AMELIORATION POTATO PLANT PERFORMANCE UNDER DROUGHT CONDITIONS IN IRAQ BY USING TITANIUM DIOXIDE, AND BIODEGRADING, BIODEGRADABLE TREATMENTS

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ABSTRACT

This study was aimed to mitigate the issue of drought in potato production and quality using number of sustainable strategies. The experiment carried out at vegetable field of the College of Agricultural Engineering Sciences - University of Baghdad during spring season 2023. The experiment was conducted using split arrangement within Randomized Complete Block Design with two factors and three replicates (2X6X3). Applying TiO_2-NPs represented the first factor (main plot) (10 mg.L^{-1}), which symbolized (T_0, T_1). six treatments were included to represent subplots (regular irrigation interval (I) prolonged irrigation interval (D), fungal biofertilizers (D_B), fungal biofertilizers + mannitol (D_{BM}), fungal biofertilizers +xanthan (D_{BZ}), fungal biofertilizers + mannitol+ xanthan (D_{BMZ}). Results showed the superiority of spraying TiO2-NPs in all yield traits. Also the results revealed interaction treatment T_1D_{BMX} in producing significant results the entire vegetative growth traits and stress related enzymes concentrations in compare to control treatment T_0D.

Keywords: biofertilizers; xanthan gum; biopolymer, mannitol; climate change; food security

تحسين اداء نبات البطاطا تحت ظروف الجفاف في العراق باستعمال ثنائي اوكسيد التيتانيوم والمعاملات المحللة والقابلة للتحلل

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المستخلص

هدفت التجربة الى تخفيف تأثير الاجهاد البيئي على انتاجية ونوعية نبات البطاطا باستعمال عدد من المعاملات المستدامة، نفذت تجربة حقلية في حقول كلية علوم الهندسة الزراعية/جامعة بغداد للموسم الربيعي 2023. طُبقت التجربة باستعمال تصميم القطاعات الكاملة المعشاة حسب ترتيب القطع المنشقة بعاملين وثلاث مكررات (3X6X2)، فيما يخص العامل الاول فتم اضافة TiO_2–NPs بمستويين (0، 10مل.لتر$^{-1}$) والذي رُمز له (T_0 وT_1)، اما العامل الثاني فتضمن ست معاملات وزعت كقطع ثانوية كالاتي (ري طبيعي I، ري بمدة متباعدة D، اسمدة احيائية تحت ظرف الري المتباعد D_B، اسمدة احيائية تحت ظرف الري المتباعد+ مانيتول D_{BM} ، اسمدة احيائية تحت ظرف الري المتباعد+ صمغ الزنثان D_{BZ} ، اسمدة احيائية تحت ظرف الري المتباعد+ مانيتول+صمغ الزنثان D_{BMZ}) . اظهرت النتائج التفوق المعنوي لرش TiO_2–NPs في جميع صفات الحاصل، فضلا عن تفوق معاملة التداخل T_1D_{BMX} بإعطائها اعلى القيم في مؤشرات النمو الخضري والانزيمات المتعلقة بالاجهاد مقارنة مع معاملة الري المتباعد بدون اضافة T_0D .

الكلمات المفتاحية: الاسمدة الاحيائية، صمغ الزانثان، بوليمر حيوي، مانيتول، التغير المناخي، الامن الغذائي.

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INTRODUCTION

The threats of climate change, drought, demographic development, and the reduction in arable land have raised concerns about food security and malnutrition throughout the past 20 years in Iraqi (7). Securing nutritious and healthy food has grown to be an issue with significant obstacles at various levels. Therefore, the solutions that be taken must reconsider in terms of introducing new drought-tolerant crops, Moreover, improving the sustainability and efficiency of the utilized resources; such as soil and plant resources, by optimally exploiting them using environmentally friendly and inexpensive tools, in addition to improve the nutritional value of the produced crop so that the individuals do not experience what is called hidden hunger. (35). Therefore, using economic, clean and sustainable methods is one of optimal solutions proposed to confront these threats (15).Potatoes (*Solanum tuberosum* L.) rank among the most crucial strategic crops globally, forming the foundation of food security for many populations, as a result of the presence of the three foundational elements of food security, which include availability, accessibility, and stability (14, 22). Consequently, addressing the challenges posed by Iraq's climatic dilemma through the implementation of sustainable and eco-friendly solutions that could help crop productivity in drought conditions, while also improving the nutritional quality of potatoes; even more; those sustainable tools preserve and rebuild soil resource (26). When it comes to drought resistance, titanium oxide is one of the most standard and efficient compounds. Spraying the aforementioned substance has been the focus of several studies in an effort to lessen the effects of salt and water stresses (29).TiO_2-NPs had shown to promote growth metrics such as shoot biomass and chlorophyll concentration under stress conditions in many crops (11, 12, 23, 24) TiO_2-NPs has been linked with lowering oxidative stress markers in plants under stress conditions (1, 16). Moreover; TiO_2-NPs raise photosynthesis efficiency through boosting the activity of its key enzymes including Rubisco (28, 30). It is evident that sustainable improvement for soil resources is achieved by biofertilizers since they promote soil microbial community over time and that reflects on plant productivity (4, 21, 34). They considered a continuous source of improvement by increasing the solubility of the nutrients (2), promoting organic matter biodegradation (8), and excreting beneficial hormones (3), Khosravifar et al (25) reported that mycorrhizal fertilization for potatoes conducive to yielding significant findings in leaf area index by 60%, Shoot dry weight by 40%, and tuber yield by 36% compared with non-inoculated plants under water deficit conditions. Mannitol demonstrated to play a role in controlling photosynthetic capacity (13). Mahdy et al (27) found that treating corn plant with mannitol and mycorrhiza biofertilizers produced significant dry matter, chlorophyll concentration, and N concentration under drought conditions. A biodegradable and eco-friendly tool to drought is the use of xanthan gum, which improves soil water retention (10). Xanthan gum is categorized as a polysaccharide (biopolymer) with drought-resistant microbiological and physical characteristics (31). According to Tran et al. (32), adding xanthan gum to soil increased its water retention and increased lawns' resilience to water deficiency. Thus, the study sought to address the issue of drought and try to mitigate it using a number of strategies that have been shown in several studies to be beneficial in reducing water stress with a sustained effect, including natural titanium dioxide, sugars, biofertilizers, and biopolymers. Thus, in addition to boosting output and enhancing quality, this could helped create an environment that aids plants in fending off the negative consequences of stress.

MATERIALS AND METHODS

Field preparation, planting, harvest: The research station (A) of the College of Agricultural Engineering Sciences, University of Baghdad (Al-Jadiryah), was the site of this experiment in the spring season of 2023. The chemical and physical properties of the soil are displayed in Table (1). Santana hybrid class (Elite) potato tubers were planted in a single row in the center of the furrows on January 28, 2023. There was drip irrigation installed in the field. Plants were spaced 0.25 meters apart from one another and 0.75m among rows.

Planting density was 53333 plant.ha^{-1}. After 120 days of planting, every plot was harvested.

Table 1. Physical and chemical properties of the soil

Character	Value
pH	6.16
$EC_{1:1}$ (ds.m^{-1})	390.8
Total N (mg kg^{-1})	53.8
P (mg kg^{-1})	12.5
K (mg kg^{-1})	168.8
Ca (mg kg^{-1})	185.8
Mg (mg kg^{-1})	168.8
Fe (mg kg^{-1})	1.4
Na (Meq L^{-1})	59.8
Cl^- (Meq L^{-1})	49.8
SO_4^{-2} (Meq L^{-1})	205.8
HCO_3^- (Meq L^{-1})	475.8
O.M. (%)	9.1
Gypsum (%)	318.8
Sand (%)	10.8
Silt (%)	38.8
Clay (%)	46.8
Texture	Clay loam

Experimental design

The experiment was implemented by using split plot arrangement within Randomized Complete Block Design with three replicates (2X6X3), in which titanium dioxide represented the main factor with two concentrations (0, and 10 mg.L^{-1}) which symbolized (T_0, T_1), six treatments were included to represent subplots (drought mitigation strategies DMS) (regular irrigation interval (I) (as control) (4 days), prolonged irrigation interval (D) (8 days) according to Al-Rubaie recommendation (5, 6), fungal biofertilizers under (D), (D_B), fungal biofertilizers + mannitol under (D) (D_{BM}), fungal biofertilizers +xanthan under (D) (D_{BZ}), fungal biofertilizers + mannitol+ xanthan under (D) (D_{BMZ}). Titanium dioxide (nano-anatase) was applied three times following the growth cycle of the potato plant; specifically, the initial application occurred during the vegetative growth phase, the second application took place at the tuber initiation stage, and the final application was done during the tuber enlargement stage. Fungal biofertilizers (mycorrhizae *Glomus intraradices* + trichoderma *Tricoderma asperellum*) mixed with corn cobs residues (50 spores.1g^{-1}) and positioned as a pad beneath the tuber during planting in the soil at a dosage of 20g for each tuber. Xanthan gum mixed with the soil at 1% percent before planting. Mannitol injected three times at a concentration (30mM.L^{-1}) according to the mentioned potato growth cycle in rhizosphere zone.

Study traits

Field traits: Vegetative traits were fixed; chlorophyll concentration in leaves (mg.100^{-1}g FW) (18), leaf area (dcm^2), vegetative dry biomass (g.). The measured yield traits were tuber weight (g), tuber dry matter percent (%), and marketable yield (ton.ha^{-1}).

Laboratory traits (Stress combating indicators): Stress combating indicators were determined in plant laboratory/ office of agricultural researches/ ministry of science and technology. The traits were detected as follows: leaves ascorbic acid concentration (mg.100g f.w.) (20), leaves peroxidase and catalase enzymes concentrations (unite.ml^{-1}) (33) (19).The data were analyzed through analyses of variance and the averages were compared using L.S.D. test under 5%probability.

RESULTS AND DISCUSSION

Vegetative growth traits

Results in table 2 reveal that spraying Titanium dioxide (nano-anatase) has a significant influence on potato plant leaf area (68.39 dcm^2), and canopy dry weight (75.83 g), when compared to non-spraying (T_0) (64.56 dcm^2, 267.9 mg.100g^{-1} f.w., 68.94 g) respectively. Table 2 also reveals that normal irrigation treatment (I) produced the highest plant leaf area (75.02 dcm^2), chlorophyll conc. (325.8mg.100g^{-1} f.w.), and canopy dry weight (88.67.5g). However; drought mitigation treatments had a profound impact in alleviating water stress. In fact; the most superior treatment is D_{BMX} (bifertilizer+mannitol+xanthan); which comes after (I) treatment in the mentioned treatments (70dcm^2, 296.8mg.100g^{-1} f.w., 80.5g) respectively , in compare with the lowest traits with untreated plants under drought conditions which show noticeable reduction in all mentioned traits. Interaction between titanium dioxide and drought mitigation treatments produces significant findings in plant height and canopy dry weight, in which T_1I exhibits superiority in producing the largest plant leaf area (78 dcm^2) and the heaviest dry canopy weight (91g). However; T_1D_{BMX} treatment doesn't significantly differ from T_1I in dry canopy weight (87g). Even more; it reveals superiority over all drought treatment in producing the highest leaf area (70. 33 dcm^2). The smallest leaf area (51 dcm^2) and the lightest vegetative dry weight (54.67g) found in untreated plants under drought conditions (T_0D).

Stress combating indicators

Spraying TiO_2-NPs shows significant impact over none spraying in all stress combating indicators (Table 3). Drought mitigation treatments show significant superiority in the entire stress combating indicators (Table 3). In fact; plants treated with bio fertilizers, biopolymer, and mannitol under drought conditions significantly accumulated Ascorbic acid (48 mg.100g $f.w.^{-1}$) peroxidase enzyme (0.465 $unite.ml^{-1}$) catalase enzyme (31 $unite.ml^{-1}$) in their leaves over all other treatments. While the lowest concentrations found in regulary irrigated potato leaves (I) (37.33 mg.100g $f.w.^{-1}$,0.178 $unite.ml^{-1}$, 11.45 $unite.ml^{-1}$) respectively. The interaction between TiO_2-NPs and drought mitigation treatments conducive to significant results in catalase enzyme individually. T_1D_{BMX} has the elevated concentration (33.63 $unite.ml^{-1}$) in comparing with T_0I treatment (11.57 $unite.ml^{-1}$).

Table 2. Effect of titanium dioxide (T), and drought mitigation strategies (DMS): biofertilizers (B), mannitol (M), and xanthan gum (X) on vegetative growth traits of potato plant under drought conditions

traits treatments	Plant leaf area (dcm^2)	Chlorophyll conc. (mg.100g^{-1} f.w.)	Canopy dry weight (g)
		T	
$T_{0\ (control)}$	64.56	267.9	68.94
T_1	68.39	289.6	75.83
LSD($_{0.05}$)	2.163	N.S.	2.886
		DMS	
I [irrigated (control)]	75.02	325.0	88.67
D [drought]	54.17	227.3	56.50
D_B	63.67	265.3	66.33
D_{BM}	67.33	273.7	68.83
D_{BX}	68.67	284.3	73.50
D_{BMX}	70.00	296.8	80.50
LSD($_{0.05}$)	2.205	12.38	3.734
		T X DMS	
T_0I (control)	72.03	336.5	86.33
T_0D	51.00	206.7	54.67
T_0D_B	60.67	255.0	63.00
T_0D_{BM}	66.00	266.7	66.33
T_0D_{BX}	68.00	275.7	74.00
T_0D_{BMX}	69.67	290.0	69.33
T_1I	78.00	313.3	91.00
T_1D	57.33	248.0	58.33
T_1D_B	66.67	275.7	69.67
T_1D_{BM}	68.67	280.6	71.33
T_1D_{BX}	69.33	293.0	77.67
T_1D_{BMX}	70.33	303.7	87.00
LSD($_{0.05}$)	3.018	N.S.	4.148

Table 3. Effect of titanium dioxide (T), and drought mitigation strategies (DMS): biofertilizers (B), mannitol (M), and xanthan gum (X) on drought stress combating indicators of potato plant leaves under drought conditions

traits / treatments	Ascorbic acid (mg.100g f.w.$^{-1}$)	peroxidase enzyme(unite.ml^{-1})	catalase enzyme (unite.ml^{-1})
		T	
$T_{0\ (control)}$	41.56	0.325	20.65
T_1	44.94	0.406	25.06
LSD$_{(0.05)}$	1.673	0.026	1.206
		DMS	
I [irrigated (control)]	37.33	0.178	11.45
D [drought]	42.17	0.320	16.67
D_B	44.17	0.381	23.66
D_{BM}	44.33	0.415	26.50
D_{BX}	43.50	0.435	27.83
D_{BMX}	48.00	0.465	31.00
LSD$_{(0.05)}$	2.233	0.033	1.563
		T X DMS	
T_0I (control)	36.00	0.146	11.57
T_0D	39.67	0.280	14.67
T_0D_B	43.00	0.363	21.33
T_0D_{BM}	43.02	0.373	23.32
T_0D_{BX}	41.67	0.380	24.67
T_0D_{BMX}	46.00	0.410	28.30
T_1I	38.67	0.210	11.33
T_1D	44.66	0.360	18.67
T_1D_B	45.34	0.400	26.00
T_1D_{BM}	45.66	0.456	29.66
T_1D_{BX}	45.30	0.490	31.00
T_1D_{BMX}	50.00	0.520	33.63
LSD$_{(0.05)}$	N.S.	N.S.	1.733

Yield traits

Table (4) presents significant impact of titanium dioxide spraying on the entire yield traits. Indeed; T_1 shows superiority in dry matter percent (21.7%), tuber weight (167.9g), and marketable yield (75.9 ton.ha^{-1}) when compared to the lowest in non-spraying (T_0) Table (4) as well depicts that D_{BMX} treatment significantly superior in dry matter percent (22%), while (I) treated plant produced the highest tuber weight and marketable yield (195.8g, 79.1 ton.ha^{-1}) respectively and the lowest dry matter percent (20.4%). Nevertheless; untreated plants under drought conditions (D) revealed the most reduction in tuber weight and marketable yield (117.5g, 53.9ton.ha^{-1}) respectively. As for interaction between titanium dioxide and drought mitigation treatments; T_1I reveals superiority over all treatment in producing the highest tuber weight (216.7 g). the lowest tuber weight found in untreated plants under drought conditions (T_0D) (106g).

Table 4. Effect of titanium dioxide (T), and drought mitigation strategies (DMS): biofertilizers (B), mannitol (M), and xanthan gum (X) on yield traits of potato plant under drought conditions

traits / treatments	Tuber dry matter percent (%)	Tuber weight (g)	Marketable yield ($ton.ha^{-1}$)
		T	
T_0 (control)	21.4	146.6	64.6
T_1	21.7	167.9	75.9
LSD(0.05)	0.133	10.14	2.15
		DMS	
I [irrigated (control)]	20.4	195.8	79.1
D [drought]	21.4	117.5	53.9
D_B	21.7	145.0	57.8
D_{BM}	22.0	148.3	71.1
D_{BX}	22.0	161.0	81.5
D_{BMX}	22.0	175.8	78.1
LSD(0.05)	0.253	17.18	15.32
T_0I (control)	20.4	175.0	69.7
T_0D	21.2	106.7	43.9
T_0D_B	21.6	140.0	51.6
T_0D_{BM}	21.8	143.3	71.3
T_0D_{BX}	21.8	154.7	79.6
T_0D_{BMX}	21.8	160.0	71.1
T_1I	20.5	216.7	88.5
T_1D	21.6	128.3	63.9
T_1D_B	21.8	150.0	64.0
T_1D_{BM}	22.1	153.3	70.8
T_1D_{BX}	22.2	167.3	83.3
T_1D_{BMX}	22.2	191.7	85.1
LSD(0.05)	N.S.	20.33	N.S.

The application of titanium dioxide nanoparticles resulted in obvious enhancement in plant metrics. This might stem from its work in altering the expression of many proteins associated with photosynthesis, energy metabolism, and antioxidant systems. Even more; TiO_2 nanoparticles facilitate better absorption of essential nutrients such as nitrogen, iron, and magnesium. This supports chlorophyll formation and overall plant fitness (16). Under water stress conditions; bio fertilizers (mycorrhizae + trichoderma) demonstrated resilience and high performance in entire plant metrics. This could be due to their role in extending the root system of plants through their hyphal networks, allowing access to water and nutrients in soil pores that are unreachable by plant roots alone. This capability significantly improves the plant's ability to absorb moisture, particularly during periods of low water availability (27). Moreover; the increase in enzymes concentrations in those treatments could be the cause of the significant results (Table 3). The addition of xanthan gum to soil under stress improves its inter-particle cohesion. xanthan gum can significantly increase soil cohesion up to three times greater than untreated soils when the water content is reduced to certain levels. This increase is attributed to the gel like properties of xanthan gum, which create a network that binds soil particles together (10, 31). The significant findings of mannitol appeared to be caused by its role as osmotic agent, creating a water deficit environment that mimics drought stress. This mechanism triggers physiological and biochemical responses in plants, promoting the accumulation of compatible solutes that maintain cellular function under stress conditions. In fact, mannitol can enhance the production of osmolytes, which are crucial for plant survival during periods of water scarcity (27). Ultimately; targeting drought from numerous mechanisms produced better results in compare with using one treatment individually. Potato plant parameters demonstrated noticeable response to the experiment treatment. Those positive findings could be generalized and applied in al a large scale In drought-affected lands in Iraq.

REFERENCES

1.Aghdam, M. T. B., H. Mohammadi, , and M. Ghorbanpour. 2016. Effects of anatase titanium dioxide on physiological and biochemical performance of *Linum usitatissimum* (Linaceae) under well-watered and drought stress conditions. Brazilian journal of botany, 39, 139-146. https://doi.org/10.1007/s40415-015-0227-x

2.Aldolaimy, O. M. S., H. A. Abdul- Ratha, and B. K. Abduljabar. 2024. Effect of bio-organic and mineral fertilization, on the growth and yield of cauliflower (*brassica oleraceae* var.botrytis). Iraqi Journal of Agricultural Sciences –55(5):1667-1675. https://doi.org/10.36103/pt592r56

3.Ali, Z. H., and S. A. Abdul-Latif. 2024. Effect of soaking with atonic, water hyacinths compost and biofertilizers on vegetative and flowering growth of tuberose . Iraqi Journal of Agricultural Sciences, 55(Special), 136-150. https://doi.org/10.36103/ijas.v55iSpecial.1893

4.Al-Khafaji, A. M. H. H., and K. D. H. Al-jubouri. 2024. Individual and interactive utility of biological and physical invigoration for various carrots seeds orders and study their field performance. Iraqi Journal of Agricultural Sciences, 55(4) :1566-1573. https://doi.org/10.36103/66873c67

5.Al-Rubaie; A. H. S. and K. D. H. Al-Jubouri. 2023. Effect of tocopherol, trehalose and soil improvement in water productivity and industrial potatoes under water stress. Iraqi Journal of Agricultural Sciences, 54(4):979-995. https://doi.org/10.36103/ijas.v54i4.1787

6.Al-Rubaie; A. H. S. and K. D. H. Al-Jubouri. 2023. Response of growth and yield of industrial potatoes to soil improvement and spraying with tocopherol and trehalose under water stress. Iraqi Journal of Agricultural Sciences, 54(4):963-978. https://doi.org/10.36103/ijas.v54i4.1786

7.Al-Timimi, Y., K., and F. Y. Baktash. 2024. Monitoring the shift of rainfed line of 250 mm over Iraq. Iraqi Journal of Agricultural Sciences, 55(3):931-940. https://doi.org/10.36103/h10cqh53

8. Asoegwu, C. R., C. G. Awuchi, K. C. T. Nelson, C. G. Orji, O. U. Nwosu, U. C. Egbufor, and C. G. Awuchi. 2020. A review on the role of biofertilizers in reducing soil pollution and increasing soil nutrients. Himalayan Journal of Agriculture, 1(1), 34-38. DOI : 10.47310/hja.2020.v01i01.006

9.Baqir, H. A., M.F.H. AL-hassan, and J. W. Mahmood. 2024. Role of Bio Health Extract on wheat Growth according to Zadoks decimal scale. Res. Crop. 25 (4): 547-552 DOI: 10.31830/2348-7542.2024.ROC-1130

10.Berninger, T, N. Dietz1 and O.G. Lopez. 2021. Water-soluble polymers in agriculture: xanthan gum as eco-friendly alternative to synthetics. Microbial Biotechnology, 14, 1881–1896. https://doi.org/10.1111/1751-7915.13867

11.Cevik, S. 2023. TiO_2 nanoparticles alleviates the effects of drought stress in tomato seedlings. Bragantia, 82, e20220203. https://doi.org/10.1590/1678-4499.20220203

12.Daler, Selda, O. Kaya, N. Korkmaz, T. Kılıç, A. Karadağ, and H. Hatterman-Valenti. 2024. Titanium Nanoparticles (TiO2-NPs) as Catalysts for Enhancing Drought Tolerance in Grapevine Saplings. Horticulturae, 10(10), 1103. https://doi.org/10.3390/horticulturae10101103

13.Davey, M., W.M.V. D. Montagu. Inze, M. Sanmartin, A. N. Kanellis, I.J.J Smirnoff. J. J. Benzie. D. Strain. F. Favell, and J. Fletcher. 2000. Plant l-ascorbic acid: chemistry, function, metabolism, bioavailability and effects of processing. J. Sci. Food Agric. 80: 825–860.

14.Devaux, A., P. Kromann, and O. Ortiz. 2014. Potatoes for sustainable global food security. Potato Research, 57, 185-199. https://doi.org/10.1007/s11540-014-9265-1

15.FAO .2022. www.fao.org/statistics

16.Farahi, S. M. M., M. E. T. Yazdi, E Einafshar, M. Akhondi, M. Ebadi, S. Azimipour, H. Mahmoodzadeh, and A.

Iranbakhsh. 2023. The effects of titanium dioxide (TiO2) nanoparticles on physiological, biochemical, and antioxidant properties of Vitex plant (*Vitex agnus-Castus* L). Heliyon, 9(11):1-12.

17.Farahi, S. M. M., M. E. T. Yazdi, E. Einafshar, M. Akhondi, M. Ebadi, S. Azimipour, H. Mahmoodzadeh, and A. Iranbakhsh. 2023. The effects of titanium dioxide (TiO2) nanoparticles on physiological, biochemical, and antioxidant properties of Vitex plant (*Vitex agnus-Castus* L). Heliyon, 9(11). doi: 10.1016/j.heliyon

18.Goodwin, T. W. 1976. Chemistry and Biochemistry of Plant Pigment. 2nd Academic. Press. London. NewYork. San Francisco, pp:373.

19.Hadwan, M. H. 2018. Simple spectrophotometric assay for measuring catalase activity in biological tissues. BMC biochemistry, 19, 1-8. https://doi.org/10.1186/s12858-018-0097-5

20.Hewitt, E. J., and G. J. Dickes. 1963. Spectrophotometric measurements on ascorbic acid and their use for the estimation of ascorbic acid and dehydroascorbic acid in plant tissues. Biochemical Journal, 78(2), p.384.

21.Ibrahim, W. A. A., and H. A. Abdul- Ratha. 2024 Effect of vermicompost and biofertilization on the availability of some soil nutrients, growth and yield of squash (*Cucurbita pepo* L.). Iraqi Journal of Agricultural Sciences, 55(5):1627-1636 https://doi.org/10.36103/v5a0jb16

22.Ijesinha B., R., and B. Mouillé. 2019. The contribution of potatoes to global food security, nutrition and healthy diets. American Journal of Potato Research, 96, 139-149. https://doi.org/10.1007/s12230-018-09697-1

23.Javan, M., A. Ameri, Y. Selahvarzi, and P. S. Amin. 2024. TiO2 NPs as a Promising Strategy for Crop Conservation Resulting from Deficit Irrigation in Fragaria× ananassa Cv. Camarosa. Communications in Soil Science and Plant Analysis, 1-17. https://doi.org/10.1080/00103624.2024.2405980

24.Karvar, M., A. Azari, A. Rahimi, S. Maddah-Hosseini, and M. J. A. Lahijani. 2022. Titanium dioxide nanoparticles (TiO_2-NPs) enhance drought tolerance and grain yield of sweet corn (*Zea mays* L.) under deficit irrigation regimes. Acta Physiologiae Plantarum, 44(2), 14. https://doi.org/10.1007/s11738-021-03349-4

25.Khosravifar, S., F. Farahvash, N. Aliasgharzad, M. Yarnia, and F. R. Khoei. 2020. Effects of different irrigation regimes and two arbuscular mycorrhizal fungi on some physiological characteristics and yield of potato under field conditions. Journal of Plant Nutrition, 43(13), 2067-2079. https://doi.org/10.1080/01904167.2020.1758133

26. Lal, R. 2020. Soil Quality and Sustainability. In Methods for Assessment of Soil Degradation (pp. 17-30). CRC press. https://doi.org/10.1201/9781003068716

27.Mahdy, A, N. O Fathi, M M Kandil, and A. E Elnamas. 2012. Synergistic effects of biofertilizers and antioxidants on growth and nutrients content of corn under salinity and water-deficit stresses. Alexandria Science Exchange Journal, 33(October-December), 292-304. http://10.21608/asejaiqjsae.2012.3167

28.Mohajjel S., H. L. Ahmadi, M. Kolahi, and E. M Kazemi. 2021. Effect of TiO 2 NPs on the growth, anatomic features and biochemistry parameters of Baby sun rose (Aptenia cordifolia). Physiology and Molecular Biology of Plants, 27, 2071-2081. doi: 10.1007/s12298-021-01050-x

29.Mohammadi, H., M. Esmailpour, and A. Gheranpaye. 2016. Effects of TiO_2 nanoparticles and water-deficit stress on morpho-physiological characteristics of dragonhead (Dracocephalum moldavica L.) plants. Acta Agriculturae Slovenica, 107(2), 385-396. http://dx.doi.org/10.14720/aas.2016.107.2.11.

30.Sheikhalipour, M., B. Esmaielpour, , G. Gohari, M. Haghighi, , H. Jafari, H. Farhadi and A. Kalisz. 2021. Salt stress mitigation via the foliar application of chitosan-functionalized selenium and anatase titanium dioxide in stevia (*Stevia rebaudiana Bertoni*). Molecules, 26(13), 4090. https://doi.org/10.3390/molecules26134090

31.Sorze, A., F. Valentini, A. Dorigato, and A. Pegoretti. 2023. Development of a xanthan gum based superabsorbent and water retaining composites for agricultural and forestry

applications. Molecules, 28(4), 1952. https://doi.org/10.3390/molecules28041952
32. Tran, A. T. P, I. Chang, and G. Cho. 2019. Soil water retention and vegetation survivability improvement using microbial biopolymers in drylands." Geomechanics and Engineering 17.5: 475-483.
33. Vives-B., Cristofol, A. Starkov, and E. Garcia-Arumi. 2007. Measurements of the antioxidant enzyme activities of superoxide dismutase, catalase, and glutathione peroxidase. Methods in cell biology, 80, 379-393.
34.Wasan, S. M. K. and Ayad W. A. Al-Juboori. 2023. Effect of biofertilizers and spraying with magnesium and calcium on vegetative growth indicators of sweet corn. IOP Conf. Ser.: Earth Environ. Sci. 1225 012031.
DOI 10.1088/1755-1315/1225/1/012031
35.WHO World Health Organization .2020. Antenatal care recommendations for a positive pregnancy experience: nutritional interventions update: multiple micronutrient supplements during pregnancy. World Health Organization, Geneva.