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MITIGATING THE EFFECTS OF CLIMATE CONDITIONS ON POTATO CULTIVATION: EXPLORING HYDROABSORBENTS AND PGPRS AS SUSTAINABLE ALTERNATIVES

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ABSTRACT

Potatoes, a widely grown and consumed food around the world, are increasingly facing drought-related challenges. Due to their sensitivity to water availability and shallow roots, prolonged periods of drought have a significant impact on potato growth and yield. To mitigate these effects, the use of water absorbents, also known as water-retaining polymers, is proving to be a promising solution. These substances have the ability to absorb water and release it gradually into the soil, ensuring a constant water supply for the potatoes. At the same time, the presence of beneficial rhizobacteria, especially PGPRs, plays a crucial role in enhancing plant growth, controlling diseases and pathogens affecting potato production, and helping the crop cope with drought stress. A comprehensive study conducted at three different sites in Morocco with different climatic conditions, encompassing a greenhouse and field settings respectively, investigated the effect of two bacterial strains, *Pseudomonas koreensis* (GAJ222) and *Serratia nematodiphila* (GAB111), with two doses of hydroabsorbents (3 g and 1.5 g) on the potato variety Agria. The results indicated that the combination of *Serratia nematodiphila* with 3 g of hydroabsorbents significantly improved growth and yield. Furthermore, treatment with *Serratia nematodiphila* alone enhanced growth, reaching 51.9 cm, and the application of 3 g of hydroabsorbents promoted robust growth with a chlorophyll concentration of 15 SPAD units. The combined treatment of *Serratia nematodiphila* and 3 g of water retainers demonstrated a harmonious improvement, with a height of 59.2 cm, and significantly increased tuber yield to 17.1 kg, surpassing yields from the control group. This highlights the potential of these combinations to optimize potato production under drought conditions.

Keywords: Potato, Drought, Hydroabsorbents, PGPRs, Plant growth

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a major crop worldwide. Ranking fourth in importance after wheat, rice, and maize, it plays a crucial role in sustaining food supplies, boosting economic prosperity, and promoting environmental sustainability **(Sampaio *et al*., 2020; Sookhtanlou *et al.*, 2022)**. Its resource efficiency and versatility further solidify its importance. In Morocco, the potato reigns supreme as a key player in the agricultural sector. Each year, the country dedicates between 50.000 and 60.000 hectares to the cultivation of this tuber, representing about 18 % to 19 % of the total area allocated to vegetables. This highlights the integral part that potatoes play in Morocco's agricultural sector, making a significant contribution to food production and the national economy **(Alaoui *et al.*, 2021)**. The Food and Agriculture Organization (FAO), a trusted source of agricultural information, further underscores the scale of potato cultivation in Morocco. With an estimated 57.534 hectares dedicated to potato farming and a production of 1.707.068 tons **(FAO, 2022)**, these figures underline the scale of agricultural activity related to potatoes in the country, reflecting both the efficiency of production and its crucial role in food security **(FAO, 2022)**, these impressive figures place potatoes, alongside sugar crops and cereals, among the most important agricultural products in Morocco.
The potato sector faces numerous challenges, including a lack of clean seed, poor pest and disease management, disorganized marketing systems, and unclear packaging policies. Potato crops are susceptible to over 40 pests and diseases, bacterial fungal and viral diseases, which cause crop failure **(Adiyoga, 2009; Dubois *et al*, 2004).** Abiotic constraints like temperature and rainfall also impact potato production, with late frosts causing damage and premature crop death **(Steyn *et al*., 1998; Franke *et al*., 2013; Haverkort *et al.*, 2013).** Addressing these challenges is crucial for improving the resilience and sustainability of the potato sector.
In recent times, scientific investigations have pinpointed crucial factors shaping the growth and yield of potatoes. Notably, two focal points have emerged: the influence of plant growth-promoting bacteria (PGPR) and the optimization of water utilization. PGPRs, situated in the roots, enhance the plant's resilience to stress **(Shah *et al*., 2021).** Furthermore, effective water management, especially through innovative irrigation techniques, plays an important role in fostering sustainable production **(Cornelis *et al.*, 2019)**. These breakthroughs are elevating the productivity and sustainability of potato cultivation, thereby addressing the global food challenge.
The PGPRs, which are beneficial micro-organisms that live in the root zone, serve as the plant's defensive allies, creating a hidden army within the plant's intricate realm. They use a variety of mechanisms to increase plant resistance to stresses, whether biotic (pathogens) or abiotic (challenging environmental conditions). These bacteria improve nutrient uptake and stimulate the production of defense compounds, thereby contributing to plant health and vigor in commonly hostile environments **(Hamid *et al.*, 2021)**. PGPRs, have a proven ability to enhance agricultural production through biofertilisation. As bio-inoculants, they enhance plant growth by stimulating key processes such as biological nitrogen fixation, phosphate solubilization, Phytohormone production and biological control. Thus, these microorganisms provide a sustainable approach to increasing yields while reducing dependence on chemicals **(Bashan *et al.*, 2014; Setiawati and Mutmainnah, 2016)**. In addition, PGPRs play a crucial role in reducing abiotic stress in plants and increasing crop resilience to environmental challenges, as confirmed by several studies **(Yang *et al.*, 2009; Sessitsch *et al.*, 2013; Meena *et al.*, 2017; Backer *et al*., 2018; Ilangumaran and Smith, 2017)**. These beneficial microorganisms help plants to better cope with challenging conditions such as drought, salinity and extreme temperatures. They activate defense mechanisms, improve nutrient uptake, and stimulate the production of protective substances **(Yang *et al.*, 2009; Sessitsch *et al.*, 2013; Meena *et al.*, 2017; Backer *et al.*, 2018; Ilangumaran and Smith, 2017)**.
With global water scarcity rising, ensuring optimal moisture levels in potato fields is crucial for both crop productivity and environmental sustainability **(Lazarovitch and Kautsky, 2005; Žiberna and Stopar, 2016)**. Advanced irrigation methods like precision irrigation and water-saving technologies offer promising solutions to conserve water while boosting yields **(Stoll *et al.*, 2018)**. Understanding potato physiology in response to water availability is crucial **(Palta and Gregory, 1997; Pereira and Soratto, 2006)**, as techniques that mitigate the negative effects of drought or excess moisture can greatly enhance sustainable potato production **(Zhang et al., 2005; López and Fenoll, 2006)**. Ultimately, careful water resource

management, as exemplified by water-absorbent polymers, can not only improve food security but also protect aquatic ecosystems for the long term.
The aim of this study is to explore the multidimensional aspects of PGPRs and the water-absorbing approach to potato production. We explored the dynamic interplay between two specific PGPR strains and potato growth, revealing their intricate influence on various agronomic parameters (vigor, height, chlorophyll, number of stems, number of leaves, leaf temperature and yield). Additionally, we studied the effect of two levels of hydroabsorbent application on potato crops. This analysis will help us identify the benefits and drawbacks of this innovative approach for agricultural productivity and sustainable water resource management.

MATERIALS AND METHODS

Study sites

The research study was meticulously conducted across three distinct sites, considering variations in climate conditions (Figure 1). The initial phase of the experiment took place in the controlled environment of the greenhouse at National Institute of Agronomic Research at El Haj Kaddour, located at 33°50'30"N 5°28'23"W with an altitude of 623 m, complemented by two field experiments in the Fez-Meknes region, providing a foundation for comprehensively exploring the effects of different climates on the study parameters. The first field trial was located in the Douyet region at the National Institute of Agronomic Research experimental station (Figure 1.A) (34°03'09.2"N 5°05'16.4"W) in the favorable Bour zone of the Sais plain (at an altitude of 416 m). The area is characterized by very fertile, deep clay-limestone soils, an average rainfall of 510 mm, cold winters and hot, dry summers with high temperatures (maximum 46 °C, minimum 19 °C). The second experimental site is located in the region of Ain Taoujdate (Figure 1.B) (33°55'59.99"N 5°12'60.00"W), also on the Saïss plain, but having a semi-arid Mediterranean climate, cooler winters and hot, dry summers, with temperatures ranging from a minimum of 2.8°C. to a maximum of 37°C.

Figure 1 Experimental stations of the National Institute of Agricultural Research, A. Green house at INRA Meknes, B. Douyet site, C. Ain Taoujdate site.

Plant material

The Agria potato cultivar (tuber with yellow to light brown flesh) used in the experiment was obtained from Holland in 2021. The potato tubers were selected without wounds or rot and as homogeneous as possible in terms of size (50 to 100 mm in diameter).

Bacterial strains and hydroabsorbents agent

The two PGPR strains, listed in Table 1, were obtained from the Phytobacteriology and Biological Control laboratory collection of National Institute of Agronomic Research in Meknes, Morocco. Our selection process was based on the proven abilities of these strains to promote and protect other crops, as demonstrated in previous studies **(Badri and Achbani, 2018; Ameur *et al.*, 2017; Haggoud *et al.*, 2017; Sadik *et al.*, 2015; Habbadi *et al.*, 2017)**. PGPR were grown on YPGA medium (yeast extract (5 g/L), peptone (5 g/L), glucose (10 g/L), and agar (15 g/L)) at 27 ± 1 °C for 48 h. The bacterial suspensions concentration were adjusted to 10^8 CFU/ml, which was used as the inoculum.

Table1 Strains tested on potato tubers

Strain code	Species	Origin	Region
GAJ222	*Pseudomonas koreensis*	Rhizosphere of *Phoenix dactylifera*	Draa-Tafilalet
GAB111	*Serratia nematodiphila*	Rhizosphere of *Phoenix dactylifera*	Draa-Tafilalet

As part of our water management strategy, we used Water Hope as a hydroabsorbent in this study. Its remarkable ability to absorb significant amounts of water makes it a valuable asset in our research to address water-related challenges.

Experimental Approach

In this study, potato tubers were pre-treated with the two strains mentioned above before planting. The treatment involved immersing the tubers in a bucket filled with a suspension of each strain, prepared and adjusted to a concentration of 10^8 CFU/ml. Each tuber was immersed in for 30 minutes. The tubers were then planted in rows using the conventional method of potato cultivation **(Neelam *et al.*, 2018)**. Potato planting in Ain Taoujdate and Douyet started, respectively, in April and May 2021.
The study followed a row design **(Bhatti and Khan, 2021)** with three replications (Annex 1). Each replicate was separated by 2 meters and contained 8 treatments with a one-meter separation between each row. Each treatment consisted of three, 10 meter-long, rows with an 80cm row spacing. Approximately 36 plants were planted in each treatment, with a spacing of 80 cm between rows and individual plants. These planting distances align with the recommendations of the Ethiopian Institute of Agricultural Research **(MoANR, 2016)**. The density is 2.673 cultivated seeds per cultivated plot of 648 m^2 (total area of 829.6 m^2), resulting in 41.250 seeds/ha.
The experimental plot was fertilized with NPK at specific rates recommended by the Ministry of Agriculture and Natural Resources **(EIAR, 2007)**: Nitrogen at 150 units/ha, Phosphorus at 165 units/ha, and Potassium at 175 units/ha. Additionally, all other management practices, such as weeding, hoeing, ridging, and pest control, were uniformly implemented across all plots **(Abebe, 2013; Wongchaochant and Taychasinpitak, 2013)**. Two doses of hydroabsorbent, D1 (3 g) and D2 (1.5 g), were applied to each potato tuber (Table 2).

Table 2 The various treatments applied

Treatment	Signification
T_{conv}	Control
S1	Strain 1 (*Pseudomonas koreensis*)
S2	Strain 2 (*Serratia nematodiphila*)
D1	Dose 1= 3 g
D2	Dose 2= 1.5 g
S1, D1	Strain 1 (*Pseudomonas koreensis*) + Dose 1= 3 g
S1, D2	Strain 1 (*Pseudomonas koreensis*) + Dose 2= 1.5 g
S2, D1	Strain 2 (*Serratia nematodiphila*) + Dose 1= 3 g
S2, D2	Strain 2 (*Serratia nematodiphila*) + Dose 2= 1.5 g

Data collection

To evaluate the effect of the two PGPR tested on potato cultivation and the hydroabsorbents dosages used at each experimental site, several parameters were considered. Measurements were taken at mid-flowering stage from five randomly selected plants within the experimental plot. Plant height was measured from the soil surface to the tip of the main stem using a ruler. The number of stems and leaves emerging from the mother tuber was recorded, while chlorophyll content and leaf temperature were measured using a SPAD meter and an infrared thermometer (SPAD-502Plus Chlorophyll Meter: User Manual and H1020 Non-Contact Digital Laser Infrared Thermometer Gun: User Manual), respectively.
The harvested tubers were weighed using a balance, results were recorded in kilograms per plot (Kg/0.05ha). Tubers weighing 25 g or more and undamaged by mechanical factors, diseases, or pests are considered marketable. Those weighing less than 25 g or damaged or rotted are classified as unmarketable. Total tuber yield was calculated by combining the weights of marketable and non-marketable tubers **(Abebe *et al.*, 2013)**.

Data analysis

The agronomic data collected in this study were analyzed using a multi-factor analysis of variance (ANOVA) with SPSS 21 statistical analysis software. This approach was used to assess differences among various factors, including treatment, site, and doses. P value of less than 0.05 was used as the critical value for interpreting the results to determine statistical significance.

RESULTS

The impact of PGPRs and hydroabsorbents on agronomic parameters.

The study evaluated several agronomic parameters affecting plant growth, including vigor, stem and leaf number, height, chlorophyll concentration and leaf temperature. Three treatments were identified as significant: strain S2, dose D2, and the combination S2-D1. To clarify, these treatments demonstrated statistically significant effects compared to the control group, with p-values less than 0.05 for each treatment, indicating that their impact on the measured parameters was not due to chance. Each treatment was evaluated based on these parameters. Strain S2 showed increased performance in vigor (4), number of stems (5), number of leaves (45), height (51.9 cm), chlorophyll concentration (13 SPAD units) and leaf temperature (21.3 °C). In comparison, dose D1 showed vigor (5), number of stems (5), number of leaves (44), height (50 cm), chlorophyll concentration (15 SPAD units) and leaf temperature (28.6 °C).
The combined treatment, S2-D1, showed vigor (4), number of stems (4), number of leaves (49), height (59.2 cm), chlorophyll concentration (13 SPAD units) and leaf temperature (25.9 °C). Analysis of the data showed that the S2 strain had a higher number of leaves and a higher chlorophyll concentration than the other treatments. Conversely, dose D1 promotes more vigorous growth with increased stem number and height, despite a higher leaf temperature. The combination of S2 and D1 represents a balanced compromise, resulting in a notable increase in height and leaf number compared to S2 alone (Figure 2).

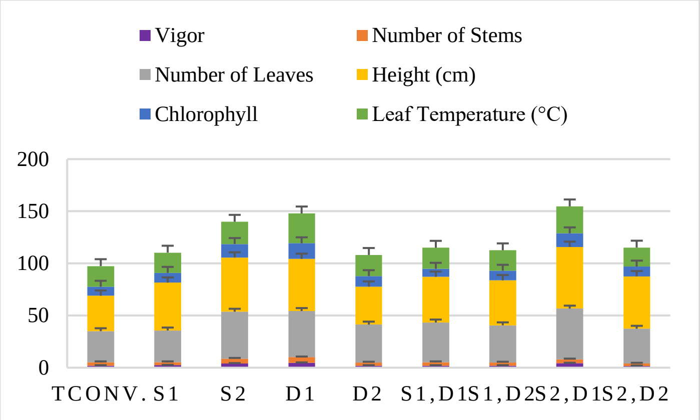

Figure 2 Graphical representation of various agronomic parameters based on eight treatments in the greenhouse.

Impact of PGPRs and hydroabsorbents on yield

In addition to agronomic parameters, this study evaluates yield measurements, a key indicator in agriculture. The results show remarkable yields for several experimental treatments, in particular strain S2 (4.31 kg), dose D1 (4.03 kg) and the combined treatment S2-D1 (4.05 kg). The data underscore that strain S2, dose D1 and the combination of S2-D1 significantly increase agricultural yield, highlighting the efficacy of these treatments in promoting substantial agricultural production (Figure 3).

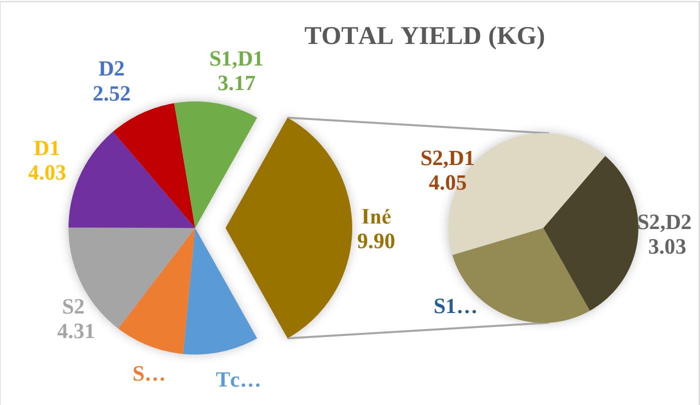

Figure 3 Percentage of the total yield for various treatments conducted in the greenhouse.

The impact of PGPRs and hydroabsorbents on agronomic parameters.

Analysis of the data between treatments S2, D1, S2-D1 and the control showed significant differences in various agronomic parameters. In terms of vigor, treatments S2, D1 and S2-D1 have equivalent vigor scores of 3, indicating similar growth, while the control has significantly lower vigor with a score of 2, indicating reduced vitality. In terms of number of stems and leaves, S2 (10 stems, 16 leaves) and D1 (11 stems, 18 leaves) show a slight superiority compared to S2-D1 (10 stems, 19 leaves) and the Control (9 stems, 13 leaves), suggesting more branched growth and leaf area in the former two treatments. Plant height data showed that the Control treatment had the lowest height (37.3 cm), while S2-D1 (54.7 cm), S2 (56.4 cm) and D1 (53.3 cm) had relatively higher values (Figure 4). In terms of chlorophyll concentration, the Control has the lowest value (28.8), while S2 (38.5), D1 (36.1) and S2-D1 (37.4) have higher concentrations, indicating better photosynthetic efficiency. The control also has the lowest leaf temperature at 14.5 °C, while S2, D1 and S2-D1 have higher temperatures at 18.4 °C, 18.0 °C and 17.6 °C respectively (Figure 4). In conclusion, the results indicate that treatments S2, D1 and S2-D1 generally outperform the control in various aspects, including vigor, number of stems and leaves, height, chlorophyll concentration and leaf temperature, highlighting the positive impact of these treatments on plant growth and health.

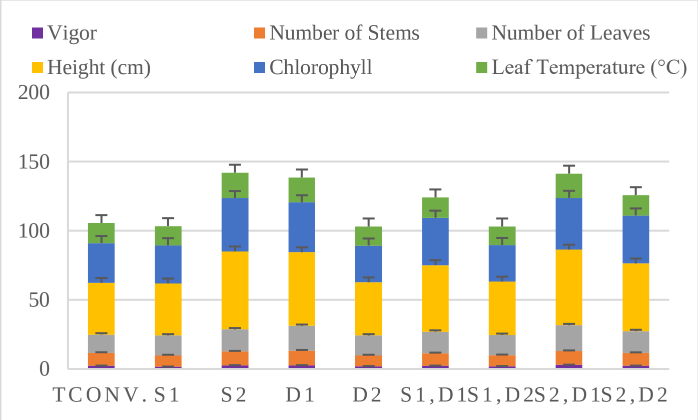

Figure 4 Graphical representation of various agronomic parameters based on eight treatments at the Douyet site.

Impact of PGPRs and hydroabsorbents on yield

Treatments S2, D1 and S2-D1 showed a significant increase in tuber yield, with significant improvements over the control group. The specific yields were as follows: 15.6 kg for S2, 15.3 kg for D1, and 15.1 kg for S2-D1, all of which exceeded the control yield of 13.2 kg. (Figure 5). These results highlight the individual efficiency of each treatment in improving tuber production. Furthermore, in terms of total yield for the whole plot, treatments S2, D1 and S2-D1 also showed high performance with yields of 127.3 kg, 124.6 kg and 121.0 kg respectively, significantly exceeding the total yield of the control of 98.0 kg (Figure 5). These results highlight the synergistic effect of the treatments on the whole crop, indicating an overall improvement in productivity compared to control conditions. In conclusion, the data confirm that treatments S2, D1 and S2-D1 have a positive effect on both individual tuber yield and total plot yield, suggesting that careful selection of variety, dose and their combination plays a crucial role in optimizing agricultural production and offers promising prospects for increasing tuber crop productivity.

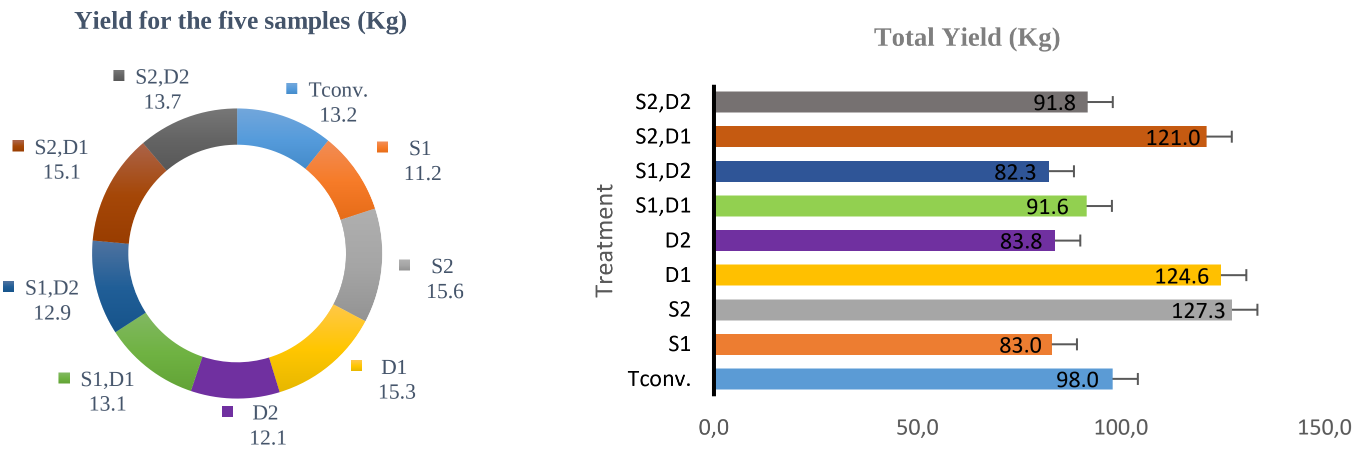

Figure 5 Impact of different treatments on yield at the Douyet site

The impact of PGPRs and hydroabsorbents on agronomic parameters.

Comparison of the data shows significant differences between the S2, D1, S2-D1 treatments and the control. Firstly, in terms of vigor, the S2-D1 and S2 treatments show an equivalent vigor of 4, indicating similar robustness in their growth. On the other hand, the control shows a significantly lower vigor of 2, indicating reduced vitality compared to the other treatments. Regarding the number of stems and leaves, treatments S2 (number of stems: 16, number of leaves: 12) and D1 (number of stems: 15, number of leaves: 13) show a slight superiority compared to S2-D1 (number of stems: 15, number of leaves: 13) and the control (number of stems: 15, number of leaves: 10), possibly indicating a more branched growth and a larger leaf surface (Figure 6). As for the height of the plants, sample D1 (height: 72.2 cm) shows the greatest height, followed by S2-D1 (height: 71.3 cm), S2 (height: 71.0 cm) and finally the control (height: 54.7 cm). This suggests that the D1 dose promotes more pronounced height growth (Figure 6). Regarding to chlorophyll concentration, treatment D1 (chlorophyll: 47.6 SPAD units) shows the highest value, indicating a potentially more efficient photosynthesis. The combination S2-D1 (chlorophyll: 46.4 SPAD units) also shows a high chlorophyll concentration, emphasizing the positive effect of D1 on this parameter (Figure 6). An interesting observation concerns leaf temperature, where the S2-D1 combination (leaf temperature: 32.1 °C) has a significantly lower temperature compared to S2 (leaf temperature: 39.9 °C) and D1 (leaf temperature: 39.9 °C), suggesting a better thermal regulation (Figure 6).
In conclusion, the results suggest that the D1 dose plays a crucial role in improving several agronomic parameters, including height and chlorophyll concentration. The S2-D1 combination shows promising characteristics with a lower leaf temperature, even though its height is comparable to that of S2. These observations provide valuable insights for the selection of optimal conditions in the context of plant growth.

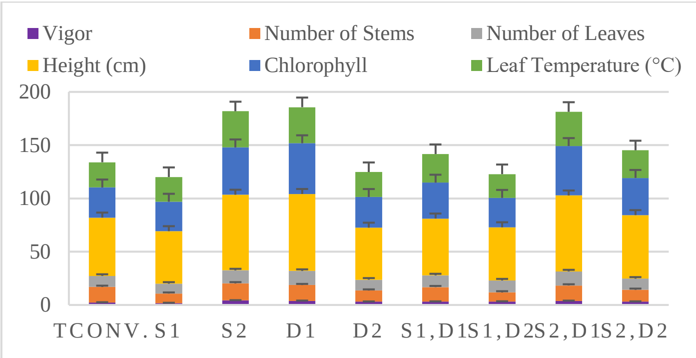

Figure 6 Graphical representation of various agronomic parameters based on eight treatments at the Ain Taoujdate site

Impact of PGPRs and hydroabsorbents on yield.

The effect of treatments S2, D1 and S2-D1 on tuber yield is significant and shows better performances over the control. Treatment S2 allowed the increase a particularly high tuber yield of 17.1 kg, closely followed by D1 with 16.2 kg. The combination S2-D1 also demonstrates a notable yield of 16.3 kg. In comparison, the control had a significantly lower yield of 10.3 kg, highlighting the effectiveness of the treatments applied (Figure 7).
When looking at the total yield for the whole plot, the results are equally impressive. Treatment S2 produced 75.6 kg, D1 80.3 kg and the combination of S2-D1 produced the highest yield of 81.6 kg. These figures are significantly higher than the total yield of the control, which was only 65.5 kg (Figure 7). The data confirm that treatments S2, D1 and S2-D1 have a positive effect on total plot yield, highlighting their potential to increase agricultural productivity. These results suggest that the choice of variety and dose, as well as their combination, is crucial in optimizing tuber crop yield.

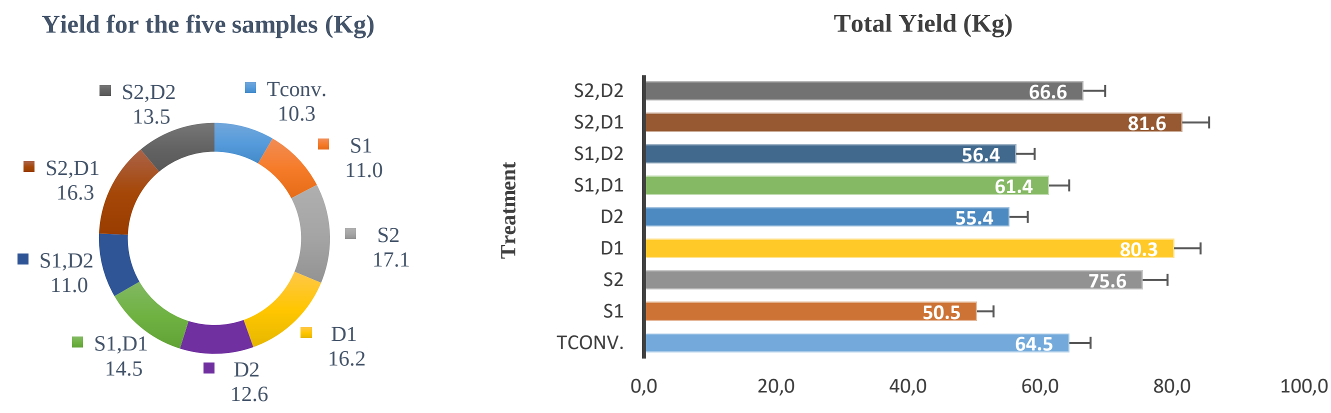

Figure 7 Impact of different treatments on yield at the Ain Taoujdate site

The results obtained in the greenhouse demonstrate significant differences with the control when using the S2, D1, and S2-D1 treatments. S2 exhibits a higher chlorophyll concentration and a greater number of leaves, while D1 promotes more vigorous growth with an increase in the number of stems and height. The S2-D1 combination represents a balanced compromise, inducing a notable increase in height and leaf number compared to S2 alone. Regarding yield, all treatments, especially S2, D1, and the S2-D1 combination, display remarkable yields, emphasizing the effectiveness of these treatments in stimulating agricultural production.

At the Douyet site, a detailed analysis of agronomic parameters reveals that the S2, D1, and S2-D1 treatments generally outperform the control group. These treatments show a significant improvement in vigor, number of stems and leaves, height, chlorophyll concentration, and leaf temperature compared to the control group. Regarding tuber yield, the S2, D1, and S2-D1 treatments all exhibit a significant increase compared to the control group, emphasizing the positive effect of these treatments not only on individual parameters but also on the total plot yield.

In Ain Taoujdate, the data highlight notable differences among the S2, D1, S2-D1 treatments, and the control group. D1 plays a crucial role in improving several agronomic parameters, such as height and chlorophyll concentration. The S2-D1 combination shows promising characteristics with a lower leaf temperature despite a similar height to S2. Concerning tuber yield, all treatments, especially S2, D1, and the S2-D1 combination, display a significant improvement compared to the control group, highlighting their potential to increase agricultural productivity.

In summary, the results obtained at these three sites indicate that PGPRs and hydroabsorbent treatments, particularly the selected combinations of the *Serratia nematodiphila* strain and a 3 g dose of hydroabsorbents, have significant positive effects on agronomic parameters and crop yield. These observations provide valuable insights to guide the selection of optimal conditions in the context of plant growth, suggesting promising prospects for the optimization of agricultural production.

DISCUSSION

Climate change is rearing up, and with it, significant increases in global temperature, and occurrence of other abiotic stresses that are adversely affecting crop productivity. In response to this challenge, the implementation of sustainable practices and the adoption of eco-friendly technologies have the potential to disrupt this detrimental cycle. By enhancing resource use efficiency and increasing yields in the face of increasingly harsh environmental conditions **(Pareek *et al.*, 2020)**, these measures aim to promote healthy food production, curtail unsustainable inputs, mitigate extreme climatic conditions, and enhance soil health through the sequestration of soil carbon, maintenance of soil organic matter, and regulation of inorganic nutrients **(Drost *et al*., 2020)**. Numerous studies in the literature have extensively documented the adverse effects of climate change on potato productivity **(Rosenzweig *et al*., 1996; Hijmans, 2003; Holden *et al*., 2003; Daccache *et al*., 2011; Van der Waals *et al*., 2013; Sparks *et al*., 2014; Kumar *et al*., 2015)**. While farmers lack the ability to control or alter climatic conditions, there are factors within their control, such as soil management, water usage, choice of cultivars, and agricultural practices, that can be optimized to mitigate the negative impacts of climate change **(Ozkan and Akcaoz, 2002; Moradi *et al.*, 2013)**.

To further investigate the effect of climatic conditions on potato agronomic parameters and production, our research included three different sites with different climates: El Haj Kaddour, Ain Taoujdate and Douyet. While the biological treatments showed consistent effects across the experimental sites, there was considerable variation in potato yields. The variation in yield rates can be attributed to several factors, mainly environmental conditions such as temperature, humidity and rainfall. Douyet, which outperformed the other two sites in terms of yield, can be attributed to its unique climatic conditions. Temperature plays a crucial role in the growth and development of potatoes, which require cool night temperatures to induce tuberization **(Burt, 1964; Ku *et al*., 1977; Cutter, 1992)**. Potatoes thrive on higher sites with more rainfall and lower temperatures **(Pazderů *et al*., 2016),** especially on lighter soils. Their preference for lighter soil types found at higher altitudes is compensated by the higher rainfall, which counteracts the negative aspect of light soils - desiccation. When considering the influence of climatic conditions, both temperature and precipitation emerge as key factors in yield formation **(Eitzinger *et al*., 2013; Rymuza *et al*., 2015; Shimoda *et al.*, 2018)**. As mentioned above, the Douyet site is characterized by very fertile, deep clay-limestone soils, an average rainfall of 510 mm, cold winters and hot, dry summers with high temperatures (maximum 46 °C, minimum 19 °C), creating a favorable environment for potato tuber growth.

Irrigation is costly and requires the maintenance of optimum soil moisture levels with sufficient nutrient and water supply to plants. Therefore, certain polymers have become popular to avoid these problems and reduce the cost of continuous irrigation. Research has revealed that the addition of polymers to sandy soils enhances plant water availability by increasing retention pores and decreasing saturated hydraulic conductivity through a reduction in drainage pores **(Leciejewski *et al*., 2009)**. Studies also indicate that the application of hydrogels in sandy soils significantly improves water retention capacity **(Hüttermann *et al.*, 1999; Paluszek *et al*., 2008)**. Hydroabsorbents polymers have the capability to absorb and retain a large volume of water **(Fern´Andez *et al*., 2005)**, swelling up to approximately 400 times their dry weight **(Bouranis *et al*., 1995)**. This property enhances the water- and nutrient-holding capacity of soils, improves soil structure, fosters plant growth and root development, reduces irrigation frequency, and enhances tree establishment **(Al-Humaid and Moftah 2007; Hüttermann *et al.*, 1999; Dehkordi *et al*., 2015; Maysinger *et al*., 2007)**. The study aimed to assess the impact of two different doses of the Hydroabsorbents polymer, Water-Hope, on various agronomic parameters and tuber yield. The results demonstrated a substantial increase in all parameters studied, including leaf number, chlorophyll concentration, leaf temperature, and yield, when dose D1 was applied to the potato tubers. This performance was consistent across all three experimental sites, indicating a clear enhancement in yield and an improvement in yield gaps under different climate conditions.

Host plant and soil characteristics, along with various environmental factors, play an important role in shaping the diversity and abundance of microorganisms in the rhizosphere **(Qiao *et al.*, 2017)**. In particular, beneficial microorganisms, including plant growth-promoting rhizobacteria (PGPR), have been reported to not only enhance crop yield, but also improve plant growth and resistance to biotic and abiotic stresses **(Backer *et al.*, 2018; Lyu *et al.*, 2020)**. Establishing sustainable strategies to enhance plant resistance to environmental constraints is crucial for securing and optimizing global food production **(Lyu *et al*., 2020; Sindhu *et al.*, 2020)**. One environmentally friendly approach is the application of PGPR and/or their by-products **(Mayak *et al.*, 2004; Bano and Fatima, 2009; Piccoli and Bottini, 2013; Zafar-Ul-Hye *et al.*, 2014; Qin *et al.*, 2016; Abd El-Daim *et al.*, 2019; Ipek *et al.*, 2019)**, which can effectively help plants withstand extreme environmental conditions. Previous studies have highlighted the positive effects of plant-PGPR interactions on various aspects such as improved seed germination, root development, shoot and root weight, leaf area, chlorophyll content, hydraulic activity, protein content, nutrient uptake and yield in potato **(Sprenger *et al*., 2018; Spitters *et al.*, 1989**).

In the present study, significant differences were observed between treatments and control for several agronomic parameters. Treatment S2, *Serratia nematodiphila*, showed increased values for leaf number and chlorophyll concentration, while dose D1 facilitated vigorous growth with higher leaf temperature. Various genera, including *Serratia,* have been shown to be as PGPR promoting plant growth and development under both normal and stress. Several species of *Serratia* are reported to enhance plant growth **(Koo and Cho, 2009; Devi *et al.*, 2013)**, and promote seed germination in quinoa **(Mahdi *et al.*, 2021)**. The combination of *Serratia nematodiphila* and D1 Hydroabsorbents dose showed a compromise, with significant height and higher leaf number. Furthermore, the study revealed notable differences between the two sites, with variety S2 showing marked vigor at Ain Taoujdate and treatments S2, D1 and S2-D1 generally outperforming the control at Douyet in terms of agronomic performance.

The study concludes that the judicious choice of strain and dose may be essential to achieve an optimal balance between different agronomic parameters, and that choices of strain, dose, and treatment combination should be carefully tailored to local conditions to maximize the efficiency of agricultural practices. These conclusions offer valuable insights to guide agricultural management decisions, emphasizing the importance of considering site-specific characteristics in the development of optimal agronomic strategies.

CONCLUSION

In conclusion, the treatments with the *Serratia nematodiphila* strain and the 3 g dose of the hydroabsorbent, as well as their combinations, both in the greenhouse and at the Ain Taoujdate and Douyet sites, show significant nuances in their effects on various agronomic parameters. The tuber yield results confirm the efficiency of the treatments, with notable performances at Ain Taoujdate, particularly the high yield of the *Serratia nematodiphila* strain. The sites show differences in how the treatments affect plant growth, highlighting the importance of taking into account specific site conditions when determining agricultural practices. Ultimately, these observations highlight the need to tailor agronomic strategies based on local characteristics to maximize yields and promote sustainable agricultural productivity. Careful selection of cultivar, dose and treatment combinations is essential to meet the specific requirements of each site. These conclusions provide valuable insights to guide agricultural management decisions and contribute to more efficient and sustainable agricultural practices.

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REFERENCES

Abd El-Daim, I. A., Bejai, S. and Meijer, J. (2019). *Bacillus velezensis* 5113 induced metabolic and molecular reprogramming during abiotic stress tolerance in wheat. Sci. Rep. 9, 1–18. doi: 10.1038/s41598-019-52567-x

Abebe, T., Wongchaochant, S. and Taychasinpitak, T. (2013). Evaluation of specific gravity of potato varieties in Ethiopia as criterion for determining processing quality. *Kasetsart J. Nat. Sci.*, 47(1), 30–41

Adiyoga, W. and Norton. G. (2009). Costs and benefits of Bt potato with resistance to potato tuber moth in Indonesia. In Projected impacts of agricultural biotechnology of fruit and vegetables in the Philippines & Indonesia, eds G.W. Norton and D. M. Hautea, 105-140. International Service for the Acquisition of Agri-biotech Applications and the SEAMEO Southeast Asian Regional Center for Graduate Study and Research in Agriculture, Los Baños, Laguna 4030, Philippines

Alaoui, K., Chafik, Z., Arabi, M., Abouloifa, H., Asehraou, A., Chaoui, J. and Kharmach, Ez-Z. (2021). *In vitro* antifungal activity of Lactobacillus against potato Late blight *Phytophthora infestans*. Materials Today: Proceedings, 45, 7725-7733. https://doi.org/10.1016/j.matpr.2021.03.338

Al-Humaid, A. I. and Moftah. A. E. (2007). Effects of hydrophilic polymer on the survival of buttonwood seedlings grown under drought stress. Journal of Plant Nutrition 30:53–66. doi:10.1080/01904160601054973

Ameur, A., Rhallabi, N., Doussomo, M. E., Benbouazza, A., Ennaji, M. M. and Achbani, E. (2017). Selection and efficacy biocontrol agents *in vitro* against fire blight (*Erwinia amylovora*) of the rosacea. Int Res J Eng Technol, 4, 539-545

Backer, R., Rokem, J.S., Ilangumaran, G., Lamont, J., Praslickova, D. and Ricci, E. (2018) Plant growth-promoting rhizobacteria: context, mechanisms of action, and roadmap to commercialization of biostimulants for sustainable agriculture. Front Plant Sci 9:1473

Backer, R., Rokem, J. S., Ilangumaran, G., Lamont, J., Praslickova, D., Ricci, E., *et al*. (2018). Plant growth-promoting rhizobacteria: context, mechanisms of action, and roadmap to commercialization of biostimulants for sustainable agriculture. Front. Plant Sci. 9:1473. doi: 10.3389/fpls.2018.01473

Badri, H., Achbani, E. H. and Jijakli, H. (2018). *Aureobasidium pullulans* strain Ach1-1 a biocontrol of postharvest diseases of apples: 15 crucial years of research before starting commercial development. In Proceedings of the International Symposium on Crop Protection, Morocco

Bano, A. and Fatima, M. (2009). Salt tolerance in *Zea mays* L. following inoculation with Rhizobium and Pseudomonas. Biol. Fertility Soils 45, 405–413. doi: 10.1007/s00374-008-0344-9

Bashan, Y., De Bashan, L.E., Prabhu, S.R. and Hernandez, J.P. (1998–2013). Advances in plant growth promoting bacterial inoculant technology: Formulations and practical perspectives. Plant Soil 2014, 378, 1–33

Bhatti, A. M. and Khan, I. (2021). Application of Randomized Complete Block Design in the design of experiments. International Journal of Social Sciences and Humanities Reviews, 11(1), 75-84

Bouranis, D. L., Theodoropoulus, A. G. and Drossopoulus, J. B. (1995). Designing synthetic polymers as soil conditioners. Communications in Soil Science and Plant Analysis 26:1455–80. doi:10.1080/00103629509369384

Burt, R.L. (1964) In fluence of short periods of low temperature on tuber initiation in the potato. Eur Potato J 7:197–208

Cornelis, W., Waweru, G. and Araya, T. (2019). Building resilience against drought and floods: the soil-water management perspective. Sustainable Agriculture Reviews 29: Sustainable Soil Management: Preventive and Ameliorative Strategies, 125-142

Cutter, E.G. (1992) Structure and development of the potato plant. In: Harris PM (ed) The potato crop- The scientific basis for improvement. Chapman and Hall, London

Daccache, A., Weatherhead, E.K., Stalham, M.A. and Knox, J.W. (2011). Impacts of climate change on irrigated potato production in a humid climate. Agric. For. Meteorol. 151, 1641–1653

Dehkordi, D.K. (2015). Evaluation of Superabsorbent Application on Corn Yield under Deficit Irrigation. Int. J. Agric. Biosyst. Eng., 9, 811–815

Devi, U., Khatri, I., Kumar, N., Kumar, L., Sharma, D., Subramanian, S., *et al.* (2013). Draft genome sequence of a plant growth-promoting rhizobacterium, serratia fonticola strain AU-P3(3). Genome Announc. 1 (6), e00946-13. doi: 10.1128/GENOMEA.00946-13

Drost, S. M., Rutgers, M., Wouterse, M., De Boer, W., and Bodelier, P. L. (2020). Decomposition of mixtures of cover crop residues increases microbial functional diversity. Geoderma 361:114060. doi: 10.1016/j.geoderma.2019.114060

Dubois, L. and Duvauchelle, S. (2004) Integrated control of potato late blight: MILPV, a new French decision support system. Phytoma 575:11–13

EIAR. (2007). Ethiopian Institute of Agricultural Research; Addis Ababa, Ethiopia. Crop Technologies Guideline, 173

Eitzinger, J., Trnka, M., Semerádová, D., Thaler, S., Svobodová, E., Hlavinka, P., Šiška, B., Takáč, J., Malatinská, L., Nováková, M. *et al*. (2013). Regional climate change impacts on agricultural crop production in Central and Eastern Europe—Hotspots, regional differences and common trends. J. Agric. Sci., 151, 787–812

FAO. (2022). (Food and Agriculture Organization of the United Nations). FAOSTAT - Crops and livestock products. https://www.fao.org/faostat/en/#data/QCL. Latest update: 17 February 2022

Fern´Andez, E., L´Opez, D., L´opez-Cabarcos, E. and Mijangos, C. (2005). Viscoelastic and swelling properties of glucose oxidase loaded polyacrylamide hydrogels and the evaluation of their properties as glucose sensors. Polymer 46:2211–17. doi: 10.1016/j.polymer.2004.12.039.

Franke, A.C., Haverkort, A.J. and Steyn, J.M. (2013). Climate change and potato production in contrasting South African agro-ecosystems. 2. Assessing risks and opportunities of adaptation strategies. Potato Research 56:51-66

Green, S. A. and Tan, T. W. (2017). Superabsorbent polymer materials: A review. Reviews in Chemical Engineering, 33(3), 263-282

Habbadi, K., Benkirane, R., Benbouazza, A., Bouaichi, A., Maafa, I., Chapulliot, D. and Achbani, E. H. (2017). Biological control of grapevine crown gall caused by *Allorhizobium vitis* using bacterial antagonists. Int. j. sci. res, 6(6), 1390-1397

Haggoud, A., Benbouaza, A., Bouaichi, A. and Achbani, E. H. (2017). Plant growth promotion and bacterial canker control of *Lycopersicon esculentum* L. cv. Campbell 33 by biocontrol agents. J. Crop Prot, 6(2), 235-244

Hamid, S., Ahmad, I., Akhtar, M.J., Iqbal, M.N., Shakir, M., Tahir, M., Rasool, A. *et al*. (2021). *Bacillus subtilis* Y16 and biogas slurry enhanced potassium to sodium ratio and physiology of sunflower (*Helianthus annuus* L.) to mitigate salt stress. Environ Sci Pollut Res Int. DOI : 10.1007/s11356-021-14344-0

Haverkort, A.J., Franke, A.C., Engelbrecht, F.A. and Steyn, J.M. (2013). Climate Change and Potato Production in Contrasting South African Agro-ecosystems 1. Effects on Land and Water Use Efficiencies. Potato Research 56:31-50

Hijmans, R. J. (2003). The effect of climate change on global potato production. Am. J. Pot. Res. 80, 271–279. doi: 10.1007/bf02855363

Holden, N., Brereton, A., Fealy, R., and Sweeney, J. (2003). Possible change in Irish climate and its impact on barley and potato yields. Agric. For. Meteorol. 116, 181–196. doi: 10.1016/s0168-1923(03)00002-9

Hüttermann, A., Zommorodi, M. and Reise. K. (1999). Addition of hydrogels to soil for prolonging the survival of Pinus halepensis seedlings subjected to drought. Soil & Tillage Research 50:295–304. doi:10.1016/S0167-1987(99)00023-9

Hüttermann, A., Zommorodi and M., Reise, K. (1999). Addition of Hydrogels to Soil for Prolonging the Survival of Pinus Halepensis Seedlings Subjected to Drought. Soil Tillage Res., 50, 295–304

Ilangumaran, G. and Smith, D.L. (2017). Plant growth promoting rhizobacteria in amelioration of salinity stress: A systems biology perspective. Front. Plant Sci 8:1768

Ipek, M., Arikan, S., Pirlak, L. and Eșitken, A. (2019). Sustainability of crop production by PGPR under abiotic stress conditions, in Plant Growth Promoting Rhizobacteria for Agricultural Sustainability, eds. A. Kumar, and V. Meena (Singapore: Springer), 293–314. doi: 10.1007/978-981-13-7553-8_15

Koo, S.-Y. and Cho, K.-S. (2009). Isolation and characterization of a plant growth promoting rhizobacterium, *serratia sp.* SY5. J. Microbiol. Biotechnol. 19, 1431–1438

Ku, G., Edwards, E. and Tanner, C.B. (1977). Effects of light, carbon dioxide and temperature on photosynthesis, oxygen inhibition of photosynthesis and transpiration in *Solanum tuberosum*. Plant Physiol 59:868–872

Kumar, S. N., Govindakrishnan, P. M., Swarooparani, D. N., Nitin, C., Surabhi, J. and Aggarwal, P. K. (2015). Assessment of impact of climate change on potato and potential adaptation gains in the Indo-Gangetic Plains of India. International Journal of Plant Production, 9(1), 151-170

Leciejewski, P. (2009). The Effect of Hydrogel Additives on the Water Retention Curve of Sandy Soil from Forest Nursery in Julinek. J. Water Land Dev., 239–247

Lyu, D., Backer, R., Subramanian, S. and Smith, D. L. (2020). Phytomicrobiome coordination signals hold potential for climate change-resilient agriculture. Front. Plant Sci. 11:634. doi: 10.3389/fpls.2020.00634

Mahdi, I., Hafidi, M., Allaoui, A. and Biskri, L. (2021). Halotolerant endophytic bacterium *serratia rubidaea* ED1 enhances phosphate solubilization and promotes seed germination. Agric. 11, 224. doi: 10.3390/AGRICULTURE11030224

Mayak, S., Tirosh, T. and Glick, B. R. (2004). Plant growth-promoting bacteria confer resistance in tomato plants to salt stress. Plant Physiol. Biochem. 42, 565–572. doi: 10.1016/j.plaphy.2004.05.009

Maysinger, D. (2007). Nanoparticles and Cells: Good Companions and Doomed Partnerships. Org. Biomol. Chem., 5, 2335–2342

Meena, V.S., Mishra, P.K., Bisht, J.K. and Pattanayak, A. (2017). Agriculturally Important Microbes for Sustainable Agriculture, Volume 2: Applications in Crop Production and Protection. Springer, Singapore. doi: 10.1007/978-981-10- 5589-8

MoANR. (2016). Ministry of Agriculture and Natural Resource; Addis Ababa, Ethiopia. Plant Variety Release, Protection and Seed Qual1ty Control Directorate. Crop Variety, 19, 178

Moradi, R., Koocheki, A., Nassiri Mahallati, M. and Mansoori, H. (2013). Adaptation strategies for maize cultivation under climate change in Iran: irrigation and planting date management. Mitigation and adaptation strategies for global change, 18, 265-284

Msimbira, L. A., Naamala, J., Lyu, D. and Smith, D. L. (2021). PGPR in agriculture: A sustainable approach to increasing climate change resilience. Frontiers in Sustainable Food Systems, *5*, 667546

Neelam, A., Sharma, P. and Saini, R. (2018). Effects of planting methods on growth, yield and economics of potato (*Solanum tuberosum* L.) in hills of Uttarakhand. Indian J Agron. 63(3), 315-318. doi: 10.5958/0974-8164.2018.00055.4

Ozkan, B. and Akcaoz, H. (2002). Impacts of climate factors on yields for selected crops in the Southern Turkey. Mitigation and Adaptation Strategies for Global Change, 7, 367-380

Paluszek, J. and Zembrowski, W. (2008). Improvement of Water-Air Properties of Eroded Soils in a Loess Landscape after the Application of Agrohydrogel. Ann. Wars. Univ. Life Sci.-SGGW. Land Reclam., 39

Pareek, A., Dhankher, O. P. and Foyer, C. H. (2020). Mitigating the Impact of Climate Change on Plant Productivity and Ecosystem Sustainability. Oxford: Oxford University Press UK. doi: 10.1093/jxb/erz518

Pazderů, K., Hamouz, K., Lachman, J. and Kasal, P. (2016). Yield potential and antioxidant activity of potatoes with coloured flesh. Plant Soil Environ., 61, 417–421

Pei, H. and Li, G. (2017). Superabsorbent polymer materials: A review. Reviews in Chemical Engineering, 33(3), 253-266

Peppas, N. A. and Merrill, E. W. (1977). Crosslinked poly (vinyl alcohol) hydrogels as swollen elastic networks. Journal of Applied Polymer Science, 21(7), 1763-1770

Piccoli, P. and Bottini, R. (2013). Abiotic stress tolerance induced by endophytic PGPR, in Symbiotic Endophytes, eds. R. Aroca (Berlin; Heidelberg: Springer), 151–163. doi: 10.1007/978-3-642-39317-4_8

Qiao, Q., Wang, F., Zhang, J., Chen, Y., Zhang, C., Liu, G., *et al*. (2017). The variation in the rhizosphere microbiome of cotton with soil type, genotype and developmental stage. Sci. Rep. 7, 1–10. doi: 10.1038/s41598-017-04213-7

Qin, Y., Druzhinina, I. S., Pan, X. and Yuan, Z. (2016). Microbially mediated plant salt tolerance and microbiome-based solutions for saline agriculture. Biotechnol. Adv. 34, 1245–1259. doi: 10.1016/j.biotechadv.2016.08.005

Rosenzweig, C., Phillips, J., Goldberg, R., Carroll, J. and Hodges, T. (1996). Potential impacts of climate change on citrus and potato production in the US. Agricultural Systems, 52(4), 455-479

Rymuza, K., Radzka, E. and Lenartowicz, T. (2015). Effect of weather conditions on early potato yields in east-central Poland. Commun. Biometry Crop Sci., 10, 65–72

Sadik, S., Mazouz, H., Benbouazza, A. B. A. and Achbani, E. H. (2015). Biological control of bacterial onion diseases using a bacterium, *Pantoea agglomerans* 2066-7. International J. Sci. Res, 4(1), 103-111

Sampaio, S. L., Petropoulos, S. A., Alexopoulos, A., Heleno, S. A., Santos-Buelga, C., Barros, L. and Ferreira, I. C. F. R. (2020). Potato peels as sources of functional compounds for the food industry: A review. Trends in Food Science & Technology, (103), 118–129. doi: 10.1016/j.tifs.2020.07.015

Sessitsch, A., Kuffner, M., Kidd, P., Vangronsveld, J., Wenzel, W.W., Fallmann, K. and Puschenreiter, M. (2013). The role of plantassociated bacteria in the mobilization and phytoextraction of trace elements in contaminated soils. Soil Biol Biochem 60:182–194

Setiawati, T. and Mutmainnah, L. (2016). Solubilization of potassium containing mineral by microorganisms from sugar cane rhizosphere. Agric Sci Procedia 9:108–117

Shimoda, S., Kanno, H. and Hirota, T. (2018). Time series analysis of temperature and rainfall-based weather aggregation reveals significant correlations between climate turning points and potato (*Solanum tuberosum* L.) yield trends in Japan. Agric. For. Meteorol., 263, 147–155

Sindhu, S., Dahiya, A., Gera, R. and Sindhu, S. S. (2020). Mitigation of abiotic stress in legume-nodulating rhizobia for sustainable crop production. Agri. Res. 9 :444. doi: 10.1007/s40003-020-00474-3

Sookhtanlou, M., Allahyari, M. S. and Surujlal, J. (2022). Health Risk of Potato Farmers Exposed to Overuse of Chemical Pesticides in Iran. Safety and Health at Work, 13(1), 23-31. doi: 10.1016/j.shaw.2021.09.004

Sparks, A. H., Forbes, G. A., Hijmans, R. J. and Garrett, K. A. (2014). Climate change may have limited effect on global risk of potato late blight. Global change biology, 20(12), 3621-3631

Spitters, C. J. T. and Groot, P. J. (1989). Effects of water stress on photosynthesis and chlorophyll fluorescence of five potato cultivars. Potato Res. 32, 17–32

Sprenger, H. *et al*. (2018). Metabolite and transcript markers for the prediction of potato drought tolerance. Plant Biotechnol. J. 16, 939–950

Steyn, J.M., Du Plessis, H.F., Fourie, P. and Hammes, P.S. (1998). Yield response of potato genotypes to different soil water regimes in contrasting seasons of a subtropical climate. Potato Research 41:239-254

Van der Waals, J. E., Krüger, K., Franke, A. C., Haverkort, A. J. and Steyn, J. M. (2013). Climate Change and Potato Production in Contrasting South African Agro-Ecosystems 3. Effects on Relative Development Rates of Selected Pathogens and Pests. Potato Res. 56(1), 67–84. doi: 10.1007/s11540-013-9231-3

Yadav, M., Khan, S. and Anis, A. (2016). Application of superabsorbent polymers (SAP) as soil conditioner in agriculture. Journal of Environmental Chemistry and Ecotoxicology, 8(1), 1-11

Yang, J., Kloepper, J.W., Ryu, C.M. (2009). Rhizosphere bacteria help plants tolerate abiotic stress. Trends Plant Sci 14:1–4

Zafar-Ul-Hye, M., Muhammad, H., Zahir, F., Ahmad, Z., Hussain, M. and Hussain, A. (2014). Application of ACC-deaminase containing rhizobacteria with fertilizer improves maize production under drought and salinity stress. Int. J. Agric. Biol. 16, 591–596. Available online at: http://www.fspublishers.org/published_papers/37071_.pdf