**Comparing the Role of Mineral Fertilizer, Organic Fertilizer and Rhizobacteria as Bio-fertilizers in Increasing the Tolerance of Maize Plants (Zea mays L.) to Water Stress**

**Abstract :**

The research aimed to study the possibility of reducing the effect of water stress (1200, 800, 400 mbar) as Ѱ1, Ѱ2, Ѱ3, on yellow maize plants by using 8- rhizobacteria (B8) as biofertilizers (B8 Ѱ 1, B8 Ѱ 2, B8 Ѱ 3) and to compare it with mineral (M Ѱ 1, M Ѱ 2, M Ѱ 3) and organic fertilizers (O Ѱ 1, O Ѱ 2, O Ѱ 3).. The research was carried out during the year 2021-2022 in the village of Al-Hanadi in Latakia Governorate. Yellow corn, Ghouta 82, was planted in experimental plots according to a randomized complete block design with three replications

The results showed a decrease in the growth and production of yellow maize plants in all treatments with increasing water stress, accompanied by an increase in the leaf content of total phenolics, proline and peroxidase activity. The plants treated with the B8 biofertilizer maintained the best growth and production with significant differences compared to mineral, organic and control fertilization. At the highest level of water stress Ѱ3, B8 biofertilizer achieved a production of 6.35 tons/ha compared to (2.1, 3.5, 4.8 tons/ha) for mineral fertilization, organic fertilization and control, respectively, i.e. an increase of 32.3% over the control, 81.4% increase over organic fertilization and 202.4% increase over mineral fertilization.

Maize plants treated with B8 biofertilizer significantly outperformed the other treatments in leaf phenolics content and peroxidase activity at the applied water stress levels, and maintained a balanced proline content between 1.7-2.06 μg/g fresh weight and less than the control. The highest leaf phenolics content was 65.5 mg/100 g fresh weight and peroxidase activity was 0.321 μmol/g due to B8Ѱ3 treatment.

We conclude that B8 biofertilizers increased phenolic content and peroxidase enzyme activity in maize leaves and consequently stimulated systemic resistance and reduced the effect of water stress, which was positively reflected on plant growth and productivity. thus, the possibility of using rhizobacteria as effective B8 biofertilizers in stimulating the resistance of maize (Ghota 82) to water stress, stimulating growth and increasing production.

**Keywords:** Maize, productivity, biofertilizers, water stress, peroxidase, phenolics, proline, PGPR rhizobacteria.

**Introduction**

Yellow maize (Zea mays L.) is one of the most important strategic and economic crops in the world. It comes in the rank of third after wheat and rice, it is called king Crops. Yellow maize is used in human and animal nutrition, and has various uses in treatment and production of dyes. It is recently used as a biofuel as an alternative to automobile fuel. The importance of the crop has rapidly increased due to the increase in world population, the expansion of livestock projects, and the increasing demand it for biofuel production (Abdul-Hamed and Abood, 2021). Although the Green Revolution has dramatically increased food production over the past 50 years, drought and salinity threaten more than 50% of cultivated land. The 2003 continental-wide drought reduced overall productivity in Europe by 30% (Ciais *et al*., 2005), and the severe drought in 2012 reduced maize yields in the USA by 25% (Rosenzweig *et al*., 2014). Drought increases the demand for irrigation by up to 70% of global water consumption (Shiklomanov and Rodda, 2003). It is expected that by 2050, climate change alone will cause the demand for irrigation water to rise by 10% (Wada *et al*., 2013). The climate change observed in recent years plays a major role in increasing water stress on crops, leading to a decrease in crop productivity (Liu *et al*., 2017). Thus, simply increasing irrigation infrastructure will not be sufficient to combat drought, so various strategies have been used in the scientific and practical environment as alternatives to mitigate water stress and its negative effects to ensure production in agricultural systems, such as using microbial fertilizers made from plant growth-promoting rhizobacteria (PGPR)(Poudel *et al*., 2021), these microorganisms can provide protection to plants against water deficiency by maintaining moisture levels and providing better root growth and nutrient supply (Niu *et al*., 2018), and therefore biofertilizers could be one of the available solutions to address water stress conditions, The results of treating yellow maize with biofertilizers under the influence of water stress showed a significant increase in plant height from 92 cm to 97.44 cm, and leaf area from 334.47 cm2 to reach 398.19 cm2 (Castelo Sousa *et al*., 2023). The study showed an increase in plant productivity when applying biofertilizers under conditions of water stress, (at irrigation 100, 85, 65)% of the field capacity amounting to 11.42, 8.99, 5.22 tons/ha, respectively, compared to the control (Eliaspour *et al*., 2020a). Exposing yellow maize plants treated with a biofertilizer to severe water stress led to an increase in the leaf content of the peroxidase enzyme by (92.47)%, and the content of phenolics by 57.59% compared to the control indicating the role of biofertilizers in increasing the drought tolerance (Begum *et al*. , 2019). The agricultural sector is one of the most important sectors that make up the national income in Syria. It is responsible for meeting the population’s food needs and providing raw materials for most food and manufacturing industries. Since water resources are among the most important main factors determining agricultural production, this justifies the necessity of searching for appropriate means that help the plant withstand water stress in order to exploit the largest possible area under conditions of water scarcity. Therefore, the research aimed to study the effect of types mineral fertilizer, organic fertilizer and rhizobacteria as biofertilizers on some growth characteristics, and productivity of yellow maize plant grown under water stress.

**Research materials and methods:**

**Plant material, study site, cultivation method and service operations**

The research was carried out during the 2021-2022 agricultural season in the town of Al-Hanadi in Latakia Governorate, and in the laboratories of the Faculty of Agricultural Engineering at Tishreen University in Syria. Yellow maize grains, Ghouta 82, obtained from the Center for Scientific Agricultural Research in Damascus. The land was prepared with deep plowing and surface plowing with leveling the soil surface. It was divided into experimental plots with dimensions of (1.25\*3.5) m2, with a plant density rate of 5.71 plants/m2. Planting was done in lines with a distance of 70 cm between the lines and 25 cm between the plants within the line. The seeds were planted in the upper third of the planting line at a depth of 5 cm. The well-known agricultural service operations of patching, hoeing and pest control were carried out according to the common and followed scientific methods.

**preparation of biofertilizer**

Eight isolates of plant growth-promoting rhizobacteria (*Azotobacter chroococcum (AC), Azospirillum.spp, Bacillus megaterium, Pseudomonas fluorescens, Frateuria aurantia, Bacillus circulans, Rhizobium leguminosarum, Rhizobium phaseoli*) were used in preparing the biofertilizer, isolated , characterized and preserved in the Soil and Water Sciences Research Laboratory (Al-Maghrabi *et al*., 2015 ; Hammad and Al-Shami, 2017; Hammad, 2020).. The bacterial isolates were activated by re-culturing them on specialized media to obtain new fresh and active cells. A bacterial suspension was prepared from each isolate using Tryptic Soy Broth (TSB) prepared in eight BIOGEN special development units with a capacity of 2 L allows for stirring of the medium, incubated at a temperature of 28°C. For 48-72 hours, the bacterial density in the suspension was set at 910 cells/ml using a Burker counting slide. Prepare biofertilizer B8 by mixing equally the suspension of the eight isolates.

-**Irrigation scheduling and determining water stress level**:

Soil samples were taken at a depth of 30 cm using cylinders to determine the gravimetric moisture and were converted to volumetric moisture. The moisture tension curve (water stress) was determined using a diaphragm pressure device, then the moisture measuring device (LUTRON-PMS-714) was calibrated based on different levels of Volumetric humidity (Figure 1).

Figure1. The graph of the volumetric humidity curve according to the device reading.

The quantities of irrigation water needed for each experimental plot were determined according to the levels of moisture stress required and maintained by adopting the surface irrigation method using irrigation with flexible pipes connected to a pump mounted on a tank and equipped with a meter to measure the amounts of water added to each experimental plot. Equal amounts of irrigation water were added upon planting until reaching field capacity to ensure germination, after that, we applied three levels of moisture tension (400=Ѱ1, 800=Ѱ2, 1200=Ѱ3) millibars on four treatments with three replicates are as follows:

1- Control (C) without fertilizer additives (1CѰ, CѰ2, CѰ3)

2- Mineral fertilizer (M): Add 12 kg/dun of nitrogen fertilizer (N) in the form of urea 46%, 17 kg/dun of phosphorus (P) in the form of triple superphosphate 46%, 18 kg/dun of potassium in the form of potassium sulfate 50%. , (1MѰ, MѰ2, MѰ3)

3- Organic fertilizer (O): Add 3 m3/dun of fermented local fertilizer, (1OѰ, OѰ2, OѰ3)

4- Bio-Fertilizer B8): Yellow maize grains were primed with bio-fertilizer B8 (bacterial suspension 109 cells/ml), by priming for 3 hours, and left in the shade until the excess moisture dried before planting, (B8Ѱ1, B8Ѱ2, B8Ѱ3).

**Collected data**

During vegetative growth stage, plant height was measured and leaf area were determined according to (El-sahookie, 1985), At harvest, productivity was calculated.

Biochemical analysis

Peroxidase activity was estimated according to Behera *et al*., 2012). Total phenolic compounds was determined using the Folin-Ciocalto reagent method (Singleton and Rossi, 1965), and proline was estimated according to Bates *et al*. (1973).

**Research design and statistical analysis**

The research included 12 treatments, with three replicates for each treatment and 16 plants for each replicate, distributed according to a complete random block system. The data was tabulated using the Excel application, and statistically analyzed using the Genstat-12 program, the One-way ANOVA test (without Blocking), and comparing the differences between the means. Using Duncan's test at 5% probability level.

**Results and discussion:**

**1 The effect of biofertilizers and different levels of water stress on some growth and productivity traits:**

The results of the analysis in the Table (1) indicate that there are significant differences between the averages in plant height. The B8 biofertilizer achieved an increase in the average plant height in treatment B8Ѱ1, amounting to 173 cm, compared to the control (CѰ1) of 142.9 cm at the same level of water stress. It was observed in the mineral fertilization treatment (M) that the plant height increased under optimal irrigation conditions (Ѱ1), where the MѰ1 treatment gave an average of (182 cm), while the plant height decreased with increasing water stress level, where the MѰ3 treatment gave the lowest average plant height (71.1 cm), compared to with all transactions.

The results of the analysis of variance are shown in the Table (1) that the B8 biofertilizer achieved an increase in leaf surface area with significant differences compared to the control, as treatment B8 achieved the highest average leaf surface area (5084, 4683, 4301) cm2 per plant at water stress levels (Ѱ1, Ѱ2.Ѱ3) respectively. A positive effect was also observed for both organic fertilizer O and mineral fertilizer M at the level of moisture stress Ѱ1 (optimal irrigation conditions) on the leaf area of the plant. The treatments OѰ1 and MѰ1 gave an average area of the leaf surface of the plant (4897, 4702) cm2, respectively, compared to the control treatment CѰ1 (4420) cm2.

The results of Table (1) show that increasing water stress reduced plant productivity, as the control treatment at (CѰ1, CѰ2, CѰ3) gave an average productivity of (6.35, 5.8, 4.8) tons/ha, respectively, while the mineral fertilization treatment MѰ3 gave less an average productivity of (2.1) tons/ha, and the OѰ3 organic fertilization treatment gave an average productivity of (4.5) tons/ha, with a significant difference from the OѰ3 treatment. Table (1) also shows the role of the biofertilizer in reducing the effect of water stress, as it gave the average productivity in the two treatments B8Ѱ2 and B8Ѱ3 (6.4, 6.35), respectively, with an increase of (15.34, 9.5)% compared to the control treatments CѰ2 and CѰ3, respectively. When moisture was available, the average productivity in the mineral fertilization treatment MѰ1 reached (7.6) tons/ha, with a significant difference from the organic fertilization treatment OѰ1, which gave an average productivity of (6.71) tons/ha.

**Table 1. Effect of mineral fertilizer, organic fertilizer and rhizobacteria as biofertilizer on morphological characteristics and productivity of maize plant grown under water stress**

|  |  |  |  |
| --- | --- | --- | --- |
| Treatments | Plant height(cm) | Surface area of leaf (cm2) | Productivity (tons/ha) |
| C Ѱ 1 | 142.9 f | 4420e | 6.35c |
| C Ѱ 2 | 122.5i | 4210h | 5.80e |
| C Ѱ 3 | **90.8j** | **3252k** | **4.80f** |
| M Ѱ 1 | 182.0a | 4702 c | 7.90 a |
| M Ѱ 2 | 125.9h | 4065i | 6.05d |
| M Ѱ 3 | **071.1k** | **1991l** | **2.10h** |
| O Ѱ 1 | 177.3 b | 4897 b | 6.71b |
| O Ѱ 2 | 150.0e | 4323f | 6.30c |
| O Ѱ 3 | **122.5i** | **4019j** | **3.50g** |
| B8 Ѱ 1 | 173.0c | 5084a | 6.62b |
| B8 Ѱ 2 | 168.0d | 4683d | 6.40c |
| B8 Ѱ 3 | **135.4g** | **4301g** | **6.35c** |
| LSD0.05 | 1.075 | 1.685 | 0.129 |

**Values followed by the same letters in the same column are not significantly different at P=0.05 according to Duncan’s multiple range test.**

The decrease in plant height with a decrease in water content in the soil is attributed to the acceleration of physiological processes, which contributes to early flowering, to complete its life cycle before being exposed to more effective water stress, which leads to a decrease in the number of days from planting until male and female flowering, which is the period during which the stem elongates ( Abdulameer and Ahmed, 2019). The decrease in leaf surface is explained by water stress reduces the rate of photosynthesis indirectly by closing the stomata or directly by reducing the ability and efficiency of photosynthesis of leaves, through reducing the leaf area, which is one of the mechanisms that the plant resorts to confront water stress to reduce the loss of leaves. Water is extracted from plants through transpiration (Prasad *et al*., 2008). This is accompanied by a decrease in productivity when exposed to water stress due to the imbalance between the formation of male and female inflorescences during the flowering period and the failure of the fertilization process as a result of the pollen losing its vitality (Parvaneh *et al*., 2014). Water stress can lead to the formation of small, atrophied, and wrinkled seeds due to accelerated maturation and shortened seed filling time, as drought shortens growth stages, forcing plants to complete their life cycle and form seeds within a shorter period of time (Sehgal *et al*., 2018). In addition to the effect of water stress in reducing the absorption of water and nutrients, which play an important role in growth and production processes (Al-Salmani and Al-Aqidi, 2015).

We note from Table (1) that the use of biofertilizers led to reduc the effect of water stress on the plant through its mechanisms of action in increasing the processing of biologically fixed nitrogen and thus increasing the soil content of available nitrogen and then stimulating the roots to absorb it (Abd El-Fattah *et al* ., 2013,) Nitrogen that is biologically fixed by bacterial species is available in the form of ammonium, and is directly assimilated by the plant after it is absorbed without expending vital energy, It can be used in other vital fields that help the plants resist drought (Taj Al-Deen and AL-Barakat, 2017), In addition to the role of the biofertilizer in securing the elements phosphorus and potassium and increasing the readiness of some nutrients such as Fe and Mn through the production of siderophores by bacteria. It contributes to meeting part of the plant’s growth needs, which is reflected in the process of photosynthesis and increased cell division by the bacteria secreting plant growth hormones such as indole acetic acid and gibberellic acid, which are among the most important mechanisms of their action, increasing cell division and elongation and thus increasing the height and area of the plant leaves, and this is in line with what he indicated. (Yasmin *et al*., 2017). It is believed that changes in the content of growth hormones during seed development and grain filling encourage increased nutrient polarization and thus increase the rate of grain filling (Kong *et al*., 2015), In addition to the role of hormones in increasing cell division and proliferation in the cob, thus increasing the diameter of the cob, which is reflected in the increasing the number of rows with cobwebs and thus increasing productivity (Ehteshami *et al*., 2007). In addition to the role of the biofertilizer in increasing the efficiency of water use by improving the physical properties of the soil, including improving the porosity of the soil on the one hand, and its contribution to increasing the root system and then the efficiency of the amount of water absorbed on the other hand, this result is consistent with Taj Al-Deen and AL- Barakat, (2017).

The reason for the increased productivity of mineral and organic fertilizers at low water stress, may be attributed to the role of nutrients (NPK) in increasing cell growth and division, regularization of the process of photosynthesis, and increased accumulation of dry matter in the plant (Wuhaib *et al*., 2009). The positive effect of mineral fertilizer and its superiority over organic fertilizer in increasing productivity is due to the fact that mineral fertilizer prepares nutrients (NPK) for the plant faster and more than those prepared by organic fertilizer, whose preparation is slow and limited and may not be sufficient to secure the plant’s need for them until the end of the season (Al-Khafaji, 2012).

The sharp decline in growth and productivity in the MѰ3 mineral fertilization treatment could be due to the effect of osmotic stress resulting from drought stress, which causes an imbalance in the hormonal balance and in the enzymatic activity of the plant, metabolic processes and their products, which negatively affects the growth of the seedlings and its productivity. (Gowtham *et al*., 2022).

**The effect of biofertilizers on some indicators of stimulating resistance of yellow maize plants to water stress.**

The results of the Table (2) show an increase in the content of total phenolics in the leaves of yellow maize plants with an increase in the level of moisture tension in the B8 biofertilizer treatments, where the two control treatments, CѰ1 and CѰ2, gave an average of 33.1, 40.6 mg/100 g fresh weight, respectively. The highest average values of total phenolics content were achieved compared to the rest of the treatments, reaching (50.1, 56.6, 63.5) mg/100g fresh weight at water stress levels of Ѱ1, Ѱ2, and Ѱ3, respectively. The highest value was at the third level of moisture tension. While it was observed in the other treatments (mineral fertilization M, organic O and control C) a decrease in the content of total phenolics at the third level of moisture tension Ѱ3 after increasing at the second level Ѱ2 compared to the first level, as it reached (21.9, 38.4, 28.2) mg/100 g fresh weight. Table (2) indicates an increase in the activity of the peroxidase enzyme with an increase in the level of moisture tension, as it reached (0.086 µmol/mg) in treatment CѰ3, with a significant difference from treatment CѰ1 (0.053 µmol/mg). When comparing the effect of B8 biofertilizer with mineral M and organic O fertilization, it was observed that B8 biofertilizer was superior with significant differences over mineral and organic fertilization, and the highest value of peroxidase enzyme activity in the B8Ѱ3 treatment was 0.321 μmol/mg. The Table (2) shows an increase in the proline content of yellow maize plants leaves with an increase in the level of water stress, with significant differences between the treatments. The average proline content of leaves in the control treatment reached 1.71, 1.9, 2.14 micrograms/gram fresh weight at moisture stress levels (Ѱ1, Ѱ2, Ѱ3), respectively.

**Table 2. Effect of mineral fertilizer, organic fertilizer and rhizobacteria as biofertilizer on total phenolic content, peroxidase activity and proline in fresh leaf tissues of maize plant grown under water stress**

|  |  |  |  |
| --- | --- | --- | --- |
| Treatments | Total phenolic content (mg/100g wet weight) | Peroxidase activity fresh weight  (μmol/mg) | Proline  (µg/g wet weight) |
| C Ѱ 1 | j33.1 | l0.053 | g1.71 |
| C Ѱ 2 | 40.6f | 0.072k | 1.90f |
| **C Ѱ 3** | **28.2k** | **0.086j** | **2.14d** |
| M Ѱ 1 | i35.8 | h0.121 | f1.88 |
| M Ѱ 2 | 43.5e | 0.155e | 2.65b |
| **M Ѱ 3** | **21.9l** | **0.173d** | **3.04a** |
| O Ѱ 1 | g40.2 | i0.103 | f1.90 |
| O Ѱ 2 | 45.1d | 0.125g | 2.03e |
| **O Ѱ 3** | **38.4h** | **0.144f** | **2.32c** |
| B8 Ѱ 1 | c50.1 | c0.183 | g1.70 |
| B8 Ѱ 2 | 56.5b | 0.267b | 1.80fg |
| **B8 Ѱ 3** | **63.5a** | **0.321a** | **2.06de** |
| LSD0.05 | 0.168 | 0.001 | 0.098 |

**Values followed by the same letters in the same column are not significantly different at P=0.05 according to Duncan’s multiple range test.**

The biofertilizer had no effect on the proline content compared to the control. On the other hand, the amount of proline in the leaves increased, reaching an average of (1.7, 1.8, 2.06) micrograms/gram wet weight in treatments B8Ѱ1, B8Ѱ2, and B8Ѱ3, respectively, compared to the control. The effects of water stress include chemical, molecular and physiological changes, including non-enzymatic oxidation compounds such as total phenolics, and enzymatic oxidation compounds such as the peroxidase enzyme. The values of these indicators increase with the increase in the level of water stress up to a certain limit.

This increase can be attributed to a natural reaction of the plant by activating protective mechanisms against stresses, as phenolic compounds play an important role in protecting the photosynthesis process from excessive radiation by absorbing short-wave, high-energy rays that are harmful to the cellular structures of the leaf (Hura *et al*., 2008). Phenolic compounds also help in scavenging free radicals (ROS) and protecting plants from the harmful effects of oxidative stress caused by drought (Akram *et al*., 2018), so water deficiency in leaf tissue can stimulate protective mechanisms involving the synthesis of phenolic compounds. This explains why increased synthesis of phenolic compounds during drought is an indicator of resistance to drought stress (Petridis *et al*., 2012), As for the biofertilizer treatment, the increase in the amount of total phenolics by increasing the level of water stress is attributed to the induction of systemic resistance within the plant by growth-stimulating bacteria. Many studies have shown that biofertilizers increase the amount of total phenolics within the plants treated with them, as the bacteria secrete hormones that encourage the plant to synthesis phenolic compounds (Chiappero *et al*., 2019; Ibrahim *et al*., 2020). We note from Table (2) a significant decrease in total phenolics in the control treatment (C) under the influence of high water stress (Ѱ3). The decrease in the total contents of total phenolics with increasing stress may be due to the deterioration of photosynthetic pigments under severe drought and insufficient phenolic compounds in reducing the damage of excess radiation and energy absorbed during the photosynthesis process, which leads to the breakdown of chlorophyll and phenolic while increasing the severity of drought (Hura *et al*., 2008).

The peroxidase enzyme is one of the redox enzymes that are widespread in plant cell walls. The increase in the peroxidase enzyme with an increase in the level of water stress may be due to the induction of genes responsible for producing this enzyme under the influence of water stress (Das and Roychoudhury, 2014).When applying the biofertilizer, PGPR bacteria play a role in suppressing oxidative stress by balancing the level of plant hormones and activating the antioxidant system. (Zhang *et al.,* 2020). PGPR bacteria can directly affect the hormonal balance of plants by generating exogenous plant hormones in addition to their ability to activate endogenous hormones in the plant. These hormones enhance and increase the activity of antioxidant enzymes, including peroxidase, and as a result, it is believed that changes in hormonal signals, PGPR, which is mediated by interactions between plants and bacteria, is a potential mechanism to make plants tolerant to water stress and oxidative stress ( Hariprasad *et al*., 2021 ). The accumulation of amino acids, especially proline, is one of the defensive means that the plant uses to cope with water deficiency (Sinay *et al*., 2015). The accumulation of amino acids in plant cells and tissues under the influence of water stress is due to the plant’s inability to biosynthesise proteins, and water stress stimulates protein hydrolysis enzymes and thus produces amino acids and proline acid. This is a physiological mechanism that the plant uses to protect its cells and prevent damage from free radicals of oxygen (ROS), in addition to the positive role of proline in regulating the osmotic pressure of plant cells, which increases its ability to withdraw water and nutrients, maintain cell elongation and open stomata, and continue plant growth under conditions of water stress.

The reason for the noticeable increase in proline concentration in the mineral and organic fertilization treatments at the third level of 1200 mbar is attributed to the plants’ response to the effect of water stress and salinity caused by drought, as the concentration of proline increases within the vacuoles of the cell cytoplasm under conditions of salinity and drought (Gowtham *et al*., 2022). In contrast, (Eliaspour *et al*., 2020b) explained that the use of biofertilizers under conditions of water stress leads to a decrease in the amount of proline in the leaves, which indicates the positive effect of microorganisms in alleviating the negative effects of water stress on the plant. This was explained by directing the absorbed nitrogen to form chlorophyll and form proteins instead of forming proline, thus improving plant nutrition and its ability to resist drought stress.

**CONCLUSION**

We conclude from the above that when there is a scarcity of water and water stress occurs, chemical and organic fertilization is an unacceptable risk (Liu *et al*., 2015), as a lack of water with fertilizers can cause burns on the leaves and damage the plant (Susan, 2023). ). Therefore, biofertilizers containing plant growth-promoting rhizobacteria (PGPR) can provide maize plants with the necessary nutrients for cellular metabolism and continued plant growth without any risks under water stress (drought) conditions (Koliai *et al*., 2012), as well as the using of fertilizers. Bio-fertilizers reduce the amount of chemical and organic fertilizers and thus save the price of these fertilizers, because the prices of bio-fertilizers are lower compared to the prices of other fertilizers (Lateifa, 2012), it can be suggested to grow yellow maize plants while rationalizing a greater amount of irrigation water, or to plant in drier areas, by using biofertilizers containing plant growth-promoting rhizobacteria (PGPR) as stimulants for systemic resistance and increase the plant’s tolerance to water stress.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**ETHICAL APPROVAL**

It is not applicable

**COMPETING INTERESTS**

Authors have declared that no competing interests exist.

**References**

**Abd El-Fattah, D. A., W. E. Eweda, M. S. Zayed and M. K. Hassan**. 2013. Effect of carrier materials, sterilization method, and storage temperature on survival and biological activities of *Azotobacter chroococcum* inoculant. Annal of Agriculture Science, 58(2):111– 118. DOI.org/10.1016/j.aoas.2013.07.001.

**Abdulameer, O. Q. and S. A. Ahmed.** 2019. Role of humic acid in improving growth characters of maize under water stress. The Iraqi Journal of Agricultural Sciences, 50(1): 420-430. DOI.org/10.36103/ijas.v50i1.308.

**Abdul-Hamed. Z. A. and N. M. Abood.** 2021. Combining ability and gene action in sunflower using cytoplasmic male sterility. Indian Journal of Ecology. 48 (15): 223-228. DOI:10.1088/1755-1315/779/1/012127.

**Akram, N. A., M. Iqbal, A. Muhammad, M. Ashraf, F. Al-Qurainy and S. Shafiq.** 2018**.** Aminolevulinic acid and nitric oxide regulate oxidative defense and secondary metabolisms in canola (*Brassica napus* L.) under drought stress. Protoplasma, 255: 163-174.

**Al-Khafaji, Raghad Qasim Kazem**. 2012. The effect of adding phosphate rock and organic matter on the ready phosphorus of wheat plants grown in gypsum soil. Master's thesis. College of Agriculture. Tikrit University. (*In Arabic*).

**Al-Maghribi, S., Y. Hammad and B. Rezk**. 2016. Effect of *Rhizobium leguminosarum* on growth of *Fusarium oxysporum* f.sp. lycopersici in vitro. Arab Journal of Plant Protection, 34(2): 135-141. (*In Arabic*). <http://www.asplantprotection.org/.>

**Al-Salmani, Hamid Khalaf and Hadeel Abdul Razzaq Al-Aqidi.** 2015. The effect of irrigation intervals and potassium levels on yield and some of its components of yellow maize plants. Al-Furat Journal of Agricultural Sciences, 7 (4):.294-301. (In Arabic)

**Bates, L. S., R. P. Waldren, and I. D. Tear.** 1973. Rapid determination of free proline for water-stress studies. Plant and Soil, 39: 205–207.

**Begum, N., M. A. Ahanger, Y. Su, Y. Lei, N. S. A. Mustafa. P. Ahmad. and L. Zhang.** 2019. Improved drought tolerance by AMF inoculation in maize (*Zea mays*) involves physiological and biochemical implications. Plants, 8(12): 1-20.‏ DOI:10.3390/plants8120579.

**Behera, B., S. Ghanty, F. Ahmad, S. Santra and S. Banerjee.** 2012. UV-visible spectrophotometric method development and validation of assay of paracetamol tablet formulation. Journal of analytical and bioanalytical techniques. Journal of Analytical and Bioanalytical Techniques, 3(6): 151-157. DOI:org/10.4172/2155-9872.1000151.

**Castelo Sousa, H., G. Gomes de Sousa, T. V. de Araújo Viana, A. Prudêncio de Araújo Pereira, C. I. Nojosa Lessa, M. V. Pires de Souza and F. Barbosa da Silva.** 2023. *Bacillus aryabhattai* Mitigates the Effects of Salt and Water Stress on theAgronomic Performance of Maize under an Agroecological System.Agriculture, 13(6): 1-20.  [DOI.org/10.3390/agriculture13061150](https://doi.org/10.3390/agriculture13061150).

**Chiappero, J., del Rosario Cappellari, L., Alderete, L. G. S., Palermo T. B. and E. Banchio.** (2019). Plant growth promoting rhizobacteria improve the antioxidant status in *Mentha piperita* grown under drought stress leading to an enhancement of plant growth and total phenolic content. Industrial Crops. Products*,* 139:111553. DOI: 10.1016/j.indcrop.2019.111553.

**Ciais, P., M. Reichstein, N. Viovy, A. Granier, J. Ogée, V. Allard, and R**. **Valentini.** 2005. Europe-wide reduction in primary productivity caused by the heat and drought in 2003. Nature, 437: 529-533.‏

**Das, K. and A. Roychoudhury**. 2014. Reactive oxygen species (ROS) and response of antioxidants as ROS-scavengers during environmental stress in plants. Front. Environ, Sci., 2(53):1-13. DOI.org/10.3389/fenvs.2014.00053.

**Ehteshami, S. M. R., M. Aghaalikhani, K. Khavazi, and M. R. Chaichi.** 2007. Effect of phosphate solubilizing microorganisms on quantitative and qualitative characteristics of maize (*Zea mays* L.) under water deficit stress. Pakistan Journal of Biological Sciences, 10(20): 3585-3591. DOI.org/10.3923/pjbs.2007.3585.3591.

**Eliaspour, S., R. Seyed Sharifi.and A Shirkhani..** 2020a. Effects of biofertilizers and iron nano-oxide on maize yield and physiological properties under optimal irrigation and drought stress conditions.Food Science and Nutrition, 8(11): 5985–5998. DOI: 10.1002/fsn3.1884.

**Eliaspour, S., Seyed Sharifi, R. and A. Shirkhani.** 2020b. Evaluation of interaction between *Piriformospora indica*, animal manure and NPK fertilizer on quantitative and qualitative yield and absorption of elements in sunflower. Food Science and Nutrition, *8*(6): 2789–2797. [DOI](https://doi). org/10 .1002/fsn3 .1571.

**El-Sahookie, M. M.** 1985.A short cut method for estimating plant leaf area in mayze. Journal Agronomy Crop Sciences. 15(4): 157-160.

**Gowtham, H. G., S. B. Singh, N. Shilpa, M. Aiyaz, K. Nataraj, A. C. Udayashankar, and R. Z**.**Sayyed.** 2022. Insight into recent progress and perspectives in the improvement of antioxidant machinery upon PGPR augmentation in plants under drought stress: a review. Antioxidants,11(9): 1-26. DOI: 10.3390/antiox11091763.

**Hammad, Y. 2020.** Isolation and identification of some species of plant growth promoting rhizobacteria (PGPR)from some bio-fertilizers. the arab journal of arid environment, 13(1): 23 – 31.

**Hammad, Y and R. Al-Shami**. 2017. Characterization of some types of rhizosphere bacteria that stimulate plant growth from some biofertilizers and soil. Al-Baath University Journal, 39:1-25. (*In: Arabic*).

**Hariprasad, P., Gowtham, H. G. and C**. **Gourav.** 2021. Beneficial plant-associated bacteria modulate host hormonal system enhancing plant resistance toward abiotic stress *in*: Biocontrol Agents and Secondary Metabolites. Ed. S. Jogaiah (Kidlington, UK: Woodhead Publishing), pp 113–151.

**Hura, T., K. Hura and S. Grzesiak.** 2008. Contents of total phenolics and ferulic acid, and pal activity during water potential changes in leaves of maize single-cross hybrids of different drought tolerance. Journal of Agronomy and Crop Science, 194(2): 104–112. DOI.org/10.1111/j.1439-037X.2008.00297.x

**Ibrahim, M.S., Y.A. Hammad and S. Raee.** 2020. The role of some bio-fertilizers and salicylic acid in phenolic content and peroxidase enzyme activity in pepper plants infected with cucumber mosaic virus. Arab Journal of Plant Protection, 38(4): 327-332. (*In Arabic*)] https://doi.org/10.22268/AJPP-38.4.327332

**Koliai, A. A., G. Akbari, G. Akbari, O. Armandpisheh and M. Tarighaleslami.** 2012**.** Effect of biological and chemical phosphorus fertilizers on yield components of maize (Zea mays L.) in different water stress conditions. [Annals of Biological Research](https://www.cabidigitallibrary.org/action/doSearch?do=Annals+of+Biological+Research), 3(8): 4204-4208. [scholarsresearchlibrary.com/ABR-vol3-iss8/ABR-2012-3-8-4204-4208.pdf](http://scholarsresearchlibrary.com/ABR-vol3-iss8/ABR-2012-3-8-4204-4208.pdf)

**Kong, L., H. Guo and M. Sun** .2015. Signal transduction during wheat grain development. Planta, 241: 789–801. DOI: 10.1007/s00425-015-2260-1.

**Lateifa S. Assefat**2012*.* Biofertilizer and its role in reducing water pollution problems with chemical fertilizers. Libyan Agriculture Research Center Journal international, 3(S2), 1457-1466.

**Liu, H., L. C., Carvalhais, M., Crawford, E., Singh, P. G., Dennis, C. M Pieterse and P. M. Schenk.** 2017. Inner plant values: diversity, colonization and benefits from endophytic bacteria. Frontiers in Microbiology. 8: 2552.DOI: 10.3389/fmicb.2017.02552.

**Liu, Z.X., P. Liu, X.C. Jia, Y. Cheng and S.T. Dong *et al*** ., 2015**.** [Effects of irrigation and fertilization on soil microbial properties in summer maize field]. Journal of Applied Ecology, 26: 113-121, (In Chinese).

**Niu, X. L. Song, Y. Xiao and W. Ge.** 2018. Drought-tolerant plant growth-promoting rhizobacteria associated with foxtail millet in a semi-arid agroecosystem and their potential in alleviating drought stress. Frontiers in microbiology, 8: 2580. DOI.org/10.3389/fmicb.2017.02580

**Parvaneh, V., N. Rahim, M. Meysam and J.** **Taiebeh.** 2014. Evaluation of qualitative and quantitative traits of maize (cv. 604) under drought stress and plant density. Journal of Stress Physiology and Biochemistry, 10(2): 144-154.‏

**Petridis, A., I. Therios, G. Samouris, S. Koundouras and A. Giannakoula**. 2012.Effect of water deficit on leaf phenolic composition, gas exchange, oxidative damage and antioxidant activity of four Greek olive (*Oleae uropaea* L.) cultivars. Plant Physiology and Biochemistry,60: 1-11. DOI.org/10.1016/j.plaphy.2012.07.014

**Poudel, M., R. Mendes, L. A. S. Costa, C. G. Bueno, Y. Meng, S.Y. Folimonova, K.A. Garrett and S. J. Martins.** 2021.The role of plantassociated bacteria, fungi, and viruses in drought stress mitigation. Frontiers in microbiology, 12: 1-21. [DOI.org/10.3389/fmicb.2021.743512](https://doi.org/10.3389/fmicb.2021.743512).

**Prasad, P. V. V., S. A. staggenborg and Z. Ristic.** 2008. Impacts of drought and/or heat stress on physiological, developmental, growth, and yield processes of crop plants. Response of crops to limited water:Understanding and modeling water stress effects on plant growth processes, 1: 301-355.‏DOI.org/10.2134/advagricsystmodel1.c11.

**Rosenzweig, C., J. Elliot, D. Deryng, A. C. Ruane, C. Müller, A. Arneth K. J. Boote, C. Folberth, M. Glotter, N. Khabarov, K. Neumann F. Piontek T. A. M. Pugh, E. Schmid, E. Stehfest, H. Yang and J. W. Jones.** 2014. Assessing agricultural risks of climate change in the twenty-first century in a gridded crop model intercomparison. Proceedings of the national academy of sciences, 111(9): 3268–3273.

**Sehgal, A., K. Sita, K. H. Siddique, R. Kumar, S. Bhogireddy, R. K. Varshney and H. Nayyar.** 2018. Drought or/and Heat-Stress Effects on Seed Filling in Food Crops: Impacts on Functional Biochemistry, Seed Yields, and Nutritional Quality. Quality. Front. Plant Science, 9: 1-19. DOI.org/10.3389/fpls.2018.01705

**Shiklomanov, I. A. and J. C Rodda.** 2003. World water resources at the beginning of the twenty-first century. Eds: Cambridge University Press. Cambridge, UK.‏ pp417.

**Sinay, H., E. L. Arumingtyas, N. Harijati and S. Indriyani**. 2015. Proline content and yield components of loca maize cultivars from kisar Island, Maluku, Indonesia. International Journal of Plant Biology, 6(1): 43-46. DOI.org/10.4081/pb.2015.6071

**Singleton, V. L. and J. A. Rossi**. 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. American Journal of Enology and Viticulture, 16: 144-58. DOI**:** 10.5344/ajev.1965.16.3.144

**Susan Jones.** [**Fertilizer Burn.**](https://web.archive.org/web/20210517190836/https:/www.aos.org/orchids/orchid-pests-diseases/fertilizer-burn.aspx) 2023. American Orchid Society. Registered 501(c)(3). EIN: 04-2161893.

**Taj AL-Deen, M. M. and H. N. K. AL-Barakat.** 2017. Effect of Biofertilizer and Humic, Fulvic Acid Application on Growth and Productivity maize Plant Zea mays L. Jornal of Al-Muthanna for Agricultural Sciences, 5(1): 1-12.

**Wada, Y., L. P. Van Beek, N. Wanders and M. F. Bierkens.** 2013. Human water consumption intensifies hydrological drought worldwide. Environmental Research Letters, 8(3): 1-14.‏DOI:10.1088/1748-9326/8/3/034036.

**Wuhaib, K. M., H. K. AL-haidary and K. A. Makyia**. 2009. Split application nitrogen for (*Zea Mays* L.) genotypes to get the best sink. Journal Tikrit University for Agriculture Science, 9(1):104-116.

**Yasmin, H., A. Nosheen, R. Naz, A. Bano and R. Keyani.** 2017. L-tryptophan-assisted PGPR- mediated induction of drought tolerance in maize (Zea mays L). Journal of Plant Interactions, 12(1): 567-578. DOI.org/10.1080/17429145.2017.1402212.

**Zhang, M., Yang, L., Hao, R., Bai, X., Wang, Y. and X**. **Yu.** 2020. Drought-tolerant plant growth-promoting rhizobacteria isolated from jujube (*Ziziphus jujuba*) and their potential to enhance drought tolerance. Plant Soil, 452: 423–440. DOI: 10.1007/s11104-20-04582-5.