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Mitigation of Drought Stress in Wheat by Bio-priming by PGPB Containing ACC Deaminase Activity

ACC Deaminaz Aktivitesi İçeren PGPB Kullanılarak Biyo-priming ile Buğdayda Kuraklık Stresinin Azaltılması

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ABSTRACT

Out of stress management strategies used for drought, inoculation of plant growth-promoting bacteria holds a major position due to sustainable, low-cost, and versatile properties. The plant growth-promoting bacteria, particularly containing 1-aminocyclopropane-1-carboxylic acid deaminase activity, have a critical location since they restrict ethylene synthesis under stress conditions thereby improving stress tolerance index. In this experiment, seeds of two wheat cultivars were primed with three bacterial strains and seedlings were grown under stress and non-stress conditions. The study was laid out in completely randomized factorial design with three replications. While plant growth achieved top performance with synthetic fertilizer in 80% of field capacity, increasing drought stress restricted the efficiency of synthetic fertilizer. In contrast, plant growth-promoting bacteria-priming promoted plant growth and dry matter accumulation under optimum and drought conditions. Increase of dry matter accumulation in treatments as control plants varied between 17.1% and 57.1% under 80% of field capacity while it changed between 0.2% and 35.1% under drought conditions. TV126C and TV24C induced stress tolerance index in sensitive and tolerant cultivars under drought and optimum conditions. In conclusion, it is considered that bio-priming with plant growth-promoting bacteria involving 1-aminocyclopropane-1-carboxylic acid deaminase enzyme activity might be an effective and sustainable management strategy to drought stress in wheat cultivation.

Keywords: Biological fertilizer, drought stress management, free-living microorganisms, seed priming, stress tolerance index, *Triticum aestivum*

ÖZ

Kuraklığa karşı kullanılan stres yönetimi stratejileri arasında, bitki gelişimini teşvik edici bakterilerin (PGPB) inokulasyonu sürdürülebilir, düşük maliyetli ve çok yönlü özellikleri sayesinde önemli bir pozisyonda yer alır. Özellikle ACC (1-aminosiklopropan-1-karboksilik asit) aktivitesi içeren PGPB'ler stres koşulları altında etilen sentezini sınırlandırarak stres tolerans indeksini iyileştirdikleri için kritik bir pozisyona sahiptir. Bu deneyde, iki buğday çeşidinin tohumları üç bakteriyel strain ile ekim öncesinde inokule edildi ve fideler stres ve stres olmayan koşullar altında yetiştirildi. Çalışma tesadüf parsellerinde faktöriyel deneme desenine göre üç tekerrürlü olarak yürütülmüştür. Bitki gelişimi %80 tarla kapasitesinde sentetik gübreleme ile zirveye çıkarken artan kuraklık stresi sentetik gübrenin etkinliğini sınırlandırdı. Aksine, PGPB-priming hem optimum hem de kurak koşullarda bitki gelişimini ve kuru madde birikimini teşvik etti. Kontrol bitkilerine göre uygulamalarda kuru madde birikiminin artışı %80 tarla kapasitesinde %17.1–57.1 aralığında değişirken kurak koşullarda %0.2–35.1 aralığında değişmiştir. TV126C ve TV24C hassas ve dayanıklı çeşitlerde kuraklık stres toleransını teşvik etti. Sonuç olarak, ACC deaminaz aktivitesi içeren PGPB ile biyo-priming uygulamalarının buğday tarımında kuraklık stresine karşı etkili ve sürdürülebilir bir yönetim stratejisi olabileceği düşünülmektedir.

Anahtar Kelimeler: Biyolojik gübre, kuraklık stres yönetimi, serbest yaşayan mikroorganizmalar, tohuma priming, stres tolerans indeksi, *Triticum aestivum*

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Introduction

Climate change is the most important factor threatening wheat yield as in all other agricultural products due to increasing temperatures, carbon emission, and severe droughts. Drought causes a reduction in yield of up to 92% in wheat, which is the most cultivated crop in the world due to its rich chemical compounds depending on the growing stage, its tolerance, and density of drought stress (FAO, 2021; Semenov et al., 2014). Hence, new approaches to the improvement and management of drought stress have major importance in agricultural production and food security. The commonly used methods for stress management are breeding of resistant varieties, water and nutrient management, using of mycorrhizal fungi and plant growth-promoting bacteria (PGPB), priming practices, and using of plant growth regulators, organic amendments, and bioengineering and biotechnological methods (Ceritoglu et al., 2018; Jha et al., 2019; Jisha et al., 2013; Nadeem et al., 2019). Out of them, PGPB applications startup with their eco-friendly, sustainable, and low-cost properties (Johnson & Puthur, 2021).

The PGPB, which mainly live in the rhizosphere, endosphere, and phyllosphere, can be described as bacterial strains that increase water and nutrient uptake, promote plant growth, and improve the tolerance to stress factors by mechanisms such as biological nitrogen fixation, dissolving inorganic phosphate compounds and mineralization of organic phosphate compounds, secretion of various phytohormones, vitamins, and growth regulators, restriction of ethylene synthesis by ACC (1-aminocyclopropane -1-carboxylic acid) deaminase enzyme activity, and decreasing pathogen damage by the secretion of antibiotic and fungicidal compounds (Çakmakçi et al., 2006; Glick, 2020). The PGPBs are more intensively colonized at the rhizosphere of plants due to root exudates such as nutrition, phytohormones, flavonoids, and enzymes (Noumavo et al., 2016). Using PGPB as a microbial inoculant has been gaining awareness as an eco-friendly method in sustainable agriculture compared to chemical fertilizers that damage soil structure, environment, and living organisms. In addition to using PGPB as biological fertilizer, it is an effective and sustainable way of stress management due to its various mechanisms such as ACC deaminase activity, production of siderophore and indoleacetic acid, and exopolysaccharide (Basu et al., 2021; Turan et al., 2014).

The ACC deaminase activity has a critical role in plants under stress conditions due to its inhibitory impact on the ethylene hormone. Although ethylene manages many physiological activities in plants, such as accelerated aging, senescence, fruit ripening, abscission, root formation, inhibition of storage organs formation, regulation of root nodulation in legumes, and supporting flowering in some species, it inhibits plant growth in high concentrations by acting on root and shoots growth via the action of ACC oxidase enzyme within plant tissues (Ahammed et al., 2020). Mechanism of ACC deaminase activity is based on hydrolysis of ACC which is the immediate precursor of ethylene hormone, thereby causing reduction of ethylene level (Raghuwanshi & Prasad, 2018). Therefore, certain PGPB strains can improve stress tolerance in plants exhibiting ACC deaminate activity. Moreover, PGPB involving ACC deaminase activity promotes root elongation and growth by reducing root ethylene levels (Penrose ve Glick, 2001). This study was laid out (i) to investigate impacts of the original bacterial strains containing ACC deaminase activity on mitigation of drought stress in wheat varieties, (ii) to improve effects of bacterial strains as a biological fertilizer via N-fixation and P-solubilizing abilities, and iii) to study the effectiveness of bacterial strains on different cultivars under different irrigation methods.

Methods

Agronomic Traits of Cultivar

The Bezostaja-1 and Gerek79 bread wheat cultivars were grown in this study. Bezostaja-1 is a drought-sensitive cultivar, which has a short stem, strong structure, hairless leaves, and white glume. Gerek79, which has a long stem, strong structure and high tillering, was used as a drought-tolerant cultivar (Bagci et al., 2007). The cultivars were obtained from Transitional Zone Agricultural Research Institute, Turkey.

Multiplication of Used Bacterial Strains and Bio-priming Process of Wheat Seeds

The strains were chosen from the collection which was constituted via the TUBİTAK project (TOVAG 108 O 147) in Van Lake Basin in 2008 (Erman et al., 2010). Three bacterial strains, which are involved in *Pseudoalteromonas tetraodonis*, *Pseudomonas agarici,* and *Brevibacillus choshinensis,* were used in the present study to alleviate effects of drought stress on wheat cultivars. Descriptive information such as Code, Microbial identification system (MIS), isolation location, host-plant, and bacterial traits including N fixation, P solubilizing, and ACC deaminase activity are given in Table 1.

Protected bacterial strains in the laboratory of Siirt University were placed in a nutrient agar medium that was prepared with 20 g nutrient agar for each liter of distilled water for multiplication. The nutrient solution was sterilized at 121°C for 15 minutes by autoclave. After sterilization, cooled feedlots were transferred into petri dishes and solidified for 24 hours at room temperature. The stock of bacterial strains was planted on agar medium by the sterile needle and incubated at 2 ± 25°C for 24 hours. The nutrient broth (Merck-VM775843711) was used for the liquid feedlot. Only one colony was taken from nutrient agar medium, transferred into nutrient broth liquid feedlot, and incubated at 2 ± 26°C for 24 hours and centrifuged at 120 rpm in the shaker. The bacteria concentrations were turbidimetrically arranged to ~10^8 CFU/mL (Sonkurt and Çığ, 2019). Before bacterial inoculation, wheat seeds were subjected to surface sterilization with 70% ethyl alcohol for 1 minute and 5% sodium hypochlorite (NaOCl) for 20 minutes. Seeds were primed with bacterial strains for 3 hours. After bio-priming, seeds were dried to initial moisture content for 24 hours under dark conditions. Control seeds were subjected to the pure nutrient broth solution to avoid impacts of early water uptake on germination and seedling growth.

Experimental Design

The experiment was laid out as a pot study under controlled conditions at a growth chamber of the Field Crops Department of Siirt University where mean temperatures and humidity were adjusted as 20–24°C and 50–70%, respectively. Two bread wheat cultivar (Bezostaja-1 and Gerek79), three irrigation levels (IL1: 25%, IL2: 50%, and IL3: 80% of field capacity) and six fertilizers (control, 100% synthetic fertilizer (SF), 50% SF, TV126C inoculation, TV24C inoculation, and TV53D inoculation) were used in the experiment. Optimum dose (100% SF) and half-dose (50% SF) were adjusted as 8 kg N/da with 6 kg P/da and 4 kg N/da with 3 kg P/da, respectively. Urea and triplesuper phosphate were used as nitrogen and phosphorus source, respectively. Control seeds were hydro-primed for 3 hours to eliminate water uptake before sowing, and

Table 1.
Descriptive Informations of Bacterial Strains Used in the Study

Code	Microbial Identification System	Location	Host–Plant	N-fix	P-sol	ACC-D
TV126C	*Pseudoalteromonas tetraodonis*	Ulupamir/Van	Wheat	H	L	N
TV24C	*Pseudomonas agarici*	Tendürek/Van	Raspberry	N	L	N
TV53D	*Brevibacillus choshinensis*	Çakırbey/Van	Taraxacum	H	H	N

Note: Bacterial strains were chosen due to their different traits and isolated host plants. The common trait of them is ACC deaminase enzyme activity since this enzyme is particularly has a major role in stress management due to restriction of ethylene synthesis during stress. N-fix = Nitrogen fixation ability, P-sol = Phosphate solubilizing capacity, ACC-D = ACC deaminase enzyme activity, H = High, N = Normal, L = Low.

no synthetic or biological fertilizer was applied to these pots. The study was laid out in a completely randomized factorial design with three replications.

Field soil, which was collected from the agricultural production area of Siirt University, was sieved and homogenized soil was placed in the autoclave for sterilization at 121°C for 20 minutes. The 18 × 18 cm of pots were used in the experiment. The 5.5 kg of dry sieved soil was placed in each pot and 100% field capacity was adjusted by the method of Amiri et al. (2017). After determining the volume of required water for 100% field capacity, the required water amount was calculated for 25%, 50%, and 80% moisture levels. All pots were adjusted to 80% of field capacity at the beginning of the study since drought does not affect germination and emergence. The eight homogeneous wheat seeds were sown per pot. After 7 days, four homogeneous seedlings were chosen for cultivation and the rest of them were ripped out. Irrigation was done at determined levels weekly and the experiment was concluded 8 weeks after thinning.

Investigated Agronomic Traits of Wheat Plants under Different Irrigation Levels

Differences between plant height (PH), shoot fresh weight (SFW), shoot dry weight (SDW), root length (RL), root fresh weight (SFW), and shoot dry weight (RDW) depending on fertilizers and irrigation levels were investigated in the study. The harvested plants at the end of the 8 weeks were carefully cut from the junction of shoot and root and then weighted separately to determine fresh weights. The PH and RL were measured by a manual meter. Plant materials were placed into the oven at 70°C and dried up to there was no change among the last two dry weights. The SDW and RDW were calculated by a precision scale. Total dry matter (TDM)-induced stress tolerance index (STI) was calculated by the methods of Fernandez (1992).

Statistical Analysis

Data were calculated by analysis of variance in the JMP (5.0.1) software according to the completely randomized design. The results were grouped by the least significant difference (LSD) test. According to multiple comparisons, significant differences were determined between all treatments.

Results

The study was carried out to understand how bacterial strains involving ACC deaminase activity, N-fixation, and P solubilizing ability exhibit performance under different nutrient and drought levels. Two wheat cultivars involving different agronomic traits and drought stress tolerance were used in the experiment to observe the effectiveness of action mechanisms of PGPR-priming. Moreover, this study investigated the effectiveness of synthetic and biological fertilizer under optimum and drought conditions. Plant growth sharply decreased with drought stress in both Bezostaja-1 and Gerek79. The highest growth parameters were obtained from 100% SF under optimum water availability, while the effectiveness of bio-priming with PGPB including ACC deaminase, N-fixation, and P-solubilizing abilities on seedling growth increased drought conditions, thereby growth scenario based on fertilizer method changed (Table 2). It was observed that PGPB-priming enhanced the STI in both cultivars while synthetic fertilizer caused low STI (Figure 1).

Cultivars, fertilizers, drought level, and their double and triple interactions significantly affected all investigated parameters except for the RDW. Only fertilizer applications did not cause any statistically significant difference in the RDW. According to the results, all treatments led to statistically significant differences (<.01) on cultivars under different irrigating conditions (Table 2). In general, Gerek79 exhibited higher growth indices particularly above-ground organs compared with the Bezostaja-1 under both stress and non-stress conditions. While all parameters except for the RL decreased with increasing drought stress, the RL increased depending on drought level. Although the 100% SF caused the highest promoting effect on seedling growth under optimum water availability, IL1 inhibited the stimulative effect of SF and restricted seedling growth. In contrast, biological fertilizer showed higher performance compared to synthetic fertilizer under drought conditions. Out of microbial strains, TV24C had superior performance than the other microbial inoculants, 50% SF, and control treatments under optimum water availability. Moreover, its promotive and protective effects were the highest under strong stress conditions. Even though TV126C, which was isolated from the rhizosphere of wild *Triticum aestivum*, exhibited relatively hopeful performance under stress conditions, TV53D was ineffective in terms of growth indices.

Total dry matter (shoot dry weight + root dry weight) significantly changed depending on treatments under stress and non-stress conditions. Changes in dry matter accumulation among optimum and water stress conditions were schematized in Figure 1. Increase of dry matter accumulation as control plants varied between 17.1% and 57.1% under 80% of the FC while it changed between 0.2% and 35.1% under drought conditions. Diagrams also denote that synthetic fertilizer exhibited lower performance than biological fertilizer in terms of dry matter accumulation under both stress and non-stress conditions, Moreover, although synthetic fertilizer promoted plant growth under optimum water conditions, it is not effective on dry matter accumulation compared with bio-fertilizer.

Discussion

Drought stress adversely affects the physiological, biochemical, and molecular processes in plants; therefore, plant growth, development, crop yield, and quality were restricted due to various

Table 2.
Analysis of Variance and Results Belonging to Cultivars under Different Treatments and irrigation Levels

Cultivar	Fertilizer	IL	PH	SFW	SDW	RFW	RDW	RL
Bezostaja-1	TV126C	25% FC	39.37^{j-l}	3.86^{mn}	0.580^{st}	0.354^{f}	0.060^{j-m}	8.2^{b-d}
		50% FC	39.40^{j-l}	3.93^{l-n}	0.640^{qr}	0.353^{f}	0.064^{f-h}	7.9^{e-i}
		80% FC	40.67^{i}	4.07^{k-m}	0.768^{j-m}	0.390^{c-e}	0.069^{c-d}	7.6^{k-m}
	TV24C	25% FC	47.97^{e}	4.52^{fg}	0.796^{hi}	0.398^{d}	0.058^{m-o}	8.2^{bc}
		50% FC	49.37^{cd}	5.71^{ab}	0.831^{g}	0.402^{c}	0.064^{g-i}	8.0^{b-h}
		80% FC	49.43^{cd}	5.72^{ab}	0.874^{f}	0.403^{c}	0.069^{c-e}	7.9^{f-j}
	TV53D	25% FC	48.30^{e}	4.77^{e}	0.778^{ei-l}	0.433^{ab}	0.067^{ef}	8.8^{a}
		50% FC	48.43^{e}	4.79^{e}	0.821^{gh}	0.446^{a}	0.068^{c-e}	8.2^{b}
		80% FC	49.63^{c}	5.57^{bc}	0.882^{ef}	0.443^{a}	0.072^{b}	8.0^{b-g}
	50% SF	25% FC	37.53^{m}	3.47^{o}	0.590^{s}	0.220^{q}	0.054^{q-s}	7.5^{mn}
		50% FC	40.03^{ij}	4.11^{j-l}	0.689^{p}	0.233^{pq}	0.055^{p-r}	7.4^{mn}
		80% FC	42.17^{h}	4.28^{g-k}	0.753^{lm}	0.285^{mn}	0.061^{j-l}	7.3^{no}
	100% SF	25% FC	39.23^{kl}	4.07^{k-m}	0.671^{qp}	0.289^{l-n}	0.047^{u}	7.5^{l-n}
		50% FC	48.10^{e}	4.06^{k-m}	0.700^{p}	0.321^{gh}	0.051^{s-t}	6.8^{p}
		80% FC	50.90^{ab}	5.85^{a}	0.827^{g}	0.243^{op}	0.053^{r-t}	7.0^{p}
	Control	25% FC	36.60^{n}	3.09^{p}	0.575^{st}	0.301^{i-m}	0.057^{n-p}	8.7^{a}
		50% FC	38.90^{l}	3.74^{n}	0.629^{r}	0.303^{i-l}	0.061^{i-k}	7.9^{f-j}
		80% FC	40.40^{i}	3.94^{l-n}	0.751^{mn}	0.310^{h-j}	0.061^{jk}	7.7^{i-m}
Mean			43.75^{B}	4.42^{B}	0.733^{B}	0.340^{A}	0.0606	7.9^{A}
Gerek-79	TV126C	25% FC	43.37^{g}	4.40^{f-i}	0.777^{i-m}	0.308^{h-k}	0.059^{k-n}	7.9^{e-i}
		50% FC	45.80^{f}	4.38^{f-i}	0.780^{i-k}	0.310^{h-j}	0.060^{j-n}	7.8^{g-k}
		80% FC	49.30^{cd}	4.38^{f-i}	0.892^{ef}	0.318^{hi}	0.067^{de}	7.6^{j-m}
	TV24C	25% FC	48.27^{e}	4.26^{h-k}	0.784^{ij}	0.290^{k-a}	0.065^{fg}	8.1^{b-e}
		50% FC	49.23^{cd}	4.47^{f-i}	0.977^{c}	0.315^{h-j}	0.069^{c-e}	8.0^{b-h}
		80% FC	50.67^{b}	5.57^{bc}	1.056^{b}	0.384^{de}	0.071^{bc}	7.9^{d-h}
	TV53D	25% FC	48.75^{de}	4.60^{ef}	0.904^{e}	0.312^{h-j}	0.070^{bc}	9.0^{a}
		50% FC	49.43^{cd}	5.41^{cd}	0.935^{d}	0.338^{fg}	0.075^{a}	8.0^{b-h}
		80% FC	50.70^{b}	5.26^{d}	1.088^{a}	0.354^{f}	0.077^{a}	8.0^{b-h}
	50% SF	25% FC	39.90^{i-k}	4.08^{km}	0.698^{p}	0.280^{n}	0.044^{v}	8.2^{b}
		50% FC	41.77^{h}	4.23^{i-k}	0.758^{k-m}	0.286^{l-n}	0.045^{uv}	7.9^{d-h}
		80% FC	46.43^{f}	5.19^{d}	0.883^{ef}	0.298^{j-m}	0.047^{uv}	7.8^{h-l}
	100% SF	25% FC	43.33^{g}	4.49^{f-h}	0.703^{op}	0.374^{e}	0.046^{uv}	7.9^{f-j}
		50% FC	43.97^{g}	4.78^{e}	0.824^{g}	0.387^{c-e}	0.051^{t}	7.5^{mn}
		80% FC	51.63^{a}	5.55^{bc}	0.973^{c}	0.421^{b}	0.056^{o-q}	7.1^{op}
	Control	25% FC	38.77^{l}	3.88^{l-n}	0.562^{t}	0.228^{pq}	0.058^{l-o}	8.1^{b-f}
		50% FC	40.00^{i-k}	4.10^{j-m}	0.658^{q}	0.232^{pq}	0.062^{h-j}	7.7^{h-l}
		80% FC	43.80^{g}	4.34^{f-j}	0.727^{no}	0.254^{o}	0.067^{ef}	7.5^{mn}
Mean			$45,84^{A}$	4.63^{A}	0.832^{A}	0.316^{B}	0.0605	7.806^{B}
Mean of cultivars			44,79	4.53	0.783	0.328	0.606	7.848
CV%			1.08	3.34	1.99	3.27	2.56	1.99
LSD	Cultivar$_x$fertilizer$_x$irrigation		0.79^{**}	0.25^{**}	0.025^{**}	0.017^{**}	0.003^{**}	0.250^{**}
	Cultivar$_x$fertilizer		0.46^{**}	0.14^{**}	0.015^{**}	0.010^{**}	0.0015^{**}	0.147^{**}
	Cultivar$_x$irrigation		0.32^{**}	0.10^{**}	0.010^{**}	0.007^{**}	0.0010^{**}	0.104^{**}
	Fertilizer$_x$irrigation		0.59^{**}	0.17^{**}	0.018^{**}	0.012^{**}	0.0018^{**}	0.558^{**}
	Cultivar		0.19^{**}	0.06^{**}	0.006^{**}	0.004^{**}	0.0006^{**}	0.061^{**}
	Fertilizer		0.32^{**}	0.10^{**}	0.010^{**}	0.007^{**}	0.0010ns	0.104^{**}
	Irrigation		0.23^{**}	0.07^{**}	0.007**	0.005^{**}	0.0007^{**}	0.074^{**}

Note: IL = Irrigation level, PH = Plant height, SFW = Shoot fresh weight, SDW = Shoot dry weight, RFW = Root fresh weight, RDW = Root dry weight, RL = Root length, SF = Synthetic fertilizer, FC = Field capacity, **<.01, ns = no significant difference.

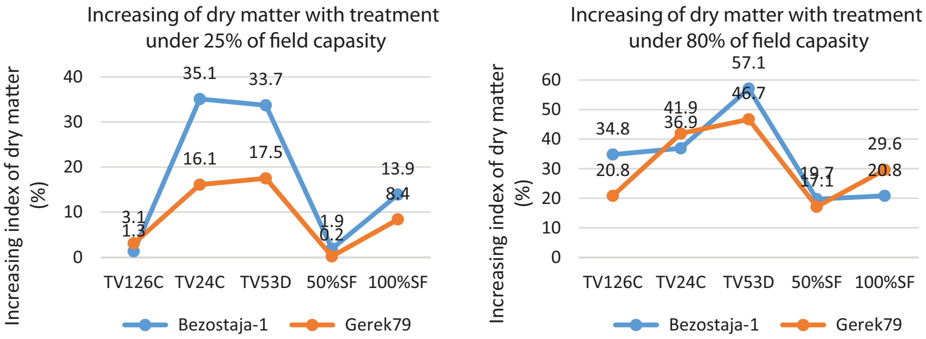

Figure 1.
Effectiveness of Fertilizers under 25% and 80% of Field Capacity. In General, Bezostaja-1 Variety was More Affected with Treatments, Particularly Bio-Fertilizers. This is an Important Indicator of the Pivotal Role of Bacteria–Genotype Interactions. Although PGPB-priming Induced Stress Tolerance of Both Cultivars, the Resistance Resistance of Sensitive Cultivars More Increased than Tolerant One.

destructive events such as osmotic stress, damaged photosystem, ion homeostasis, and inhibition of K$^+$ transportation, etc. Moreover, synthetic fertilization loses its effectiveness if there is not enough water in the environment and cannot support the plant on stress resistance (Emery et al., 2020). Thus, PGPB-priming that provides direct and indirect advantages to plants is a sustainable and low-cost strategy as bio-fertilizer and bio-protectant. This study is a pivotal step to observe the effectiveness of our original strains on mitigation of drought stress in wheat plants.

Plant growth achieved top performance with synthetic fertilizer in 80% of field capacity. However, increasing drought stress restricted the efficiency of synthetic fertilizer and seedling growth. Although there are some differences among cultivars, the scenarios were similar for drought-tolerant and sensitive cultivars. The main reason for this situation is considered to be caused by low water availability that can change nutrient uptake by disrupting the kinetics of nutrient uptake mechanisms by roots (Bista et al., 2020). Besides, many researchers have stated that drought decreases the rate of water and nutrient uptake per unit root, thereby superior traits of strains such as N-fixation, P-solubilizing, phytohormone secreting, and siderophore production increase nutrient availability in the rhizosphere and promote root system (Richardson et al., 2009). He et al. (2021) stated that PGPB strains improve drought tolerance of ryegrass by enhancing the antioxidant defense system and regulating abscisic acid signal. Also, the different researchers stated that PGPB stimulates the number and length of lateral roots (Chamam et al., 2013) and promotes root elongation (Contesto et al., 2008), therefore, it induces water and nutrient uptake and increases plant growth. Vacheron et al. (2013) indicated that root-bacteria interaction has a complex mechanism based on molecular and gene-induced factors; therefore, PGPB applications lead to improve root system architecture and help plants under different adverse conditions.

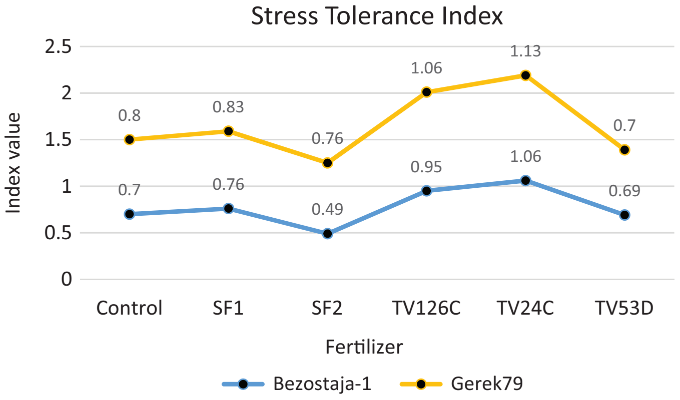

Figure 2.
Diagram of Stress Tolerance Index (STI) Belongs to Gerek79 (Drought-Tolerant) and Bezostaja (Drought-Sensitive) Cultivars with Different Fertilization Treatments. It is Clear that PGPB-priming Induced the STI in Both Cultivars depending on Bacterial Strain. The Effectiveness of Synthetic Fertilization Does Not Nnly Decrease under Stress Conditions. It Even also Inhibited Seedling Growth and Mitigated the STI with Water Deficiency. The Bacterial Strains were Isolated from Different Wild Species. Thus, It Is Considered That There is a Major Relationship Between the Host–Plant of Isolate and Inoculated plant. This Diagram also Indicates That Using Drought-Tolerant Cultivars is Not Only Enough for Stress Management, PGPB Applications Also Contribute to Stress Tolerance Mechanisms and Stimulate Plant Growth and Crop Yield.

The results of Rashid et al. (2021) supported our findings, in which *Bacillus megaterium* isolated from semi-arid region induced germination index (11–46%), seedling vigor index (11–151%), and fresh and dry weight (35–192% and 58–226%) under optimum irrigation and drought conditions. Moreover, they indicated that PGPB inoculation induced the STI in wheat plants by increasing 59% relative water content, 260% chlorophyll a, 70% chlorophyll b, 174% carotenoid, 136% protein content, 117% proline content and decreasing 57% Malondialdehyde (MDA) content. These findings support our results as seen in Figure 2. According to Fig 2, PGPB increased the STI in both tolerant and sensitive wheat plants.

The STI is a major indicator in stress management. Gerek79 has a higher drought tolerance compared with Bezostaja-1 under control and treatment conditions (Figure 2). A stunning information was determined that synthetic fertilizer caused decreasing in the STI while biological fertilizer depending on used bacterial strain enhanced the STI under drought stress conditions. Another significant information obtained from the results was that drought-tolerant variety was more positively affected by PGPB inoculation compared with drought-sensitive cultivar. The major mechanisms of PGPB are ACC deaminase and exopolysaccharides (EPS) activity. While ACC deaminase activity restricts the ethylene synthesis via converting the ACC into ammonia and α-ketobutyrate, EPS is effective in bioremediation, biofilm formation, surface attachment of bacteria, microbial aggregation, protection against stresses, and improvement in plant–microbe interactions (Manca de Nadra et al., 1985). Ansari et al. (2021) determined that PGPB inoculation mitigates drought stress in wheat and increases root colonization due to biofilm development ability. On the other hand, drought stress reduces leaf sugar content, thereby altering physiological and biochemical processes because sugar protects the structure of macromolecules and membrane stability during extreme osmotic stress (Prado et al., 2000). Hoekstra et al. (2001) demonstrated that PGPB-accumulated soluble sugars provide drought tolerance since soluble sugars derivatives acted as an osmoprotectant under drought conditions. Thus, PGPB-priming provided advantages to both tolerant and sensitive cultivars under drought conditions. Various researchers demonstrated similar results on wheat (Khan & Bano, 2019), maize (Naseem & Bano, 2013), mung bean (Kumari et al., 2016), chickpea (Khan et al., 2019), and common bean (Steiner et al., 2020).

Conclusion

Drought stress has been affecting wheat cultivation directly and indirectly by restricting nutrient uptake. This study indicated that water deficiency decreased the effectiveness of synthetic fertilizers and therefore plant growth was restricted. However, PGPB-priming had a promotive effect under both optimum and particularly stress conditions. Moreover, biological fertilizer is a more sustainable, cost-effective, and eco-friendly strategy compared with synthetic fertilizer. After various optimization and stability analyses, developing different commercial formulations and spreading the use of PGPB can be effective stress management against increasing drought conditions.

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