0, 400, 800µg/ml) and water interval (D-daily, 4-days, 8-days) stress on chlorophyll content of *Triticum aestivum*. Different letters indicating significant differences between treatments using Duncan's multiple range test (P = 0.05) [C - control; bacterial strains – *Pseudomonas* sp. (DS1), *Shewanella putrefaciens* (DS2), *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4), *Pseudomonas aeruiginosa* (ES2)].

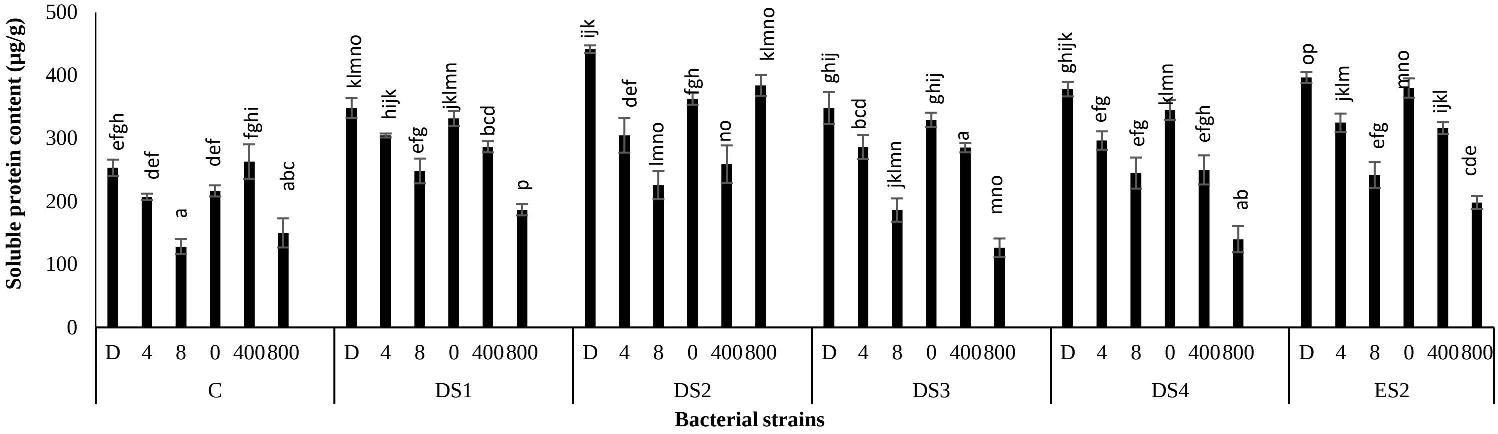

Fig. 5: Effect of bacterial inoculation with and without PEG stress (0, 400, 800µg/ml) and water interval (D-daily, 4-days, 8-days) stress on soluble protein content of *Triticum aestivum*. Different letters indicating significant differences between treatments using Duncan's multiple range test (P = 0.05) [C - control; bacterial strains – *Pseudomonas* sp. (DS1), Shewanella putrefaciens (DS2), *Pseudomonas* sp. (DS3), *Pseudomonas aeruginosa* (DS4), *Pseudomonas aeruiginosa* (ES2)].

Discussion

PGPR had been reported to significantly enhanced plant height, root length, number of leaves, and plant dry matter content as compared to irrigated and stressed control plants. In current study increased plant health after PGPR treatment under drought stress have been observed. Plant roots play a key role in water use efficiency. Bacterially treated plants have shown improved root system in current study this can be corelated with better stress tolerance and improved plant health under water stress. Better plant root system increases the roots surface that contribute in soil exploration that help plant in nutrient acquisition moreover, proliferation of adventitious roots resulting in increased number of root tips which are important for root water uptake capacity [9, 13]. Increased nutrient and water uptake eventually enhance plant biochemical parameters i.e., chlorophyll, protein content etc. that ensure plant fitness and help in enduring stress. Leaf relative water content specifies the water status of plant and indicates the balance between water supply and transpiration. Khan and Bano [14] reported the beneficial effects of PGPR on chlorophyll content, leaf protein and sugar content, shoot and root weight in chickpea plants grown under sandy soil condition. Whole plant health depends on root: shoot ratio which ultimately maintain balance in biomass and nutrient allocation under stress. In this aspect, improved chlorophyll content of the treated plants both under stress and irrigated conditions indicate that PGPR might have affected the photosynthetic pigments that eventually increased the photosynthetic rate. Hafez et al. [15] refer this increased photosynthetic rate is due to increased CO_2 assimilation and enhanced stomatal conductance in treated plants. In current study bacterial strains used were EPS producing. EPS benefit plant tolerance to environmental stress especially drought by providing moisture and nutrients. It forms hydrophilic biofilms around root surface that act as rhizosheath, protecting plant roots from pathogenic organisms [16]. Moreover, EPS have ability to form soil aggregates that can retain more water as compared to rest of soil. Additionally, polysaccharides released from EPS are the source of nutrients. This on the one hand, improves plant growth by providing water and nutrients and on the other hand, improve soil quality by increasing soil moisture content and fertility [17]. Therefore, EPS producing growth promoting bacteria showed significant results under low water conditions. Enhanced protein content is also observed in current study. Enhanced protein content is related to accumulation of osmoprotectants that suggest drought tolerance in inoculated plants [18]. PGPR have also been reported in regulation of various stress proteins under drought that positively effect plant growth [19,20].

Conclusion

Plant growth promoting bacteria increased nutrient absorption ability of treated plants in both irrigated and drought stress conditions, thereby, proving them as a plant growth stimulating agents. Hence, these can be used as a biofertilizers, moreover, these PGPR if used in consortium might positively effect plant productivity. In current studies, three levels of drought have been studied and it has been observed that all bacterial species respond differently to enhance plant growth. Hence, these PGPR are promising and efficient biostimulants that can be used as biofertilizers in sustainable agriculture.

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Conflict of Interest

The authors declare no conflict of interest.

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