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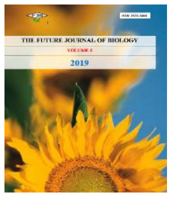

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ALLEVIATING ADVERSE EFFECTS OF IRRIGATION BY SALINE WATER ON GROWTH, PRODUCTIVITY AND FRUIT QUALITY OF STRAWBERRY BY USING SOME SALINITY REDUCERS

Abou El-Khair, E.E.[1] and Manal A. Mandour[2,*]

[1]Hort. Res. Inst., Agric. Res. Centre, Giza**, Egypt.**
[2]Centre Lab. Organic Agriculture, Agric. Res. Centre, Giza, **Egypt.**

[*]**Corresponding author:** manalmandour1968@gmail.com **Received:** 7 May 2022 **; Accepted:** 22 June 2022

ABSTRACT: This experiment was carried out during two successive seasons of 2019/2020 and 2020/2021 at the Experimental Farm of El-Kassasein, Hort. Res. Station, Ismailia Governorate, Egypt, to study the effect of irrigation water sources (ground water, EC= 1254 ppm) and (Nile River water, EC =282 ppm) and treating plants with some salinity reducers (plant growth promoting rhizobacteria, Salt Free as salinity reducer with water irrigation at 2 liter /fad. each and trehalose as foliar application at 2 ml /l) on growth, some plant water relationships, yield and fruit quality of strawberry under sandy soil conditions. Under the irrigation with ground water conditions, treating strawberry plants with some salinity reducers (plant growth promoting rhizobacteria, Salt Free with water irrigation and trehalose as foliar application) increased plant growth, yield and fruit quality compared to control (without salinity reducers) and gave similar results with the plants which irrigated with Nile River water only. In this concern, foliar spray with trehalose at 2 ml/l gave the highest values of dry weight of shoots, total water, free water, total chlorophyll in leaf tissues, salt tolerance index, average fruit weight, yield / plant and total yield/fad., fruit firmness, total soluble solids and vitamin C contents in fruits.

Key words: Strawberry, irrigation water salinity, growth, yield, fruit quality

INTRODUCTION

Strawberry (*Fragaria x ananassa*) cultivation is very important in Egypt's horticultural sector, both domestically and internationally. Salt stress in various forms, on the other hand, causes major problems in strawberry production. The reaction to salt stress in strawberries, as well as certain other crops, has proved highly variable in terms of yield, agronomic, and physiological features (**Gulen *et al*., 2006**).

Strawberry is categorized as one of the most salt-sensitive crops with varying degrees of tolerance among cultivars. Salinity causes leaf edge burn, necrosis, nutrient imbalance or specific ion toxicity, reduction in fruit quality and yield, and potential plant death if salinity stress persists or increases. The plant growth and fruit yield across all strawberry cultivars were reduced by the increased salinity of the irrigation water, but the level of reduction varied with cultivar and the level of salinity (**Sun *et al.*, 2015).** Increasing salinity level significantly reduced fruit yield, fruit weight, fruit volume, fruit length and fruit number of strawberry. On the other hand, they claimed that elevated salinity levels significantly promoted the mortality percentage and enhanced total soluble solids (TSS) resulting in improving fruit quality **(Turhan and Eris, 2004).**

Humic substances might show anti-stress effects under abiotic stress conditions such as unfavourable temperature, salinity, pH, etc. (**Kulikova *et al*. ,2005)**. Humic substances are well known as stimulators of plant germination and growth **(Masciandaro *et al.*, 2002).** Humic acid is a commercial product which is proposed to improve soil fertility and increase the availability of nutrient elements. It consequently affects plant growth and yield and ameliorates the deleterious effects of salt stress. **Saidimoradi *et al.* (2019)** indicated that using humic acid under irrigation with saline water enhanced total dry weight / plant, chlorophyll contents, proline amino acid in leaves, fruit number / plant, average fruit weight and total yield / plant than plants irrigated with saline water only of strawberry.

Trehalose is an organic solute that acts as an osmoprotectant in various crops. It is a non-reducing disaccharide of glucose **(Sadak, 2019).** A very important sugar, trehalose, has been found to be a possible abiotic stress mitigation agent **(Yang *et al.*, 2014).** It acts as a compatible solute and aids in the stabilisation of macromolecules in stressful situations **(Shafiq *et al.*, 2015).** The application of Tre reduced shoot Na accumulation of strawberry (**Samadi *et al.*, 2019**).

Plant growth promoting rhizobacteria can significantly enhance plant growth and represent a mutually helpful plant microbe interaction. Bacillus species are a major type of rhizobacteria that can form spores that can survive in the soil for long period of time under harsh environmental conditions. *Bacillus subtilis* enhances stress tolerance in their plant hosts by inducing the expression of stress-response genes, phytohormones, and stress-related metabolites **(Hashem *et al.*, 2019)**. Treated strawberry cv. 'Chandler with PGPR **(***Bacillus sp***)** significantly increased plant growth, yield and fruit quality, **(Anuradha *et al.*, 2019).** *Bacillus sp* as PGPR inoculations significantly increased the growth, chlorophyll content, nutrient element content, and yield of strawberry plants under salinity conditions. The leaf relative water content of plants rose with bacterial inoculation **(Karlidag *et al.*, 2013).**

Therefore, the object of this work was to enhance the strawberry plants tolerance to salinity and obtain a good yield and best fruit quality by using some salinity reducers through drip fertigation and foliar spray.

MATERIALS AND METHODS

This experiment was carried out during two successive winter seasons of 2019/2020 and 2020/2021 at the Experimental Farm of El-Kassasein, Hort. Res. Station, Ismailia Governorate, Egypt, to study the effect of irrigation water source , i.e., Ground water (GW) and Nile River water **(**NRW**)** and treated plants with some salinity reducers, i.e., plant growth promoting rhizobacteria (PGPR), Salt Free (SF) and trehalose (Tre) on growth, yield and fruit quality and of strawberry under sandy soil conditions.

The soil was sandy in texture which had 0.07 and 0.08 % organic matter, 8.01 and 7.88 pH, 1 and 1.14 mmhos/cm EC, 4.74 and 4.92 ppm available N, 3.53 and 3.49 ppm available P and 9.53 and 9.58 ppm available K, in the 1st and 2nd seasons, respectively. Physical and chemical properties of irrigation water as shown in Table A.

Table A. Some physical and chemical properties of irrigation water

Irrigation water sources	Physical properties		Chemical properties of the irrigation water						
			Soluble cations (meq/l)				Soluble anions (meq/l)		
	pH	EC ds/m	K^+	Na^+	Mg^{++}	Ca^{++}	CO_3^-	HCO_3^-	Cl^-
RNW	7.3	0.44=280 ppm	10.79	14.24	7.0	2.0	0	0.12	2.0
GW	8.3	1.96=1254 ppm	18.82	48.36	4.0	4.0	0	0.2	6.0

Physical and chemical analysis of irrigation water according to Central Laboratory for Soil, Food and Feedstuff (CLSFF), Fac. Of Technology and Development, Zagazig University, Egypt.
NRW: Nile River water, GW: Ground water.

The experiment included eight treatments, which were the combinations between two sources of water (NRW and GW) and three salinity reducers, i.e., PGPR, SR and Tre, beside untreated control plants. These treatments were arranged in a split plot in a randomized complete block design with three replicates. Irrigation water sources were arranged in the main plots and the salinity reducers were distributed in sub plots.

The experimental unit area was 14.7 m^2. It contains three dripper lines, 7 m length and 70 cm distance between the two drippers lines. The distance between plants was 25cm. One line (4.9 m^2) was used to measure the morphological and physiological traits and the other two lines (9.8m^2) were used for yield and quality determinations. In addition, one row was left between each two experimental units as a guard area to avoid the overlapping foliar sprayed and irrigation infiltration. Frigo transplants of strawberry (Festival cultivar) were transplanted on 22th and 28th September during the 1st and 2nd seasons, respectively.

PGPR, which contain isolate of *Bacillus subtilis* and used at dilution of 1:100 (1 mlcontain 10^7 cfu) and SF as salinity reducer contain humic substances (humic and folvic acids), carboxylic acids (an organic acid that contains a carboxyl group) and calcium, these compounds produced by Central Lab. Of Organic Agriculture (CLOA), Agricultural Research Centre, Giza, Egypt, were added through drip irrigation (fustigation system) at 2 l / fad. of each, while Tre, (C_{12} H_{22} O_{11}) was obtained from Sigma Chemical Co. USA. and added as foliar spray at 2 ml/ l. All treatments were added eight applications every two weeks begging transplanting stage. Untreated plants were left as a control treatment.

The agricultural practices concerning cultivation, irrigation, fertilization and insect and disease control were conducted according to the recommendation of the Ministry of Agriculture for strawberry commercial production.

Data recorded

A random sample of five plants from each plot was taken after 105 days from transplanting in the two growing seasons for measuring the vegetative growth, i.e., plant height (cm), number of leaves/plant, and shoot dry weight/plant (g) was measured using dried fresh shoot / plant at 70 ^{o}C till constant weight.

Total chlorophyll (SPAD-unit) was determined in leaves of strawberry in the field immediately by SPAD- 502 meter after 105 days from transplanting according to the method outlined by **Markwell *et al.* (1995)**.

Plant water relations: Total, free and bound water as well as osmotic pressure were determined according to the method described by **Gosev (1960).**

Proline amino acid content: It was determined in dry leaves according to the method described by **Bates (1973).**

Salt tolerance index (STI): Salt tolerance index (STI) is the ratio of the plant dry weight (DW) of the control treatment and plant dry weight of the salt treatments. The STI was calculated from the following relation: **(El Goumi *et al.*, 2014)**: STI% = (Total DW of salt stress % / Total DW of control) x100

Yield and its components: The early yield was determined as weights of all harvested fruits from each plot during February and March months, and then early yield per fadden was calculated. Total yield was recorded from each plot all over the harvested season up to the mid of May, then total yield per faddan (ton) was calculated. (Faddan =4200 m^2=0.42 ha.).

Fruit quality: Samples of ten ripe fruits were chosen randomly from each experimental plot at full ripe stage to determine total soluble solids (T.S.S.%) using hand refractometer, total titratable acididy (TAA) as g of citric acid/ 100 g fruit juice, Ascorbic acid content, it was determined in mg/100g fresh weight using 2, 6 Di chloro phenol Indophenol for titration as the method mentioned in **A.O.A.C. (2018).** Firmness was determined by using a Chattilon pressure meter equipped with a plunger (N,4, USA) a needle 3mm diameter.

Statistical analysis: Recorded data were subjected to the statistical analysis of variance according to **Snedecor and Cochran (1980)**, and means separation were done according to **Duncan (1958).**

RESULTS AND DISCUSSION

1- Plant growth

Effect of irrigation water sources

Data in Tables 1, 2 and 3 show that irrigation of strawberry plant with Nile River water (NRW) gave higher plant height, number of leaves / plant and dry weight of shoots than the irrigation with ground water (GW) at 105 days after transplanting in both seasons. The increases in dry weight of shoots per plant were about 8.12 and 8.77 g for irrigation with NRW over the irrigation with GW in the 1st and 2nd seasons, respectively. The negative effect of salinity on plant growth is function of the relationship between dry mater production and water content (related to water uptake and transpiration) in plant tissue.

Effect of the salinity reducers

Spraying with trehalose (Tre) at 2 ml /l gave the highest values of plant height, number of leaves / plant and dry weight of shoots, followed by SF at 2 l / fad. via fertigation treated plants in both seasons. The increases in dry weight of shoots per plant were about 7.74 and 8.43 g for spraying with Tr, 5.76 and 4.70 g for SF and 3.96 and 3.30g for PGPR over the untreated plants in the 1st and 2nd seasons, respectively.

Trehalose reduced the inhibitory effects of salinity on growth which may be through improving the water status of the plant tissues, since the relative water content of the shoot increased **(Zeid, 2009).** Treated strawberry cv. 'Chandler with PGPR (*Bacillus sp*) significantly increased plant growth **(Anuradha *et al.*, 2019).**

Effect of the interaction

The interaction between irrigation with NRW and spraying with Tr at 2 ml/l increased plant height, number of leaves / plant and dry weight of shoots.

Strawberry plants irrigated with NRW and sprayed with Tre at 2 ml/l recorded the tallest plants and gave the highest number of leaves/ plant and shoot dry weight in both seasons. There were no significant differences between the interaction between irrigation with GW and spraying with Tre at 2 ml /l and the interaction between irrigation with NRW and untreated plants in both seasons regarding plant height, number of leaves/ plant and dry weight of shoots in both seasons , except number of leaves / plant in the 1st season . The increases in dry weight of shoots per plant were about 16.34 and 16.96 g for the interaction between irrigation with NRW and spraying with Tre at 2 ml / over the plants irrigated with GW without salinity reducers in the 1st and 2nd seasons, respectively.

The inhibitory effects of salinity with Trehalose on growth may be through improving the water status of the plant tissues, since the relative water content of the shoot increased **(Zeid, 2009).** Growth reduction due to salinity stress was restored by trehalose treatments by improving water status of plant tissues, and dry weight of different plants **(Sadak, 2016).** Finally using Tre as foliar spray and humic acid through drip irrigation mitigated the negative effects of salinity on plant growth of strawberry.

This positive effect of Tre on strawberry was possibly attributed to the improvement of carotenoids, flavonoids and anthocyanins compounds in leaves resulting in normal photochemical functioning, the activation of the enzymatic antioxidants and the compartmentalization of Na for better growth under salt stress (**Samadi *et al.*, 2019**). *Bacillus sp* as PGPR inoculations significantly increased the growth, of strawberry plants under salinity conditions (**Karlidag *et al.*, 2013).**

Table 1. Effect of the interaction between water sources and some salinity reducers on plant height (cm) of strawberry cv. Festival at 105 days after transplanting during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	8.75 e	9.50 e	10.75 d	12.12 d	**10.28 b**
Nile River water	12.40 d	14.16 c	16.32 b	18.95 a	**15.45 a**
Mean (SR)	**10.57 d**	**11.83 c**	**13.53 b**	**15.53 a**	**--**
			2020/2021 season		
Ground water	8.50 g	9.87 f	11.00 e	12.59 d	**10.49 b**
Nile River water	12.37 d	15.03 c	16.64 b	18.28 a	**15.58 a**
Mean (SR)	**10.43 d**	**12.45 c**	**13.82 b**	**15.43 a**	--

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.
Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 2. Effect of the interaction between water sources and some salinity reducers on number of leaves / plant of strawberry cv. Festival at 105 days after transplanting during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	9.12 g	10.49 f	12.12 e	14.03 d	**11.44 b**
Nile River water	15.25 c	16.84 b	17.32 b	19.95 a	**17.34 a**
Mean (SR)	**12.18 d**	**13.66 c**	**14.72 b**	**16.99 a**	**--**
			2020/2021 season		
Ground water	8.49 f	11.37 e	11.70 e	14.74 d	**11.57 b**
Nile River water	14.11 d	15.99 c	17.11 b	19.28 a	**16.62 a**
Mean (SR)	**11.30 d**	**13.68 c**	**14.40 b**	**17.01 a**	--

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.
Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 3. Effect of the interaction between water sources and some salinity reducers on dry weight of shoots / plant (g) of strawberry cv. Festival at 105 days after transplanting during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR) Control	PGPR	SF	Tre	Mean (WS)
			2019/2020 season		
Ground water	19.12 g	22.97 f	24.24 ef	25.14 de	**22.86 b**
Nile River water	26.01 d	30.07 c	32.41 b	35.46 a	**30.98 a**
Mean (SR)	**22.56 d**	**26.52 c**	**28.32 b**	**30.30 a**	
			2020/2021 season		
Ground water	20.62 e	21.71 e	23.60 d	25.60 c	**22.88 b**
Nile River water	25.71 c	31.21 b	32.13 b	37.58 a	**31.65 a**
Mean (SR)	**23.16 d**	**26.46 c**	**27.86 b**	**31.59 a**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l. Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

2- Water relationship, proline and total chlorophyll

Effect of irrigation water sources

The obtained results in Tables 4 to 8 show that irrigation with NRW increased total and free water percentages in leaf tissues, while irrigation with GW increased bound water percentage and proline amino acid content in leaf tissues at 105 days after transplanting in both seasons. There were no significant differences between NRW and GW on total chlorophyll in leaf tissues.

Effect of the salinity reducers

Spraying strawberry plants with Tre at 2 ml /l increased total and free water percentages and total chlorophyll contents in leaf tissues, while bound water and proline amino acid content in leaf tissues decreased with plant growth promoting (PGPR) and SF at 2 l/fad. of each which applied as fertigation and Tre at 2 ml /l which applied as foliar spray. This means that control treatment increased bound water and proline amino acid content in leaf tissues.

Salinity stress was restored by trehalose treatments by improving water status of plant tissues **(Sadak, 2016)**. The leaf relative water content of plants rose with bacterial inoculation **(Karlidag *et al.*, 2013).**

Effect of the interaction

The interaction between irrigation with NRW and spraying with Tre at 2 ml /l significantly increased total water, fresh water percentages and total chlorophyll in leaf tissues , whereas, bound water percentage and proline amino acid content in leaf tissues significantly decreased with the same treatment in both seasons (Tables 4 to 8).

Table 4. Effect of the interaction between water sources and some salinity reducers on total water (%) in leaves of strawberry cv. Festival at 105 days after transplanting during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR) Control	PGPR	SF	Tre	Mean (WS)
			2019/2020 season		
Ground water	81.30 e	82.21 d	82.91 bc	83.53 ab	**82.48 b**
Nile River water	82.52 cd	83.26 b	83.08 bc	84.02 a	**83.22 a**
Mean (SR)	**81.91 c**	**82.73 b**	**82.99 b**	**83.77 a**	
			2020/2021 season		
Ground water	78.44 d	80.64 c	83.00 b	83.16 ab	**81.31 b**
Nile River water	83.03 b	83.00 b	83.31 ab	83.86 a	**83.30 a**
Mean (SR)	**80.73 c**	**81.82 b**	**83.15 a**	**83.51 a**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Strawberry plants which irrigated with NRW and sprayed with Tre at 2 ml /l recorded the maximum values of total water, free water and total chlorophyll in leaf tissues, whereas plants which irrigated with GW and sprayed with Tr at 2 ml /l gave the lowest values of bound water (%) and proline amino acid content in leaf tissues. Proline metabolic accumulation of different plants under salinity stress usually correlates with enhanced plant tolerance to different abiotic stress. In the present work, salinity stress caused significant increase in proline contents whereas decreased by trehalose application (Table 7).

Table 5. Effect of the interaction between water sources and some salinity reducers on free water (%) in leaves of strawberry cv. Festival at 105 days after transplanting during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	46.94 g	51.81 f	56.33 d	60.93 ab	**54.00 b**
Nile River water	53.99 e	59.51 bc	58.72 c	61.05 a	**58.31 a**
Mean (SR)	**50.46 d**	**55.66 c**	**57.52 b**	**60.99 a**	
			2020/2021 season		
Ground water	40.04 f	44.26 e	47.76 d	56.78 a	**49.60 b**
Nile River water	49.21 d	51.64 c	53.34 b	56.43 a	**52.65 a**
Mean (SR)	**44.62 d**	**47.95 c**	**50.55 b**	**56.54 a**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.
Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 6. Effect of the interaction between water sources and some salinity reducers on bound water (%) in leaves of strawberry cv. Festival at 105 days after transplanting during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	34.14 a	30.40 b	26.57 cd	22.60 e	**28.42 a**
Nile River water	28.53 bc	23.75 e	24.36 de	22.97 e	**24.90 b**
Mean (SR)	**31.33 a**	**27.07 b**	**25.46 c**	**22.78 d**	
			2020/2021 season		
Ground water	38.40 a	36.38 b	35.24 bc	26.38 e	**34.10 a**
Nile River water	33.82 c	31.36 d	29.97 d	27.43 e	**30.64 b**
Mean (SR)	**36.11 a**	**33.87 b**	**32.60 c**	**26.91 d**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l. Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 7. Effect of the interaction between water sources and some salinity reducers on proline amino acids (mg /100 g DW) in leaves of strawberry cv. Festival at 105 days after transplanting during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	132.48 a	98.08 b	92.43 cd	72.12 f	**98.78 a**
Nile River water	94.44c	84.16 e	89.99 d	75.56 f	**86.04 b**
Mean (SR)	**113.46 a**	**91.12 b**	**91.21 b**	**73.84 c**	
			2020/2021 season		
Ground water	147.58 a	99.24 b	95.08 c	68.54 e	**102.61a**
Nile River water	89.54d	87.30 d	86.70d	71.15 e	**83.67 b**
Mean (SR)	**118.56 a**	**93.27 b**	**90.89 c**	**69.85 d**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 8. Effect of the interaction between water sources and some salinity reducers on total chlorophyll (SPAD) in leaves of strawberry cv. Festival at 105 days after transplanting during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGR	SF	Tre	
			2019/2020 season		
Ground water	3.46 e	4.11 d	4.27 d	4.93 ab	**4.19 a**
Nile River water	3.64 e	4.41 cd	4.64 bc	5.05 a	**4.43 a**
Mean (SR)	**3.55 d**	**4.26 c**	**4.45 b**	**4.99 a**	
			2020/2021 season		
Ground water	3.43 e	4.10 d	4.30 cd	4.93 ab	4.19 a
Nile River water	3.58 e	4.41 cd	4.67 bc	5.11 a	4.44 a
Mean (SR)	**3.50 c**	**4.25 b**	**4.48 b**	**5.02 a**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

The inhibitory effect of salinity stress on the photosynthetic pigments may be due to the effect of salinity on the activities of photosynthetic enzymes and this may be a secondary effect mediated by the reduced CO_2 partial pressure in the leaves caused by stomatal closure **(Kosová *et al.*, 2011).** Humic acid application improved chlorophyll content and reduced negative effects of salinity. With increasing osmotic potential due to ion accumulation, water uptake is restricted by plant roots. Salinity limits the absorption of enough water by plants and leads to a decline in plant water status **(Singh *et al*., 2015).**

These results are harmony with those reported by **Saidimoradi *et al.* (2019)** who indicated that using humic acid under irrigation with salinity water enhancing chlorophyll contents and proline amino acid in leaves than plants irrigated with salinity water only of strawberry. *Bacillus sp* as PGPR inoculations significantly increased chlorophyll content, of strawberry plants under salinity conditions **(Karlidag *et al.*, 2013).**

Salt tolerance index (STI)

Salt tolerance index (STI) increased by using PGPR , SF and Tre gave the highest values of STI as shown in Table 9 . Salt tolerance index was improved by increasing the amount of total and free water in plant tissues using the PGPR, SF and Tre (Tables 4 and 5). A high significant association was observed between STI and total dry weight and total chlorophyll. All salinity reducers improved the growth of the shoot under salinity which be contributed to an increase in the salt tolerance index. Reducing total dry weight is one of the reasons for the decreasing of STI.

Table 9. Salt tolerance index (%) of strawberry plants under irrigation with ground water condition during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Treatments	2019/2020 season	2020/2021 season	Mean
Nile River water	**Control**	-----	-----	------
Ground water	**Salinity**	73.51	80.20	76.85
	Salinity+ PGPR	88.31	84.44	86.37
	Salinity+SF	93.19	91.79	92.49
	Salinity+Tre	96.65	99.57	98.99

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.

3- Yield and its components

Effect of irrigation water sources

Data in Tables 10 to 14 indicate that average fruit weight, early yield / plant, early yield /fad. total yield / plant and total yield /fad. significantly increased with irrigation of strawberry with NRW compared to the irrigation with GW in both seasons. The negative effect of irrigation with GW on average fruit weight may be attributed to water uptake by strawberry plants declines with the increase in salt concentration in irrigation water causing the decrease in yield / plant and total yield **(Greenway and Munns 1980).** In this regard**, Turhan and Eris (2004)** reported that the increasing salinity level significantly reduced fruit yield, fruit weight, fruit volume, fruit length and fruit number of strawberry.

Effect of the salinity reducers

All salinity reducers treatments significantly increased average fruit weight, early yield / plant, early yield /fad. total yield / plant and total yield /fad. as compared to untreated plants in both seasons. However, foliar spray with Tre at 2 ml /l recorded the highest values of yield and its components, followed by PGPR treatment in both seasons (Tables 10 to 14).

Effect of the interaction

The interaction between irrigation with NRW and spraying with Tre at 2 ml /l significantly increased average fruit weight, early yield / plant, early yield /fad. , total yield / plant and total yield /fad. in both seasons. The highest values of average fruit weight, early yield / plant, early yield /fad. total yield / plant and total yield /fad. of strawberry obtained by irrigation with NRW and spraying with Tre at 2 ml /l, followed by the interaction between irrigation with NW and treated with PGPR at 2 l/fad. via drip irrigation in both seasons. Treated strawberry cv.'Chandler with PGPR **(***Bacillus sp*) significantly increased yield and fruit quality, **(Anuradha *et al.*, 2019).** *Bacillus sp* as PGPR inoculations significantly increased yield of strawberry plants under salinity conditions. **Saidimoradi *et al.* (2019)** indicated that using humic acid under irrigation with salinity water enhanced fruit number / plant, average fruit weight and total yield / plant than plants irrigated with salinity water only.

Table 10. Effect of the interaction between water sources and some salinity reducers on average fruit weight (g) strawberry cv. Festival during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	13.95 e	16.16 d	14.86 de	18.98 c	**15.98 b**
Nile River water	19.56 c	21.24 b	22.24 b	23.83 a	**21.71 a**
Mean (SR)	**16.75 c**	**18.70 b**	**18.55 b**	**21.40 a**	
			2020/2021 season		
Ground water	12.48 f	16.76 d	14.59 e	19.18 c	15.75 b
Nile River water	19.37 c	21.38 b	22.46 ab	23.32 a	21.63 a
Mean (SR)	**15.92 c**	**19.07 b**	**18.52 b**	**21.25 a**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.
Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 11. Effect of the interaction between water sources and some salinity reducers on early yield (g/plant) strawberry cv. Festival during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	58.58 e	68.81 cd	65.39 d	70.12 cd	**65.72 b**
Nile River water	69.10 cd	88.20 b	73.39 c	98.00 a	**82.17 a**
Mean (SR)	**63.84 d**	**78.50 b**	**69.39 c**	**84.06 a**	
			2020/2021 season		
Ground water	60.96 d	66.12 d	64.22 d	75.72 bc	66.75 b
Nile River water	75.00 c	90.48 a	82.53 b	95.36 a	85.84 a
Mean (SR)	**67.98 d**	**78.30 b**	**73.37 c**	**85.54 a**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.
Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 12. Effect of the interaction between water sources and some salinity reducers on early yield (ton/fed.) strawberry cv. Festival during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	2.764 e	3.303 d	2.829 e	3.316 d	**3.053 b**
Nile River water	3.317 d	4.134 b	3.523 c	4.604 a	**3.894 a**
Mean (SR)	**3.040 d**	**3.718 b**	**3.176 c**	**3.960 a**	**---**
			2020/2021 season		
Ground water	2.926 f	3.174 e	3.003 f	3.605 d	3.177 b
Nile River water	3.600 d	4.243 b	3.961 c	4.577 a	4.095 a
Mean (SR)	**3.263 d**	**3.708 b**	**3.482 c**	**4.091 a**	---

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.
Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 13. Effect of the interaction between water sources and some salinity reducers on total yield (g/ plant) strawberry cv. Festival during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	206.09 e	229.77 d	215.30de	262.85 c	**228.50 b**
Nile River water	269.54 c	314.79ab	308.20 b	326.74 a	**304.82 a**
Mean (SR)	**237.82 c**	**272.28 b**	**261.75 b**	**294.79 a**	
			2020/2021 season		
Ground water	202.14 e	238.59 d	222.97de	272.32 c	234.01 b
Nile River water	276.98 c	319.15ab	299.49bc	329.39 a	306.25 a
Mean (SR)	**239.56 d**	**278.87 b**	**261.23 c**	**300.86 a**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.
Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 14. Effect of the interaction between water sources and some salinity reducers on total yield (ton/fed.) strawberry cv. Festival during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	9.914 e	11.005 d	10.300de	12.781 c	**11.000b**
Nile River water	12.918 c	15.082ab	14.774 b	15.604 a	**14.594a**
Mean (SR)	**11.416 c**	**13.044 b**	**12.537 b**	**14.193 a**	
			2020/2021 season		
Ground water	9.681 e	11.427 d	10.667 d	13.034 c	**11.202b**
Nile River water	13.277 c	15.091ab	14.356 b	15.771 a	**14.624a**
Mean (SR)	**11.479d**	**13.259b**	**12.512c**	**14.403a**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

4- Fruit quality

Effect of irrigation water sources

The obtained results in Tables 15 to 18 illustrate that the irrigation of strawberry plants with GW increased fruit firmness, TSS acidity and vitamin C contents in fruits compared to the irrigation with NRW in both seasons.

Husk tomato fruits grown under saline water irrigation show high titratable acidity, this may be attributed to the accumulation of organic acids in tomato fruits grown under salinity seems to counter balance the cation (K^+ and Na^+) excess respective to anions (Cl^- and SO_4^{--}) so maintaining fruits pH (**Petersen *et al.*, 1998**). In addition, increased total soluble solids and acidity content associated with saline irrigation may also be ascribed to the concentration effects due to smaller fruit size as reported by **Ho *et al.* (1996). In** this concern**, Turhan and Eris (2004)** claimed that elevated salinity levels significantly promoted the mortality percentage and enhanced total soluble salt (TSS) resulting in improving fruit quality of strawberry**.**

Effect of the salinity reducers

Spraying with Tre at 2 ml /l increased fruit firmness, TSS acidity and Vitamin C contents, followed by treated plants with PGPR at 2 L/fad. via fertigation, except total acidity in both seasons (Tables 15 to 18). Treated strawberry cv. 'Chandler with PGPR **(***Bacillus sp*) significantly increased fruit quality, **(Anuradha *et al.*, 2019).**

Effect of the interaction

The interaction between irrigation with GW and foliar spray with Tr at 2 ml/l significantly increased fruit firmness, TSS, acidity and Vitamin C contents, followed by the interaction between irrigation with GW and treated plants with PGPR at 2 L/fad. via fertigation, except total acidity in both seasons (Tables 15 to 18).

Table 15. Effect of the interaction between water sources and some salinity reducers on fruit firmness (g/cm^2) of strawberry cv. Festival during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	364.9 c	415.9 b	360.0 c	441.6 a	**395.6 a**
Nile River water	294.3 d	312.4 d	304.9 d	339.9 c	**312.8 b**
Mean (SR)	**329.6 c**	**364.1 b**	**332.4 c**	**390.7 a**	
			2020/2021 season		
Ground water	387.4 c	425.5 b	372.0 c	460.8 a	411.4 a
Nile River water	297.6 f	332.4 de	308.4 ef	349.9cd	322.0 b
Mean (SR)	**342.5 c**	**378.9 b**	**340.2 c**	**405.3 a**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 16. Effect of the interaction between water sources and some salinity reducers on TSS (brix°) in fruits of strawberry cv. Festival during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	8.16 c	8.47 b	8.24 c	8.69 a	**8.39 a**
Nile River water	6.87 f	7.68 d	7.57 e	7.62 de	**7.43 b**
Mean (SR)	**7.51 d**	**8.07 b**	**7.90 c**	**8.15 a**	**---**
			2020/2021 season		
Ground water	7.74 cd	8.47 a	8.24 b	8.54 a	**8.24 a**
Nile River water	6.78 e	7.70 d	7.72 d	7.90 c	**7.52 b**
Mean (WS)	**7.26 c**	**8.08 b**	**7.98 b**	**8.22 a**	-

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 17. Effect of the interaction between water sources and some salinity reducers on total acidity (mg/100 ml juice of strawberry cv. Festival during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	0.357 d	0.413 b	0.476 a	0.480 a	**0.431 a**
Nile River water	0.320 e	0.360 d	0.323 e	0.375 c	**0.344 b**
Mean (SR)	**0.338 d**	**0.386 c**	**0.399 b**	**0.427 a**	
			2020/2021 season		
Ground water	0.357 d	0.432 b	0.457 a	0.461 a	0.426 a
Nile River water	0.332 e	0.360 d	0.353 d	0.390 c	0.358 b
Mean (WS)	**0.344 d**	**0.396 c**	**0.405 b**	**0.425 a**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 18. Effect of the interaction between water sources and some salinity reducers on vitamin C (mg/100 ml juice of strawberry cv. Festival during 2019/2020 and 2020/2021 seasons

Water sources (WS)	Salinity reducers (SR)				Mean (WS)
	Control	PGPR	SF	Tre	
			2019/2020 season		
Ground water	37.72 cd	40.32ab	40.32ab	41.56 a	**39.98 a**
Nile River water	35.27 e	37.22 d	36.02 de	38.87 bc	**36.84 b**
Mean (SR)	**36.49 c**	**38.77 b**	**38.17 b**	**40.21 a**	
			2020/2021 season		
Ground water	39.07 c	39.64 bc	41.28ab	41.95 a	40.48 a
Nile River water	35.72 d	38.27 c	35.72 d	39.22 bc	37.23 b
Mean (WS)	**37.39 c**	**38.95 b**	**38.50 bc**	**40.58 a**	

PGPR= Plant growth promoting rhizobacteria at 2 liter /fad. SF = Salt Free at 2 liter /fad. were applied as fertigation, while Tre = trehalose was applied as foliar spray at 2 ml /l.

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Conclusion

Under drip irrigation with ground water conditions, treating strawberry plants with some salinity reducers (plant growth promoting rhizobacteria, Salt Free with water irrigation and trehalose as foliar application) increased growth, yield and fruit quality compared to control (without salinity reducers) and gave the similar results with the plants which irrigated with Nile River water only.

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RESEARCH ARTICLE

Alleviating adverse effects of irrigation by saline water on growth, productivity and fruit quality of strawberry by using some salinity reducers

Authors' contributions

Author details: Abou El-Khair, E.E.[1] and Manal A. Mandour[2],

[1]Hort. Res. Inst. and [2]Centre Lab. Organic Agriculture Agric. Res. Centre, Giza**, Egypt.**

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