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Assessing the Effects of Water Scarcity and Biofertilizer Application (*Pseudomonas putida*) on the Growth and Productivity of Different Eggplant (*Solanum melongena*) Genotypes in Northeastern Morocco

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ABSTRACT

Drought had affected the crops production in Morocco, during the last decade. Plants breeding is still a solution to increase crops tolerance for water scarcity. Using natural biofertilizer based on microorganisms still a good practice to enhance the resilience of agriculture to drought. The objective of this study is to investigate the effect of water shortage and use of a biofertilizer based on the strain of *Pseudomonas putida* on five genotypes of eggplants selected for drought tolerance under the semi-arid of the northeast of Morocco. Two irrigations regimes: 100% (amount of water irrigation made by growers) and 50% of this amount with and without the biofertilizer (1 × 108 UFC/g). The biofertilizer was applied three times during the plant growth stages. The experiment was conducted at commercial farm production and using a randomized complete block design. Plants were organized in blocks containing 3 plants for each genotype and repeated in 5 repetitions. Crops were planted on August 3rd, 2022, and experiments ended on January 2nd, 2023. The results showed different responses among the genotypes in terms of growth. The effect of Pseudomonas on plant height showed that there was a significant increase, at 100% irrigation for C14, B3, C8, B5 and C11 with 20%, 19%, 17%, 14.29% and 12,5%, respectively compared with the control. For C8 and B3, when subjected to 100% water with biofertilizer, there was an increase in the average number of fruits compared to 100% water without the biofertilizer. The highest yield was recorded with B5 under 100% irrigation + fertilizer (1.35 kg/plant). Water shortage impacted the productivity of all genotypes and the fruit number and yield increased with the use of the biofertilizer. Our study is still valuable under the conditions of this trial and more experiments will be needed at several seasons and at different growing conditions.

Keywords: biofertilizer, chlorophyll a fluorescence, microorganisms, physiology, relative water content, water shortage, yield.

INTRODUCTION

During the last decades, the climate has undergone changes, mainly due to warming caused by greenhouse gas emission, triggered by industrial and human activities (IPCC, 2013). Climate changes have significant impacts on agriculture, posing challenges to food security, productivity, and sustainability. As temperatures rise and precipitation patterns shift, agricultural systems face increased risks of crop failures, reduced yields, and soil degradation (Malhi, et al., 2021). Droughts exacerbate these effects by causing water scarcity, hindering growth (Hazrati et al., 2017). A reduction of up to

30% in global crop production by 2025 is possible because drought conditions affect an estimated 45% of the world's agricultural land (Abdelraheem et al., 2019; Per et al., 2017).

Many studies have proven that, under drought stress, many plants can effectively improve their adaptability to stress by adjusting their own material distribution pattern (Pandit et al., 2020). For instance, under drought, crops will preferentially accumulate the biomass of roots to improve the water absorption capacity and reduce the amount of dry matter in stems and leaves above ground to reduce transpiration and water loss, thus improving the overall adaptability of plants (Liu et al., 2004). Moreover, under water scarcity, many metabolic processes, including photosynthesis, are negatively affected; for example, water deficiency damages basic organization structure, which inhibits carbon assimilation and damages photosynthetic apparatus (Ali and Ashraf., 2011). For these reasons, the selection of plants tolerant to water deficit has become a high priority. Genetics and breeding aimed at enhancing crop resilience to abiotic stress, such as water scarcity, currently represent one of the primaries focuses of research in agriculture. Many strategies for the genetic improvement of crop stress tolerance were developed during the last decades (Nakashima et al., 2017). In addition, measurements of the chlorophyll fluorescence offer an appropriate means of assessing the crops' stress level and photosynthesis efficiency (Strasser et al., 2004; Kumar et al., 2020). Typically, chlorophyll fluorescence signifies the transfer of electrons from the light-induced excitation of chlorophyll to the dark-phase electron transfer that occurs during the light phase of photosynthesis. During the stress condition, specific indexes were used to indicate the stress level of plants. F_v/F_m provides an estimate of the maximum photochemical efficiency of PSII photochemistry (Baker, 2008). This ratio for leaves that are not stressed are extremely stable, averaging around 0.83 (Björkman and Demmig, 1987).

Most plants have various mechanisms to benefit from the association with microbial populations in the rhizosphere and enhance their tolerance for drought. Different strains Plant Growth Promoting Rhizobacteria (PGPR) are considered as stimulants of abiotic stress (Joshi et al., 2009). Biofertilization plays a crucial role in regulating the dynamics of nutrient uptake, enhancing soil fertility, and promoting plant growth and optimizing water use efficiency (Khalilpour et al., 2021). These beneficial bacteria can therefore influence the acquisition of nutrients and mitigate the negative impacts of abiotic stress such as water stress by enhancing leaf water status during challenging conditions (Irankhah et al., 2021; Ngumbi et al., 2016).

Previous studies showed that PGPR could help plants to extend the surface area of the root system and help to search for water in the soil (Vacheron et al., 2013). The use of PGPR inoculation in these extreme situations could help the plant to face, at least in part, this stress by increasing root length, which allows a better access to water (Cohen et al., 2015). More precisely, they increase the number and the size of secondary roots (Chamam et al., 2013). Microbial biofertilizers applied to seeds or soils increase the growth and yields of vegetable crops, including tomato, eggplant, and lettuce (Bernabeu et al., 2015; Seymen et al., 2013). During water scarcity, PGPR contributes to the reduction of water loss via production of ABA in plants, a key hormone in stomatal control (Dodd et al., 2010). Certain bacteria are therefore capable of modifying the capacities of photosynthetics (Rincon et al., 2008) but also to modulate the chlorophyll content during water stress (Heidari et al., 2012; Stefan et al., 2013). Significant variations were found by Ramya et al. (2015) in the plant's vegetative growth, plant height, total number of leaves, total chlorophyll concentration in leaves, and number of fruits and yield. Inoculation with the *Azospirillum* strain induces an increase in concentration of ABA and leads to a better water status during stress (Cohen et al., 2009), improved root development and increases the absorption of vital nutrients (Meena, et al., 2017). The most significant bacteria that add more minerals to the soil are *Azotobacter* spp. and *Pseudomonas* spp. These bacteria also produce substances that control growth and have an impact on plant development and yield (Hayat et al., 2010). Research into plant stress has shown that many *Pseudomonas* strains have been shown to be effective in alleviating a specific climate-related stress in plants (Antoine, 2023).

Eggplant (*Solanum melongena* L.), one of the significant solanaceous, found in tropical and subtropical areas, occupies an area of about 1.86 million ha of cultivation area (FAO, 2019; Toppino et al., 2020). Eggplant production worldwide is around 58 Mt, with China, India, and Egypt being the primary producers (FAO, 2021). In Morocco, the production was estimated around 81.044 tons from the total harvested area of 2.910 ha. In eggplant, water stress inhibits growth, reduces productivity and degrades the quality of the fruit (Fu et al., 2013). The aim of this study was to test the effects of the application of the biofertilizer (*Pseudomonas putida*) on physiological parameters and productivity of five eggplant genotypes cultivated under water stress conditions.

MATERIALS AND METHODS

Plant material and growth condition

Five genotypes of eggplant, including: C8, C11, and C14 were obtained from the collection at the Research Centre for Genomics and Bioinformatics, Montanaso, Italy (CREA) and B3 and B5 were selected from Bati Akdeniz Agricultural Research Institute, Antalya, Turkey (BATEM), were utilized in this study. Seeds were sowed in seed cell-multi-pots and were irrigated twice a day in accordance with the greenhouse's climate, on 21 June 2022. The seedlings were transplanted into the field on 03 August 2022.

Application of biofertilizer

The natural occurrence level of *Pseudomonas* in soil varies between 103 and 106 UFC12/g of soil according to the French National Agency for Food, Environmental and Occupational Health and Safety. Dosing ranges from 0.5 to 1.2 kg/ha, with each plant receiving 0.1 g of concentrate dissolved in 0.5 L of water for the prototype plants, while control plants receive only 0.5 l of water. The biofertilizer are applied every 15 days during the vegetative growth phase of the plants. Application involves carefully administering the product at the root level of each plant per block, with 5 repetitions per treatment for the five genotypes.

Irrigation treatments

It consists of two different water levels: control: 100% and 50% of irrigation. Control treatment was irrigated using a tape line system with 10 cm spacing between two drippers, while another tape line with identical characteristics to the control tape, but with 20 cm spacing between drippers, was utilized for 50%. Both treatments utilized the same dripper flow rate (1.5 l/h). The 100% irrigation treatment present the mode of irrigation used by the local growers and it depends on theirs experiences for irrigation and according to growth stage, weather conditions, etc. The 50% irrigation treatment present the half amount of water applied in the control.

Experimental design

The study was carried out on an agricultural production farm located in Arid, in the municipality of Nador in north-eastern Morocco (35°08'52.2''N 2°57'41.6''W). The trial was organized using a randomized complete block design (RCBD) with five replicates. There were 5 replicates of each block (3 plants). The plot used covered an area of 1200 m^2, the distance between rows was 1.2 m and plants were spaced 0.70 m on the same row and the length of each row was 50 m.

Plants growth

Three weeks after the transplanting, a series of growth parameters were recorded. The fifth expanded leaf from the plant's apex was selected for measurement. Plant height was measured using a metric ruler (cm); leaf length and width, number of flowers and leaves.

Crops yield

To estimate yield, the number and weight of fruits on plants of different genotypes for each treatment were determined by counting and using a precision balance, respectively. Fruit harvest was carried out weekly starting from October 1st, 2022, and ended on January 2nd, 2023.

Relative water content

Relative water content (RWC) was determined based fresh (FW), turgid (TW), and dry weights (DW) of leaf discs. Fresh weight was determined at time of cutting, turgid weight after 24 h in sterile distilled water and weighted. DW was obtained after drying these leaves at 80 °C in an oven for 48 h to a constant weight. Relative water content percentage was determined following the (Equation 1):

$$RWC(\%) = [(FW - DW) \div (TW - DW)] \times 100 \quad (1)$$

where: FW – fresh weight, TW – turgid weight, DW – dry weight.

Dry root biomass

The roots of five plants for each treatment were pulled up and then weighed to determine their fresh weight (FW); they were then placed in an oven at 80 °C for 72 hours until the mass of the samples had completely stabilized. They were then weighed using a precision balance to determine the dry biomass yield (DW).

Chlorophyll a fluorescence

The measured parameters are good indicators of stress because they show the electron transfer that occurs during the light phase of photosynthesis (Strasser and Tsimilli-Michael, 2001). Chlorophyll a fluorescence was measured using HPEA instrument (Handy Plant Efficiency Analyzer HPEA (Handey PEA, Hansatech, UK). The measurements were carried out on August 15, 2022; during a sunny day at a temperature of 34 °C. Recordings were performed on leaves (5 leaves per plant per repetition). Dark adaptation (0.5 hour) of the leaves preceded the measurement using a clip at 10:30 am. A light flash of 3000 µmol/m/s (650 nm) was then applied for 1s (gain = x1). The measurements were taken on 5 repetitions of each genetic line for each treatment. Measurements were taken on five plants of each variety for each treatment applied from 10:30 a.m. to 1:00 p.m. Fv/Fm ratio was measured.

Measurement of chlorophyll content

The SPAD-502 chlorophyll meter (Konica-Minolta, Japan) is a simple, portable, diagnostic and nondestructive light weight device used to estimate leaf chlorophyll content. Five plants per treatment for each genotype were selected and SPAD values were recorded from the fifth expanded leaf counted from the top of the plants.

Statistical analyses

SPSS (IBM SPSS Statistics 21-Software) was used to analyze the variance of the data. The values of the various growth and yield were subjected to a two-factor analysis of variance (ANOVA) (replicates and treatment) with interaction to assess the effect of the treatments. A study of the means was carried out, to compare the treatments and identify the most effective using the Duncan test at the 5% threshold.

RESULTS AND DISCUSSION

Plant growth

Treatments showed different responses among the genotypes in terms of growth. The effect of biofertilizer on plant height showed that there was a significant increase for C14, B3, C8, B5 and C11 irrigated at 100% water + biofert with 20%, 19%, 17%, 14.29% and 12.5%, respectively compared with the control (Fig. 1A). Similarly, 50% irrigation with biofertilizer gave better results for almost all genotypes, except B3 compared to the water-deficient control lots without the use of biofertilizer. Results showed that in 100% water + Biofert., the C11 and C14 showed the greatest value of height with 40.80 cm. The lowest value was observed for C8 (33.14 cm). For 50% water + Biofert., B5 registered the highest value 36.18 cm. Also, the number of leaves improved with the use of biofertilizer, both with the 100% and 50% water regimes. The analysis of variance concerning the number of leaves varieties exposed to water stress, compared to those under the 100% water regime, reveals a notable reduction in the number of leaves across all three varieties: C11, B3, and B5, regardless of the treatment applied. However, this reduction did not result in a significant effect ($p > 0.05$). Inoculation of P*seudomonas* showed an increase in the number of leaves of the genotypes studied, even with inadequate irrigation. The highest value was noted for C8 in 100% + Biofert. and 50% + Biofert. with 26.85 and 24.95, respectively. B5 disclosed the smallest value in 100% water, 50% water, 100% water + Biofert., 50% water + Biofert (Table 1). These findings imply that eggplant respond to water stress by decreasing foliage, although without a statistically significant impact. Sghir et al., (2014) reported that the application of different biofertilizers benefited growth mainly leaf number. For the number of flowers, C11 and B3 did not exhibit any significant effects in response to the irrigation and biofertilization (Fig. 1B). However, for C8, C14, and B5, noticeable differences ($p < 0.05$) were observed. For the C8, 100% irrigation coupled with biofertilization, the average number of flowers surpassed that of its control, which received 100% water without biofertilization. Conversely, no significant difference in the average number of flowers was observed under 50% irrigation. Regarding the C14, there was no significant difference between the prototypes and the controls under 100% irrigation

Table 1. The average number of leaves of five genotypes under 100%, 50%, with and without biofertilizer

The average of number of leaves				
Genotypes	100% Irr + Biofert	50% Irr + Biofert	100% Irr	50% Irr
C8	$26.85^{a} \pm 2.45$	$24.95^{a} \pm 2.45$	$24.20^{a} \pm 2.45$	$21.95^{a} \pm 2.45$
C11	$25.87^{a} \pm 2.59$	$24.17^{a} \pm 2.59$	$23.07^{a} \pm 2.59$	$23.02^{a} \pm 2.59$
C14	$25.87^{a} \pm 2.66$	$24.32^{a} \pm 2.66$	$23.05^{a} \pm 2.66$	$21.42^{a} \pm 2.88$
B3	$23.89^{a} \pm 2.42$	$23.57^{a} \pm 2.42$	$21.65^{a} \pm 2.39$	$21.31^{a} \pm 2.45$
B5	$17.21^{a} \pm 0.60$	$16.59^{a} \pm 0.60$	$15.09^{a} \pm 0.59$	$14.67^{a} \pm 0.61$

Note: *The means followed by the same letter do not differ significantly at the 5% threshold (Duncan test). NB: the data are the average of 5 repetitions per treatment ± standard deviation

plus biofertilization. However, under 50% irrigation plus biofertilization, a significant difference ($p < 0.05$) was noted, with the former exhibiting a greater number of flowers compared to its control. The biofertilizer seems to have a positive effect on the leaf length and width (cm) in combination with the two types of water regime 100% and 50% for all the genotypes except the untreated variety B5 which increased its width by 7% more than the treated lot when irrigated 50% (Table 2). The highest leaf length was observed for C11 value 17.64 cm and 16.15 cm in 100% + biofert and 50% + biofer, respectively compared to the rest. The leaf length and width indicate that water stress does not significantly affect these two growth parameters for the B3. However, for the C8, C11, C14, and B5, the results demonstrate that 100% irrigation combined with biofertilization, notably for the C14, has a significant effect on the average length and width of leaves compared to its control receiving 100% water without fertilization, concerning leaf count. This suggests that the leaf surface area of plants decreases under water stress conditions. Similar results to those we obtained concerning a significant effect on tissue growth and water content parameters have also been reported by (Gobu et al., 2017) after exposing plants to 15 days of water stress during vegetative growth. Ahmad et al., (2006) reported that the promoting rhizobacteria positively influence plant growth and development which can be explained by better seed germination and subsequent development of roots, which leads to an increase in the absorption capacity of nutrients and water in plants (Fig. 1).

Crops yield

Number and weight of fruits showed an increase in the case of both treatments. B5 recorded the best results for the various parameters recorded

Table 2. The average leaf length (cm) and width (cm) of five genotypes under the four treatments.

The average leaf length (cm)				
Genotypes	100% Irr + Biofert	50% Irr + Biofert	100% Irr	50% Irr
C8	$16.65^{ab} \pm 0.55$	$15.64^{b} \pm 0.55$	$17.88^{a} \pm 0.55$	$16.58^{ab} \pm 0.55$
C11	$17.64^{a} \pm 0.62$	$16.15^{ab} \pm 0.62$	$17.86^{a} \pm 0.62$	$15.01^{b} \pm 0.62$
C14	$15.60^{b} \pm 0.61$	$15.28^{b} \pm 0.61$	$17.88^{a} \pm 0.61$	$15.01^{b} \pm 0.61$
B3	$16.77^{a} \pm 0.59$	$15.45^{a} \pm 0.59$	$15.61^{a} \pm 0.58$	$15.41^{a} \pm 0.60$
B5	$17.21^{a} \pm 0.60$	$14.67^{c} \pm 0.60$	$16.59^{ab} \pm 0.59$	$15.09^{bc} \pm 0.61$
The average leaf width (cm)				
Genotypes	100% Irr + Biofert	50% Irr + Biofert	100% Irr	50% Irr
C8	$10.37^{ab} \pm 0.28$	$9.85^{b} \pm 0.28$	$9.22^{a} \pm 0.28$	$9.09^{b} \pm 0.28$
C11	$10.86^{a} \pm 0.33$	$10.25^{b} \pm 0.33$	$9.30^{a} \pm 0.33$	$8.95^{b} \pm 0.33$
C14	$10.25^{a*} \pm 0.33$	$9.30^{b} \pm 0.33$	$9.14^{b} \pm 0.33$	$8.80^{b} \pm 0.33$
B3	$9.55^{a} \pm 0.30$	$9.20^{a} \pm 0.30$	$9.11^{a} \pm 0.30$	$8.68^{a} \pm 0.30$
B5	$9.54^{a} \pm 0.32$	$9.37^{b} \pm 0.32$	$9.07^{ab} \pm 0.32$	$8.27^{ab} \pm 0.33$

Note: *The means followed by the same letter do not differ significantly at the 5% threshold (Duncan test). NB: the data are the average of 5 repetitions per treatment ± standard deviation

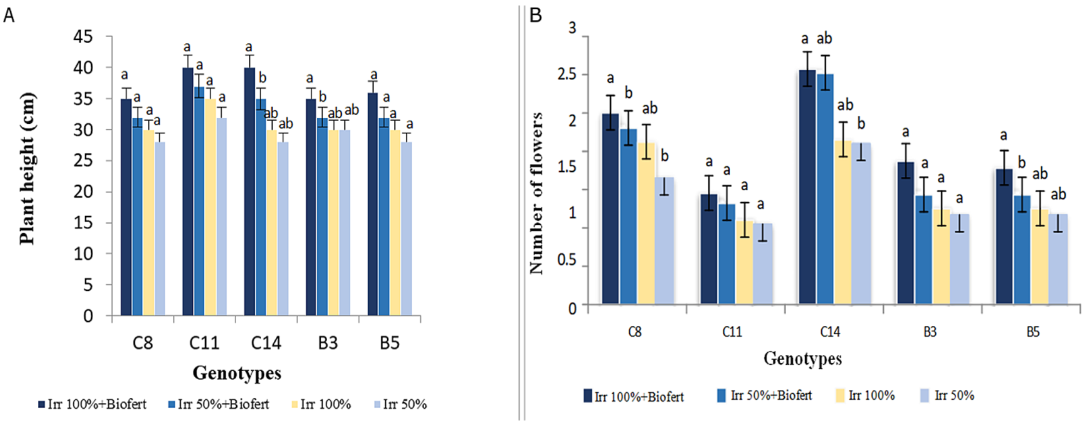

Figure 1. The effect of the treatments (100%, 50%, with and without biofertilizer) on (A) plant height and (B) number of flowers, of the five genotypes. *The means followed by the same letter do not differ significantly at the 5% threshold (Duncan test). The data are the average of 5 repetitions per treatment ± standard deviation

(Fig. 2A). The treatments applied had different effects depending on the variety. For C11 and C14, it was observed that there was no significant difference ($p > 0.05$) in the average number of fruits. However, for C8 and B3, when subjected to 100% water with biofertilization, there was an increase in the average number of fruits compared to their respective control receiving 100% water without fertilizer. These results indicate that water stress adversely impacted the productivity of all genotypes. The weight of fruits varies among different varieties and treatments. For C8, C11, C14, and B3, no significant difference ($p > 0.05$) was observed. However, in B5, a significant difference ($p < 0.05$) was noticed (Fig. 2B). Specifically, with 100% irrigation plus biofertilizer, it was

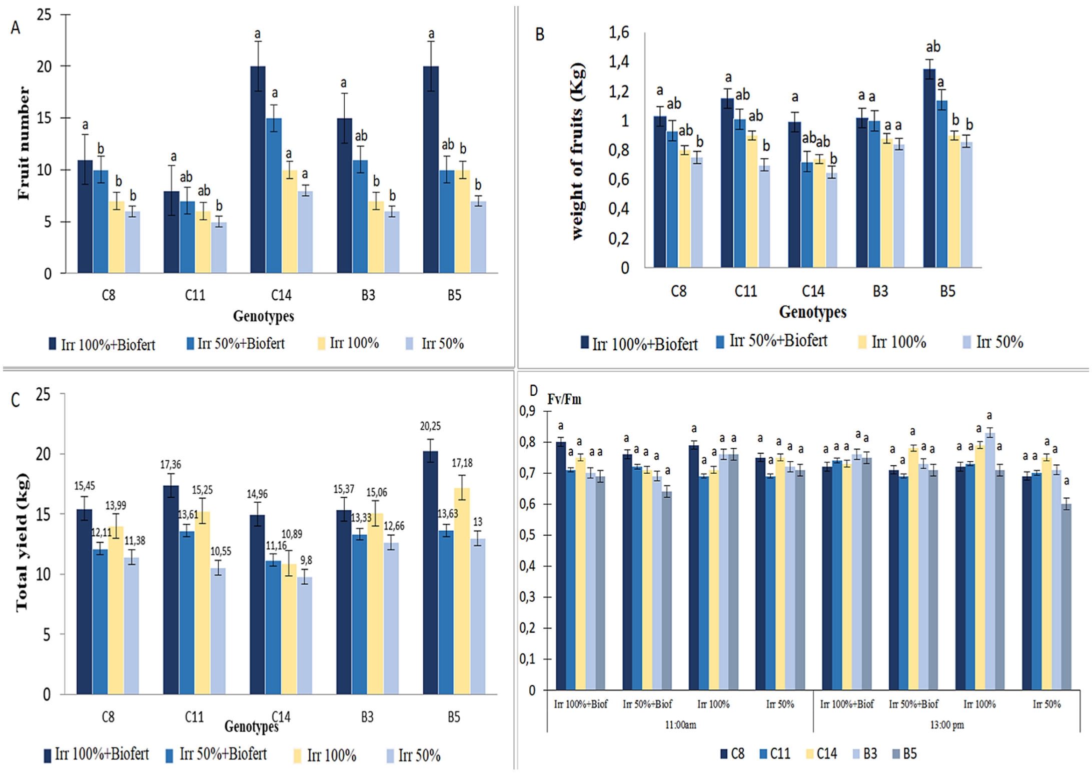

Figure 2. The effect of the treatments (100%, 50%, with and without biofertilizer) on (A) fruit number, (B) fruit weight, (C) total yield and (D) F_v/F_m ratio, of the five genotypes. *The means followed by the same letter do not differ significantly at the 5% threshold (Duncan test). The data are the average of 5 repetitions per treatment ± standard deviation.

observed that the average fruit weight was higher 1.35 kg/plant compared to the control group receiving 100% irrigation without biofertilization with 0.90 kg/plant. The lowest value was recorded for C14 in 100% + biofert and 50% + biofert and their control 100% and 50%. This suggests that the biofertilizer influenced the fruit weight of B5. The number and yield of fruits increases with the use of PGPR. This increase can be attributed to the plant's biosynthesis of phytohormones such as auxin (Arun et al., 2023). Similar results were reported by (Suryanto, et al., 2017) that biofertilizer increase the weight of fruits.

The total yield of cultivated plants displays variation based on both varietal types and applied treatments. The highest yield, approximately 20.25 kg, was recorded in the B5 under 100% water plus biofertilizer, while the lowest yield, around 14.96 kg, was observed in the C14 (Fig. 2C). Interestingly, consistently higher yields were associated with treatments involving 100% water plus biofertilizer. The range of variation among the treatments appears relatively narrow, fluctuating between 0.31% and 3.07% for the treatment with 100% water plus biofertilizer compared to its respective control without biofertilizer. Similarly, the range spans from 0.63% to 3.06% for the treatment with 50% water plus biofertilizer in contrast to its control without biofertilizer. It's evident that water stress adversely affects the productivity of all varieties. According Tringovska (2011), it indicated that the utilization of bio-fertilizer can lead to increase the total yield of tomato.

Relative water content

RWC was developed as an indicator of water status balance. The relative water content demonstrates a notable variation among the studied varieties. However, when comparing each genotype under the 100% irrigation with its counterpart under the 50%, no significant difference was found ($p > 0.05$) across all varieties, except for the C14. In the case of C14, there was a significant difference ($p < 0.05$) observed under the 100% irrigation with fertilization (Table 3), where the average RWC was higher compared to its control receiving 100% water without fertilization. C11 preserved the highest value of RWC in the 100% + biofert and 100% control. However, in 50% + biofert and 50% control, C14 recorded the greatest value compared to the other genotypes. This suggests that water stress affects the relative water content in the leaves of plants, as evidenced by the results. Our results are in agreement with those of (Ghorbanpour et al., 2003). The results shows that the RWC of the leaves was significantly highest in all conditions, with values of 92.10% and 79.07% for the highest and lowest, respectively. It has been recorded by (Khalilpour et al., 2021; Kiran et al., 2022) that PGPRs have affects due to RWC under drought for many species.

Dry root biomass

For C11, C14, B5, and B3, the treatment did not have a significant effect ($p > 0.05$) on root biomass. However, the results show that the varieties increased their root biomass after using the biofertilizer, in the case of C8, a highly significant difference ($p < 0.01$) was observed, particularly under the 50% irrigation with biofertilizer treatment. The C8, C14 and B3 significantly increasing their biomass when subjected to the treatment of 100% plus biofertilizer (Table 4). This finding suggests that the root system of plants, when combined with the biofertilizer, developed a substantial root surface, enabling adaptation to water stress. A literature review by Somal and Karnwal (2022) has been carried out extensively on the beneficial effect of microorganisms in rhizospheres and their effect on growth by optimizing stress resistance

Table 3. The RWC % of five genotypes under the four treatments

RWC%				
Genotypes	Irr 100% + Biofer	Irr 100%	Irr 50% + Biofer	Irr 50%
C8	53.60 ± 5.80^{b}	52.00 ± 5.80^{ab}	76.20 ± 5.80^{a}	63.40 ± 5.80^{ab}
C11	50.80 ± 4.45^{c}	49.60 ± 4.45^{b}	59.20 ± 4.45^{c}	48.60 ± 4.45^{a}
C14	76.40 ± 5.28^{a}	60.20 ± 5.28^{b}	42.80 ± 5.28^{b}	42.40 ± 5.28 ^{b}
B3	59.40 ± 7.87^{ab}	51.80 ± 7.87^{b}	86.20 ± 7.87^{a}	61.60 ± 7.87^{b}
B5	86.20 ± 7.19^{ab}	51.40 ± 7.19^{b}	68 ± 9.17^{a}	50.8 ± 7.19a^{b}

Note: *The means followed by the same letter do not differ significantly at the 5% threshold (Duncan test). NB: the data are the average of 5 repetitions per treatment ± standard deviation

Table 4. The average of dry root biomass (g) in the four treatments.

The average of dry root biomass (g)				
Genotypes	Irr 100% + Biofert	Irr 50% + Biofert	Irr 100%	Irr 50%
C8	21.03 ± 2.57 [a]	21.33 ± 2.57 [a*]	11.01 ± 2.57 [b]	10.47 ± 2.57 [b]
C11	26.59 ± 4.12 [a]	17.10 ± 4.12 [a]	26.66 ± 4.12 [a]	23.17 ± 4.12 [a]
C14	12.64 ± 1.84 [a]	09.29 ± 1.84 [a]	10.86 ± 1.84 [a]	12.06 ± 1.84 [a]
B3	18.72 ± 1.81 [a]	16.45 ± 1.81 [a]	16.62 ± 1.81 [a]	16.62 ± 1.81 [a]
B5	21.76 ± 2.97 [a]	14.94 ± 2.97 [a]	21.67 ± 2.97 [a]	20.50 ± 2.97 [a]

Note: [*]The means followed by the same letter do not differ significantly at the 5% threshold (Duncan test). NB: the data are the average of 5 repetitions per treatment ± standard deviation

in adverse environmental conditions. Also, in our study, the root mass of the C8 increased in both water regimes when treated with pseudomonas, but the B3 and B5 responded differently; this can be explained by the fact that the phytohormone content secreted by the different varieties was not similar. Yuwono et al., (2005) reported that increased root proliferation and improved water absorption in plants inoculated by the strain and under drought can be induced by IAA. The beneficial effects of PGPR and common adaptation mechanisms of drought-prone plants are always mutually related to exceptional changes in root morphology, such as root dry weight and root water absorption (Backer et al., 2018).

Chlorophyll a fluorescence

The chlorophyll a fluorescence indicates that the ratio F_v/F_m did not exhibit a significant difference ($p > 0.05$) among the studied plants (Fig. 2D). The results demonstrate that the value of F_v/F_m is approximately 0.85 in al treatments. Previous studies reported that significant improvement of plant physiology when biofertilizers were applied under drought (Boutasknit et al., 2021b; Meddich et al., 2021). The results of the present study are in agreement with that reported by (Abideen et al., 2022) that the inoculation increased F_v/F_m under well-watered conditions. Additionally, significant increase in this ratio was observed in the application of biofertilizer compared to those without biofertilizer (Soufiani et al., 2023).

Measurement of chlorophyll SPAD

The obtained results suggest that treatments did not have a significant effect ($p > 0.05$) on C8 and C14. However, among C11, B3, and B5, the treatment exhibited a highly significant effect ($p < 0.01$), specifically in the case of 100% irrigation without the addition of biofertilizer for B5 and B3 (Table 5). Chlorophyll content was more influenced by irrigation; the content was higher with the 100% compared to the 50%. Biofertilizer appears to be more effective for C8 under the 100% and for C11 under 50% of irrigation, whereas other varieties were less influenced. Furthermore, the results showed that inoculation with strains of *Pseudomonas* significantly ($p < 0.05$) improved chlorophyll contents in response to water stress. This study found that chlorophyll content decreases with 50% in C11 and B5; in agreement with the work of (Croft et al., 2020) who reported that the content of photosynthetic pigments decreases with water deficit. In the present experimental conditions, chlorophyll content variation under drought has been proposed as a suitable

Table 5. The average of SPAD chlorophyll content of eggplant leaves under the three treatments

The SPAD chlorophyll content				
Genotypes	100% Irr + Biofert	50% Irr + Biofert	Irr 100%	Irr 50%
C8	57.14 ± 0.99 [a]	54.79 ± 0.99 [a]	55.15 ± 0.99 [a]	55.19 ± 0.99 [a]
C11	59.58 ± 0.66 [a]	57.23 ± 0.66 [b]	59.71 ± 0.66 [b]	55.73 ± 0.66 [a]
C14	59.50 ± 0.37 [a]	59.72 ± 0.37 [a]	58.93 ± 0.37 [a]	59.22 ± 0.37 [a]
B3	57.23 ± 0.71 [a]	57.88 ± 0.71 [b]	56.03b ± 0.71*	56.03 ± 0.71 [a]
B5	56.03 ± 0.71 [a*]	54.93 ± 0.71 [b]	56.03a ± 0.71*	54.11 ± 0.71 [b]

Note: [*]The means followed by the same letter do not differ significantly at the 5% threshold (Duncan test). NB: the data are the average of 5 repetitions per treatment ± standard deviation stress marker in different eggplant materials allowing the ranking of the analyzed genotypes in combination with other morphological and physiological parameters (Gobu et al., 2017; Sseremba et al., 2018). An experiment carried out by (Ghorbanpour et al., 2003) suggested that the total chlorophyll content was dropped in untreated plants subjected to severe water stress. This observation suggests that stress may influence this parameter by reducing photosynthesis, thus impacting the chlorophyll content of leaves. Decreases, due to drought have been reported in many crops (Dbira et al., 2018). This appears to be due to a combined effect of chloroplasts alteration, inhibition of enzymes, associated with biosynthesis and activation of chlorophyllase, involved in degradation (Munné-Bosch and Alegre, 2004).

CONCLUSIONS

The use of *Pseudomonas* strain in this study was efficient to increase plant growth and yield in case of most of the genotypes used in this study and with and without water shortage. Also, reduction in irrigation water didn't reduce, significantly, plant height, flower number, fruit number and weight in most of the genotypes compared to 100% irrigation, for all the genotypes. For our knowledge, this is the first time that those genotypes are tested under the conditions of this study and in combination with the *Pseudomonas* strain. An interesting finding was shown in this study; under those conditions, crop selection and using biofertilizer could be a good agronomic practice to help grower to adapt their crops for drought situations and save field irrigation water. However, our results stay valid under the conditions of this trial. Different parameters might change the results such as soil, microclimate, agronomic practices, season of conducting experiments, etc. Therefore, more trials are needed in the future with those different conditions and with the use of different strains of PGPR and other genotypes.

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