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Improving Productivity and Quality of Faba Bean Irrigated with Agricultural Drainage Water *Via* Biochar and Natural Extracts Rich in Antioxidants

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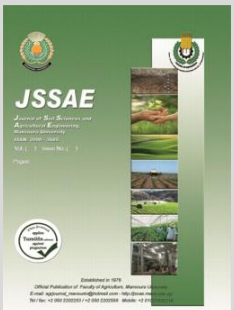

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ABSTRACT

Currently in Egypt, using the agricultural drainage water (ADW) for irrigation purposes as a partial or complete alternative to fresh water (FW) is unavoidable. Therefore, it must find approach that will reduce this harm and maintain productivity without a significant decline in productivity. For this purpose, a field experiment was implemented during two successive seasons (2023/24 and 2024/25) to evaluate applying enhanced biochar (EB) combined with natural extracts on the faba bean irrigated with ADW. Three factors were studied under split-split plot design, as the main factor was the irrigation water type (FW and ADW), while the sub main factor was applying EB [applied at 2.4 ton/hectare]. Also, four foliar treatments [control, green tea, turmeric, and grape seed extracts at a rate of 10.0 cm^3 L^{-1} for each extract] were arranged in the sub-sub plots. The growth criteria (*e.g.,* fresh and dry weights), quantitative and qualitative traits (*e.g.,* seed yield, carbohydrate and protein contents) of faba bean were evaluated. The values of the evaluated parameters under FW treatment were higher than that under AWD treatment. Additionally, the boichar led to improvements in all studied criteria. The superior natural extract was grape seed followed by green tea then turmeric. On the other hand, applying the biochar combined with the grape seed extract under irrigation with ADW had a non-significant effect on the faba bean performance compared to the irrigation with FW without any studied substances. Therefore, it can be recommended to incorporate this approach into the management of low-quality irrigation water.

***Keywords*:** Biochar, Green tea, Turmeric, Grape seed

INTRODUCTION

Egypt has been suffering from increasing water challenges for many years due to increased demand for fresh water and the shortage the water resources, placing a great pressure on its agricultural sector, which is the largest consumer of fresh water (Khedr, 2019). Due to these challenges, it has become necessary to rely on unconventional alternatives for irrigation purposes, such as incorporating agricultural drainage water into irrigation programs, especially in areas suffering from water scarcity. However, the use of this water poses several potential risks to both soil and plants, as it may contain high concentrations of pollutants (Barnes, 2014; Ashour et al. 2021). Hence, there is an urgent need to find an approach that contributes to mitigating the harmful effects of agricultural drainage water.

Biochar is at the forefront of promising solutions. It is an organic carbon material with a high capacity to improve soil properties, adsorb pollutants on its surface, and thus reduce their movement in the root zone (She et al. 2018; Abd El-Hady et al. 2023). This reduces the negative impact of agricultural drainage water on growing higher plants (Huang et al. 2019). Biochar is a reformer produced by the thermal decomposition of farm byproducts at high temperatures (400 to 700°C) under anaerobic conditions (without oxygen) (Wang & Wang, 2019).

On the other hand, some natural plant extracts contain high amounts of antioxidants, making them effective as biostimulants when sprayed on higher plants. They contribute to enhancing the resistance of higher plants to various environmental stress such as salinity, drought, high temperatures, and cold, thanks to their content of phenolic compounds and flavonoids with antioxidant properties (Ahmad et al. 2022).

Turmeric extract (Curcuma longa L.) is one of these extracts, distinguished by its antioxidant properties. It contains curcumin, demethoxycurcumin, and bisdemethoxycurcumin, all of which are powerful antioxidants. It also contains other compounds such as turmerone, atlantone, and zingiberene, which have antimicrobial properties. Furthermore, it contains phenolic compounds, which are powerful antioxidants that can protect higher plant cells. It also contains polysaccharides, which play a unique role in enhancing higher plant immunity, in addition to its mineral and vitamin content (Maizura et al. 2011; Ejimofor, 2022).

Green tea extract (Camellia sinensis L.) is rich in powerful antioxidants such as catechins, flavonoids, and vitamin C. It also contains vitamin E, which enhances the stability of plant cell membranes. It is also rich in the amino acid such as L-theanine, which reduces stress in higher plants. It also contains a high percentage of caffeine, which plays a unique role in plant metabolism (Çavuşoğlu, 2020). It also contains saponins, which have properties that enhance higher plant immunity. Saponins make this extract antifungal and antibacterial. It also contains macro- and micronutrients, which contribute to the nutrition of plants and improve their vital functions (Ibrahim & Al-Sereh, 2019).

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Grape seed extract (Vitis vinifera L.) is also characterized by its high content of natural antioxidants. It contains proanthocyanidins (polymers of flavonoids) that have a very high antioxidant capacity, higher than vitamins C and E. Its proanthocyanidin content protects the higher plant tissues from oxidative damage while simultaneously maintaining plant cell integrity. Grape seed extract also contains flavonoids such as quercetin and kaempferol, which stimulate plant defense enzymes. It also contains gallic acid and ellagic acid, which play a role in combating microbes and reducing damage caused by pollution. It also contains vitamins E and C, and small amounts of vitamin K. It also contains a significant amount of nutrients such as magnesium, iron, and zinc (Memar et al. 2019; Elsherif et al. 2024).

In Egypt, faba bean (*Vicia faba* L.) is of great strategic importance due to its nutritional value, making it one of the most important sources of plant protein (Abou-Khater *et al.* 2022). It is an ideal choice for the current study, evaluating its response to various treatments aimed at reducing damage caused by irrigation with agricultural drainage water and improving its performance.

Therefore, the main objective of the current study is improving productivity and quality of faba bean irrigated with agricultural drainage water *via* biochar as a salt-binding material and foliar spraying with natural extracts rich in antioxidants such as green tea, turmeric, and grape seed.

MATERIALS AND METHODS

A field experiment was implemented during two successive seasons (2023/24 and 2024/25) to achieve the aims of the current study in a private farm located at Meet-Anter Village, Talkha District, Dakahlia governorate, Egypt. Three factors were studied under split-split plot experimental design with three replicates. The main factor was the irrigation water type [fresh water (FW) and agricultural drainage water (ADW)], while the sub main factor was applying acidified biochar [applied at rate of 2.4 ton/hectare or not]. Also, four foliar application treatments [control (tap water), green tea, turmeric and grape seed extracts at a rate of 10.0 cm^3 L^{-1} for each extract] were arranged in the sub-sub plots. The properties of the experimental soil (initial) and both types of irrigation water are shown in Tables 1a & 1b. The preparation methods of the studied substances are shown in Table 2, while Table 3 illustrates their characteristics. Initial soil sample was taken at depth of 25-30 cm and analyzed according to the standard methods mentioned by Tandon, (2005). Irrigation water sample was taken using a bottle immersed at a depth of 50 cm, 1.2 m away from canal bank and analyzed according to the standard methods mentioned by Nollet and De Gelder, (2000).

Faba bean seeds "cv. Nobaria 2, salt-tolerant variety" were obtained from Agricultural Research Center ARC and were sown directly by hand on December 1st in both studied seasons at rate of 30 kg fed^{-1}, with one seed for each hill on one side only under the flooding irrigation system. The experimental area of each sub-sub plot measured 3.0 m^2 (1.5 m long x 2.0 m wide), with 20 cm among each hill.

Seeds were mixed with rhizobium bio-fertilizer (Okadeen) before sowing. Also, an effective nitrogen dose (20 unit N fed^{-1}) were added for all plots in two equal doses, the 1st N-dose was applied with the sowing irrigation event, while the 2nd N-dose was added after three weeks (the time of establishment irrigation), in the form of ammonium sulphate (21% N). Calcium superphosphate (6.6% P) was applied for all plots of the experiment before sowing at three weeks, as its added dose was 25 unit P fed^{-1} as well as plant compost was added at rate of 15 m^3 fed^{-1} for all plots at the same time. Potassium sulfate (39.8% K) was added with the irrigation event that followed the establishment irrigation at a rate of 40 unit K fed^{-1}. Other agriculture practices were implemented as mentioned in the guidelines of the Ministry of Agriculture and Soil Reclamation.

Table 1a. The soil properties before planting

Characteristics	EC, dSm^{-1}	pH	OM, %	N	K	P	Sand	Silt	Clay	Textural class
				ppm			%			
Values	2.25	8	1.25	29.9	188.8	7.58	25.0	26.0	49.0	Clay

Table 1b. The irrigation water properties before planting

Type	pH	EC, dSm^{-1}	Soluble Cations (meq L^{-1})				Soluble Anions (meq L^{-1})			
			Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}	CO_3^{-2}	HCO_3	Cl	SO_4^{-2}
Fresh water	7.25	0.44	1.15	1.09	0.9	1.29	*ND	1.78	2.15	0.5
Agricultural drainage water	7.97	3.46	3.24	5.08	1.1	25.2	*ND	6.2	24.92	3.5

*ND= not detected

Table 2. Preparation methods of the studied substances

Substance	Preparation method	References
Acidified biochar	Dried rice straw was used to produce the studied biochar after being cut into 2-5 cm pieces by pyrolysis at 550°C in a muffle in the absence of oxygen for 2 hours. Then it was left to cool. After cooling, the biochar was ground then screened using a 2 mm sieve. . The biochar was mixed with the acid (dilute sulphuric acid (1% H_2SO_4) dissolved in distilled water) at a ratio of 1:10 (w/v), then the mixture was left to stand for 24 hours with periodic stirring. In the last step, the obtained acidified biochar was washed then dried in an oven at 60°C for 24 hours.	El-Sharkawy *et al.* (2022); Farid *et al.* (2025)
Turmeric extract	To prepare the turmeric extract, 100 g of natural turmeric powder were steeped in 1.0 liter of distilled water at a gentle boil for 60 minutes with stirring continuously. The obtained suspension was filtered using double cheesecloth then *via* Whatman No. 1 filter paper. The final extract was refrigerated in dark bottles in refrigerator.	Park *et al.* (2022)
Green tea extract	To prepare the green tea extract, 100 g of dried green tea leaves were steeped in 1.0 liter of distilled water at a gentle boil for 30 minutes. The obtained tea was filtered using double cheesecloth then *via* Whatman No. 1 filter paper. The final extract was refrigerated in dark bottles in refrigerator.	Komes *et al.* (2010)
Grape seed extract	To prepare the turmeric extract, the grape seeds were dried and finely ground using an electric grinder under room temperature conditions. 100 g of the grape seeds powder were steeped in 1.0 liter of distilled water at a gentle boil for 45 minutes with stirring continuously. The obtained suspension was filtered using double cheesecloth then *via* Whatman No. 1 filter paper. The final extract was refrigerated in dark bottles in refrigerator.	Mandic *et al.* (2008); Mirkarimi *et al.* (2013)

Table 3. The characteristics of the studied substances

Acidified biochar properties					
pH 1:5 w/v in distilled water)	**EC,dSm^{-1}**	**Total carbon,%**	**CEC, cmol kg^{-1}**	**Surface area, m^{2}g^{-1}**	**Bulk density, g cm^{-3}**
6.59	1.40	69	68	260	0.39
		Extracts antioxidants			
Compound/ group			Turmeric E	Green tea E	Grape seed E
Total phenolic content, mg GAE g^{-1} DW			70	95	193
Total flavonoids, mg QEg^{-1} DW			22	56	99.5
Vitamin C, mg g^{-1}			1.5	3.75	3.25
Vitamin E, mg g^{-1}			3.9	1.85	4.85
Antioxidant activity DPPH,%			72	88	95
Epigallocatechin gallate EGCG, mg g^{-1} DW			//	75	//
Proanthocyanidins, mg g^{-1} DW			//		199
Epicatechin, mg g^{-1} DW			//	13	19
Curcumin, mg g^{-1} DW			35	//	//

Concerning the studied treatments, the studied irrigation treatments were implemented after the establishment irrigation event. Fresh water (FW) sourced from Nile River, while agricultural drainage water (ADW) sourced from near the experimental site. Biochar was added, according to the studied treatments, before sowing at three weeks. The foliar application of the studied natural extracts [control (tap water), green tea, turmeric and grape seed extracts] was done three times with 15 days intervals, where the first spraying time was at 30 days from sowing. Harvest was done on May16th during both growing seasons. To evaluate the response of faba bean to studied treatments, some measurements were taken as shown in Table 4. The obtained data were statistically analyzed according to Gomez and Gomez (1984) *via* CoStat software (Version 6.303, CoHort, USA, 1998-2004).

Table 4. The studied measurements of faba bean at two stages

Measurement stage	Measurements	Methods	References
Flowering stage (65-70 days fromsowing)	Plant height (cm), No. of leaves plant^{-1}, fresh weight (g plant^{-1}), dry weight (g plant^{-1}) and leaf area (cm^2 plant^{-1})	Manually (traditional method)	—
	Chlorophyll a, b and carotene (mg g^{-1} FW)	Spectrophotometric method	Picazo *et al.* (2013)
	Leaf N, P and K content (%)	Micro-Kjeldahl, Olsen method (Spectrophotometric) and Flame photometer methods, respectively, after digestion with H_2SO_4:$HClO_4$ (1:1)	Peterburgski, (1968); Walinga *et al.*(2013)
	Catalase CAT, (unit mg^{-1} protein) and peroxidase POD , (unit mg^{-1} protein)	Spectrophotometric method	Elavarthi & Martin, (2010)
	Malondialdehyde (MDA, µmol g^{-1} F.W.)		Valenzuela, (1991)
Harvest time	No. of pods plant^{-1}, pod length (cm), seeds weight plant^{-1}, weight of 100 seed (g), seed yield, ton fed^{-1}	Manually (traditional method)	—
	Carbohydrate content (%) Protein content (%) Total soluble solids (TSS, %) Fiber (%)	Standard laboratory methods	AOAC, (2000)

RESULTS AND DISCUSSIONS

Flowering Stage

All studied traits (*i.e.,* growth criteria, leaf chemical content, photosynthetic pigments, enzymatic antioxidants, and MDA as an oxidation indicator) were significantly affected at the flowering stage due to the irrigation water type, biochar and natural extracts during both studied seasons (Tables 5, 6, 7 and 8). Growth criteria, including plant height (cm), No. of leaves plant^{-1}, fresh weight (g plant^{-1}), dry weight (g plant^{-1}), and leaf area (cm^2 plant^{-1}) were inserted in Table 5. The values of leaf chemical content, *i.e.,* N, P, and K (%) were in Table 6, while the leaf photosynthetic pigments, including chlorophyll a, b and carotene (mg g^{-1}) were tabled in Table 7. Table 8 shows the values of catalase CAT and peroxidase POD enzymes (unit mg^{-1} protein). The values of all parameters under fresh water treatment were higher than those under agricultural drainage water treatment, except for CAT, POD and MDA values, which followed another trend. In other words, the fresh water treatment achieved values of CAT, POD and MDA that were lower than those under agricultural drainage water treatment were. On the other hand, the values of all aforementioned traits, except CAT, POD and MDA values, were higher in the presence of biochar than in the absence of biochar. Regarding the oxidation indicators, the values of CAT, POD, and MDA were lower in the presence of biochar than in its absence. The superior natural extract was grape seed, followed by green tea, then turmeric and lately the control treatment (tap water) in terms of all aforementioned traits, except CAT, POD and MDA, which took the opposite trend, as the highest values of CAT, POD and MDA were achieved with the control treatment. In addition, the lowest values of CAT, POD and MDA were achieved with the grape seed extract treatment. Concerning the interaction effect, the maximum values of growth criteria , chemical and photosynthetic pigments as well as the minimum values of oxidation indicators were recorded when the faba been plants were irrigated with fresh water in conjunction with addition of biochar and grape seeds extract. On the other hand, it can be noticed that applying the biochar combined with the grape seed extract under irrigation with agricultural drainage water had a non-significant effect on the faba bean performance compared to the irrigation with fresh water without any studied substances

Table 5. Effect of irrigation water type, biochar and natural extracts on the growth criteria of faba bean plants at flowering stage during the growing seasons of 2023/24 and 2024/25

Treatments			Plant height,cm		No. of leaves plant^{-1}		Fresh weight, g plant^{-1}		Dry weight, g plant^{-1}		Leaf area, zcm^2 plant^{-1}	
			1stseason	2ndseason	1st season	2ndseason	1st season	2ndseason	1st season	2ndseason	1st season	2ndseason
A: Irrigation water type												
Agricultural drainage water			97.36b	101.26b	20.67b	25.54b	93.29b	94.55b	16.87b	17.58b	396.95b	405.30b
Fresh water			109.41a	114.02a	34.54a	36.33a	108.59a	110.25a	22.57a	23.54a	446.77a	456.14a
F. Test			**	**	**	**	**	**	**	**	**	**
LSD $_{at\ 5\%}$			2.66	1.91	4.35	1.53	0.39	0.23	0.76	0.40	1.61	2.06
B: Biochar addition												
Control (without biochar)			99.96b	104.08b	24.88b	27.54b	96.70b	98.08b	18.16b	18.94b	407.50b	415.50b
With biochar			106.81a	111.20a	30.33a	34.33a	105.19a	106.72a	21.28a	22.18a	436.22a	445.93a
F. Test			**	**	**	**	**	**	**	**	**	**
LSD $_{at\ 5\%}$			0.53	0.88	3.02	4.38	0.63	0.20	0.46	0.17	2.68	0.77
C: foliar application of the natural extracts												
Control (without)			101.07c	105.13d	25.50b	28.58b	97.96d	99.41d	18.49d	19.26d	411.54d	420.20d
Turmeric. E			102.90b	107.00c	27.00ab	30.42ab	99.75c	101.12c	19.28c	20.07c	418.93c	427.32c
Green tea. E			103.92b	108.41b	28.33ab	31.83a	101.47b	103.03b	20.12b	20.97b	424.90b	433.06b
Grape seed. E			105.66a	110.02a	29.58a	32.92a	104.59a	106.04a	20.99a	21.94a	432.07a	442.31a
F. Test			**	**	*	*	**	**	**	**	**	**
LSD $_{at\ 5\%}$			1.08	1.06	2.87	2.81	1.07	1.07	0.46	0.19	4.43	1.56
Interaction among the three factors (A×B×C)												
Agricultural drainage water	Without biochar	Control	90.58	94.08	16.33	19.33	86.83	88.13	13.50	14.08	361.71	367.73
		Turmeric. E	92.97	96.52	17.33	22.00	87.23	88.30	14.76	15.36	377.02	384.40
		Green tea. E	94.47	98.19	18.67	22.00	88.38	89.74	15.78	16.50	377.61	385.54
		Grape seed. E	94.83	98.68	18.67	24.67	92.18	93.53	16.39	17.09	398.02	406.02
	With biochar	Control	98.50	102.30	20.33	26.67	94.50	95.83	17.50	18.21	408.63	416.49
		Turmeric. E	100.91	105.22	23.67	30.67	96.48	97.83	18.02	18.71	410.81	418.52
		Green tea. E	101.67	106.15	23.67	29.33	98.96	100.21	18.83	19.55	420.12	426.09
		Grape seed. E	104.97	108.94	26.67	29.67	101.79	102.83	20.21	21.09	421.68	437.64
Fresh water	Without biochar	Control	105.12	109.64	29.67	31.00	102.16	103.50	20.34	21.19	429.10	438.29
		Turmeric. E	106.40	110.65	30.33	31.33	102.68	104.12	20.74	21.57	432.70	441.96
		Green tea. E	107.04	111.85	33.67	34.33	106.02	107.72	21.35	22.27	439.13	447.72
		Grape seed. E	108.30	113.00	34.33	35.67	108.10	109.60	22.41	23.42	444.68	452.36
	With biochar	Control	110.10	114.50	35.67	37.33	108.35	110.18	22.61	23.58	446.73	458.29
		Turmeric. E	111.31	115.61	36.67	37.67	112.63	114.22	23.61	24.62	455.18	464.38
		Green tea. E	112.49	117.44	37.33	41.67	112.52	114.44	24.52	25.53	462.71	472.87
		Grape seed. E	114.54	119.46	38.67	41.67	116.29	118.20	24.95	26.14	463.91	473.20
F. Test			**	**	*	*	**	**	**	**	**	**
LSD $_{at\ 5\%}$			2.17	2.12	5.75	5.61	2.14	2.14	0.92	0.39	8.87	3.12
F. Test of bilateral interaction												
A×B			**	**	*	*	**	**	**	**	**	**
A×C			**	**	*	*	**	**	**	**	**	**
B×C			**	**	*	*	**	**	**	**	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 6. Effect of irrigation water type, biochar and natural extracts on the chemical leaf content of faba bean plants at flowering stage during the growing seasons of 2023/24 and 2024/25

Treatments			N,%		P,%		K,%	
			1st season	2nd season	1st season	2ndseason	1st season	2nd season
A: Irrigation water type								
Agricultural drainage water			3.36b	3.42b	0.341b	0.348b	1.97b	2.07b
Fresh water			3.77a	3.85a	0.409a	0.420a	2.54a	2.67a
F. Test			**	**	**	**	**	**
LSD $_{at\ 5\%}$			0.08	0.10	0.010	0.001	0.01	0.01
B: Biochar addition								
Control (without biochar)			3.46b	3.53b	0.358b	0.366b	2.13b	2.23b
With biochar			3.67a	3.75a	0.392a	0.401a	2.38a	2.51a
F. Test			**	**	**	**	**	**
LSD $_{at\ 5\%}$			0.04	0.02	0.002	0.002	0.03	0.04
C: foliar application of the natural extracts								
Control (without)			3.50b	3.58c	0.361d	0.368d	2.16c	2.27d
Turmeric. E			3.55ab	3.62bc	0.371c	0.381c	2.21c	2.32c
Green tea. E			3.58ab	3.65b	0.380b	0.387b	2.29b	2.40b
Grape seed. E			3.63a	3.71a	0.388a	0.398a	2.36a	2.50a
F. Test			*	*	**	**	*	**
LSD $_{at\ 5\%}$			0.08	0.05	0.004	0.003	0.02	0.05
Interaction among the three factors (A×B×C)								
Agricultural drainage water	Without biochar	Control	3.20	3.25	0.308	0.314	1.68	1.77
		Turmeric. E	3.23	3.29	0.325	0.331	1.78	1.87
		Green tea. E	3.26	3.32	0.333	0.339	1.86	1.95
		Grape seed. E	3.31	3.38	0.335	0.342	1.94	2.01
	With biochar	Control	3.38	3.43	0.343	0.348	2.05	2.15
		Turmeric. E	3.46	3.53	0.349	0.357	2.06	2.16
		Green tea. E	3.49	3.57	0.364	0.371	2.14	2.24
		Grape seed. E	3.53	3.61	0.370	0.380	2.25	2.46
Fresh water	Without biochar	Control	3.61	3.69	0.374	0.383	2.36	2.48
		Turmeric. E	3.66	3.75	0.389	0.401	2.40	2.52
		Green tea. E	3.68	3.75	0.392	0.400	2.48	2.60
		Grape seed. E	3.75	3.81	0.408	0.420	2.55	2.67
	With biochar	Control	3.84	3.94	0.420	0.428	2.56	2.68
		Turmeric. E	3.84	3.93	0.422	0.433	2.61	2.75
		Green tea. E	3.87	3.95	0.431	0.439	2.68	2.82
		Grape seed. E	3.95	4.02	0.439	0.452	2.71	2.86
F. Test			*	**	**	**	**	**
LSD $_{at\ 5\%}$			0.17	0.09	0.008	0.007	0.10	0.11
F. Test of bilateral interaction								
A×B			*	**	**	**	**	**
A×C			*	*	**	**	*	**
B×C			*	*	**	**	*	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 7. Effect of irrigation water type, biochar and natural extracts on the photosynthetic pigments content of faba bean plants at flowering stage during the growing seasons of 2023/24 and 2024/25

Treatments			Chlorophyll a, mg g^{-1}		Chlorophyll b, mg g^{-1}		Carotene, mg g^{-1}	
			1st season	2nd season	1st season	2nd season	1st season	2nd season
A: Irrigation water type								
Agricultural drainage water			0.851b	0.867b	0.587b	0.602b	0.270b	0.274b
Fresh water			1.102a	1.130a	0.803a	0.823a	0.300a	0.304a
F. Test			**	**	**	**	**	**
LSD at 5%			0.018	0.008	0.019	0.023	0.001	0.002
B: Biochar addition								
Control (without biochar)			0.915b	0.935b	0.643b	0.658b	0.278b	0.281b
With biochar			1.038a	1.062a	0.747a	0.767a	0.293a	0.297a
F. Test			**	**	**	**	**	**
LSD at 5%			0.008	0.007	0.004	0.007	0.001	0.004
C: foliar application of the natural extracts								
Control (without)			0.931d	0.955d	0.657d	0.674d	0.279d	0.283d
Turmeric. E			0.959c	0.981c	0.681c	0.694c	0.284 c	0.288c
Green tea. E			0.995b	1.021b	0.704b	0.724b	0.287b	0.291b
Grape seed. E			1.022a	1.037a	0.738a	0.758a	0.291a	0.294a
F. Test			**	**	**	**	**	**
LSD at 5%			0.009	0.008	0.006	0.006	0.002	0.003
Interaction among the three factors (A×B×C)								
Agricultural drainage water	Without biochar	Control	0.708	0.723	0.472	0.482	0.258	0.261
		Turmeric. E	0.753	0.764	0.504	0.514	0.263	0.266
		Green tea. E	0.802	0.818	0.529	0.541	0.266	0.270
		Grape seed. E	0.838	0.856	0.561	0.575	0.270	0.274
	With biochar	Control	0.873	0.891	0.600	0.618	0.271	0.274
		Turmeric. E	0.903	0.926	0.635	0.648	0.276	0.280
		Green tea. E	0.941	0.970	0.665	0.686	0.280	0.284
		Grape seed. E	0.991	0.989	0.727	0.755	0.281	0.284
Fresh water	Without biochar	Control	0.999	1.030	0.741	0.759	0.283	0.286
		Turmeric. E	1.035	1.056	0.750	0.765	0.290	0.294
		Green tea. E	1.085	1.111	0.778	0.801	0.294	0.297
		Grape seed. E	1.100	1.123	0.805	0.826	0.301	0.304
	With biochar	Control	1.142	1.175	0.814	0.837	0.305	0.310
		Turmeric. E	1.146	1.176	0.833	0.850	0.307	0.312
		Green tea. E	1.152	1.186	0.844	0.869	0.310	0.314
		Grape seed. E	1.157	1.180	0.858	0.875	0.312	0.316
F. Test			**	**	**	**	**	**
LSD at 5%			0.018	0.017	0.011	0.012	0.005	0.006
F. Test of bilateral interaction								
A×B			**	**	**	**	**	**
A×C			**	**	**	**	**	**
B×C			**	**	**	**	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 8. Effect of irrigation water type, biochar and natural extracts on the oxidation indicators in leaves of faba bean plants at flowering stage during the growing seasons of 2023/24 and 2024/25

Treatments			CAT, unit mg^{-1} protein^{-1}		POD , unit mg^{-1} protein^{-1}		MDA, µmol.g^{-1} F.W	
			1st season	2nd season	1st season	2nd season	1st season	2nd season
A: Irrigation water type								
Agricultural drainage water			0.359a	0.370a	3.06a	3.12a	17.71a	16.36a
Fresh water			0.311b	0.321b	2.21b	2.26b	12.86b	11.87b
F. Test			**	**	**	**	**	**
LSD at 5%			0.003	0.005	0.01	0.03	0.38	0.07
B: Biochar addition								
Control (without biochar)			0.347a	0.358a	2.83a	2.88a	16.58a	15.29a
With biochar			0.323b	0.334b	2.45b	2.50b	14.00b	12.93b
F. Test			**	**	**	**	**	**
LSD at 5%			0.001	0.002	0.03	0.02	0.07	0.05
C: foliar application of the natural extracts								
Control (without)			0.344a	0.354a	2.78a	2.83a	16.20a	14.95a
Turmeric. E			0.337b	0.349b	2.71b	2.77b	15.81b	14.62b
Green tea. E			0.332c	0.343c	2.57c	2.62c	15.09c	13.95c
Grape seed. E			0.327d	0.337d	2.49d	2.54d	14.05d	12.94d
F. Test			**	**	**	**	**	**
LSD at 5%			0.003	0.004	0.03	0.03	0.20	0.15
Interaction among the three factors (A×B×C)								
Agricultural drainage water	Without biochar	Control	0.383	0.395	3.32	3.40	20.40	18.82
		Turmeric. E	0.372	0.384	3.27	3.33	19.98	18.47
		Green tea. E	0.370	0.381	3.24	3.30	18.96	17.49
		Grape seed. E	0.364	0.375	3.16	3.23	17.64	16.22
	With biochar	Control	0.359	0.369	3.05	3.10	17.32	15.99
		Turmeric. E	0.354	0.367	3.01	3.07	16.71	15.52
		Green tea. E	0.341	0.353	2.74	2.81	15.87	14.70
		Grape seed. E	0.330	0.340	2.71	2.76	14.83	13.66
Fresh water	Without biochar	Control	0.329	0.338	2.54	2.59	14.62	13.50
		Turmeric. E	0.324	0.334	2.49	2.54	14.19	13.07
		Green tea. E	0.319	0.330	2.37	2.42	14.15	13.08
		Grape seed. E	0.319	0.330	2.23	2.28	12.67	11.69
	With biochar	Control	0.306	0.315	2.20	2.25	12.46	11.48
		Turmeric. E	0.300	0.312	2.09	2.13	12.37	11.42
		Green tea. E	0.297	0.309	1.93	1.97	11.39	10.51
		Grape seed. E	0.294	0.305	1.85	1.88	11.04	10.19
F. Test			**	**	**	**	**	**
LSD at 5%			0.006	0.007	0.06	0.06	0.39	0.30
F. Test of bilateral interaction								
A×B			**	**	**	**	**	**
A×C			**	**	**	**	**	**
B×C			**	**	**	**	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Harvest Stage

Table 9 indicates the effect of irrigation water type, biochar and natural extracts on the quantitative yield [*i.e.*, No. of pods plant^{-1}, pod length (cm), seeds weight plant^{-1}, weight of 100 seed (g), seed yield, ton fed^{-1}] of faba bean plants at harvest stage during the growing seasons of 2023/24 and 2024/25, while Table 10 points out the effect of the studied treatments on biochemical traits of faba bean [carbohydrates, protein, TSS and fiber (%)] at harvest stage during the growing seasons of 2023/24 and 2024/25.

Table 9. Effect of irrigation water type, biochar and natural extracts on the quantitative yield of faba bean plants at harvest stage during the growing seasons of 2023/24 and 2024/25

Treatments			No. of pods plant^{-1}		Pod length, cm		Seeds weight plant^{-1}		Weight of 100seed,g		Seed yield, ton fed^{-1}	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
A: Irrigation water type												
Agricultural drainage water			12.33b	14.71b	10.11b	10.23b	28.53b	29.07b	79.90b	81.64b	1.27b	1.29b
Fresh water			20.92a	22.75a	11.52a	11.68a	34.92a	35.62a	86.52a	88.52a	1.55a	1.58a
F. Test			**	**	**	**	**	**	**	**	**	**
LSD $_{at\ 5\%}$			0.64	0.47	0.02	0.02	0.86	0.59	0.12	1.47	0.04	0.03
B: Biochar addition												
Control (without biochar)			14.50b	16.75b	10.30b	10.45b	30.04b	30.64b	81.55b	83.41b	1.34b	1.36b
With biochar			18.75a	20.71a	11.33a	11.47a	33.41a	34.05a	84.87a	86.75a	1.48a	1.51a
F. Test			**	**	**	**	**	**	**	**	**	**
LSD $_{at\ 5\%}$			1.27	1.41	0.02	0.01	0.16	0.25	0.15	0.63	0.01	0.01
C: foliar application of the natural extracts												
Control (without)			15.42b	17.08c	10.63c	10.75d	30.55c	31.15c	82.24b	84.27b	1.36c	1.38c
Turmeric. E			15.92b	17.83bc	10.72c	10.87c	30.76c	31.35c	82.56b	84.31b	1.37c	1.39c
Green tea. E			16.67b	19.17b	10.87b	11.02b	32.40b	33.04b	83.11b	85.06b	1.44b	1.47b
Grape seed. E			18.50a	20.83a	11.05a	11.19a	33.19a	33.83a	84.93a	86.70a	1.48a	1.50a
F. Test			*	*	*	**	**	*	*	*	*	*
LSD $_{at\ 5\%}$			1.49	1.62	0.11	0.12	0.03	0.31	0.87	0.85	0.01	0.01
Interaction among the three factors (A×B×C)												
Agricultural drainage water	Without biochar	Control	9.33	11.33	9.66	9.77	25.62	26.13	78.44	80.25	1.14	1.16
		Turmeric. E	9.67	11.33	9.83	9.99	26.00	26.47	78.98	80.64	1.16	1.18
		Green tea. E	10.00	12.33	9.97	10.07	27.54	28.06	79.18	80.95	1.22	1.25
		Grape seed. E	11.67	14.33	10.17	10.27	27.65	28.23	79.63	81.24	1.23	1.25
	With biochar	Control	13.00	14.33	10.19	10.32	28.83	29.32	79.97	82.00	1.28	1.30
		Turmeric. E	13.67	16.00	10.30	10.40	29.15	29.73	80.34	81.84	1.30	1.32
		Green tea. E	14.67	18.00	10.35	10.47	31.11	31.76	80.36	82.63	1.38	1.41
		Grape seed. E	16.67	20.00	10.44	10.58	32.31	32.83	82.33	83.58	1.44	1.46
Fresh water	Without biochar	Control	17.67	20.33	10.46	10.59	32.31	32.89	82.55	84.69	1.44	1.46
		Turmeric. E	18.00	20.67	10.50	10.67	32.36	32.98	82.84	84.75	1.44	1.47
		Green tea. E	19.00	21.67	10.73	10.94	33.89	34.59	84.58	86.39	1.51	1.54
		Grape seed. E	20.67	22.00	11.07	11.27	34.96	35.76	86.22	88.38	1.55	1.59
	With biochar	Control	21.67	22.33	12.19	12.32	35.42	36.23	88.00	90.13	1.57	1.61
		Turmeric. E	22.33	23.33	12.25	12.42	35.53	36.23	88.07	90.00	1.58	1.61
		Green tea. E	23.00	24.67	12.42	12.58	37.04	37.77	88.32	90.26	1.65	1.68
		Grape seed. E	25.00	27.00	12.51	12.65	37.85	38.49	91.57	93.59	1.68	1.71
F. Test			*	*	**	**	**	**	**	**	**	**
LSD $_{at\ 5\%}$			2.98	3.25	0.23	0.23	0.66	0.62	1.74	1.70	0.03	0.03
F. Test of bilateral interaction												
A×B			**	**	**	**	**	**	**	**	**	**
A×C			*	*	**	**	**	**	*	*	**	**
B×C			*	*	**	**	**	**	*	*	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 10. Effect of irrigation water type, biochar and natural extracts on the qualitative yield of faba bean plants at harvest stage during the growing seasons of 2023/24 and 2024/25

Treatments			Carbohydrates, %		Protein, %		TSS, %		Fiber, %	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
A: Irrigation water type										
Agricultural drainage water			58.77b	59.48b	16.81b	17.01b	3.44b	3.55b	11.64b	11.77b
Fresh water			60.27a	61.05a	20.21a	20.51a	4.21a	4.35a	12.29a	12.46a
F. Test			**	**	**	**	**	**	**	**
LSD $_{at\ 5\%}$			1.47	0.04	0.49	0.08	0.01	0.08	0.20	0.08
B: Biochar addition										
Control (without biochar)			59.00b	59.73b	17.63b	17.88b	3.65b	3.76b	11.82b	11.97b
With biochar			60.05a	60.80a	19.40a	19.63a	4.00a	4.14a	12.11a	12.25a
F. Test			**	**	**	**	**	**	**	**
LSD $_{at\ 5\%}$			0.31	0.13	0.09	0.19	0.01	0.05	0.09	0.16
C: foliar application of the natural extracts										
Control (without)			59.21a	59.93a	17.91d	18.16d	3.68d	3.78d	11.86c	12.01c
Turmeric. E			59.40a	60.22a	18.29c	18.55c	3.78c	3.91c	11.90bc	12.06bc
Green tea. E			59.66a	60.42a	18.69b	18.93b	3.87b	4.00b	12.00ab	12.15ab
Grape seed. E			59.83a	60.49a	19.16a	19.40a	3.98a	4.11a	12.09a	12.23a
F. Test			*NS	*NS	**	**	**	**	*	*
LSD $_{at\ 5\%}$			*NS	*NS	0.19	0.17	0.04	0.02	0.12	0.14
Interaction among the three factors (A×B×C)										
Agricultural drainage water	Without biochar	Control	57.64	58.20	15.30	15.53	3.12	3.21	11.41	11.56
		Turmeric. E	58.02	58.69	15.56	15.71	3.22	3.32	11.44	11.55
		Green tea. E	58.58	59.43	16.03	16.18	3.31	3.40	11.46	11.58
		Grape seed. E	58.85	59.70	16.62	16.86	3.41	3.51	11.54	11.69
	With biochar	Control	59.13	59.76	17.18	17.33	3.44	3.53	11.61	11.72
		Turmeric. E	59.20	60.07	17.47	17.68	3.54	3.67	11.73	11.86
		Green tea. E	59.23	59.98	18.00	18.25	3.71	3.83	11.86	12.00
		Grape seed. E	59.54	59.99	18.36	18.55	3.79	3.90	12.05	12.18
Fresh water	Without biochar	Control	59.54	60.26	18.79	19.09	3.91	4.02	12.10	12.27
		Turmeric. E	59.64	60.54	19.19	19.60	3.98	4.09	12.10	12.34
		Green tea. E	59.87	60.52	19.54	19.87	4.04	4.18	12.20	12.43
		Grape seed. E	59.84	60.49	19.99	20.23	4.20	4.36	12.26	12.38
	With biochar	Control	60.54	61.49	20.39	20.68	4.25	4.36	12.31	12.49
		Turmeric. E	60.74	61.57	20.94	21.20	4.39	4.56	12.33	12.48
		Green tea. E	60.97	61.75	21.18	21.43	4.42	4.59	12.47	12.61
		Grape seed. E	61.07	61.80	21.66	21.94	4.51	4.66	12.51	12.68
F. Test			*	*	**	**	**	**	*	*
LSD $_{at\ 5\%}$			1.26	1.26	0.39	0.34	0.08	0.05	0.24	0.28
F. Test of bilateral interaction										
A×B			*	*	**	**	**	**	**	**
A×C			*	*	**	**	**	**	*	*
B×C			*	*	**	**	**	**	*	*

Means within a row followed by a different letter (s) are statistically different at a 0.05 level*NS= non-significant

Regarding the irrigation water type, the values of all aforementioned traits under fresh water treatment were higher than those under agricultural drainage water treatment. Concerning biochar treatments, the values of all aforementioned traits were higher in the presence of biochar than in its absence. As for foliar applications, the superior natural extract was grape seed, followed by green tea, then turmeric and lately the control treatment (tap water) in terms of all aforementioned traits. Concerning the interaction effect, the superior combined treatment was fresh water + biochar + grape seed extract. Moreover, it can be noticed that applying the biochar combined with the grape seed extract under irrigation with agricultural drainage water had a non-significant effect on the quantitative and qualitative parameters of faba bean compared to the irrigation with fresh water without any studied substances.

Discussion

The results show that faba bean plants irrigated with freshwater outperformed in most growth and productivity indicators compared to those irrigated with agricultural drainage water, which resulted in higher oxidation indicators compared to freshwater (Kalibatienė *et al.* 2025). The agricultural drainage water used in this study contains high levels of electric conductivity, sodium, and possibly heavy metals, in addition to pathogens, causing osmotic and physiological stress for growing faba bean (Abd El-Aziz *et al.* 2025). Furthermore, the agricultural drainage water negatively affected water and nutrient uptake due to its poor quality. All of this resulted in poor performance of the faba bean plant under these conditions. Furthermore, an increase in malondialdehyde (MDA) levels was observed in the tissues of faba bean plants irrigated with agricultural drainage water. MDA is a biochemical marker used to assess the severity of oxidative damage in plant cells resulting from membrane lipid peroxidation. This increase is associated with increased free radical (ROS) production within faba bean plants under salt and mineral stress circumstances, caused by irrigation with agricultural drainage water, which contains salts and organic and mineral pollutants. In response, the faba bean plant activated its defense mechanisms by increasing its self-production of antioxidant enzymes, such as catalase (CAT) and peroxidase (POD). These enzymes may have degraded hydrogen peroxide (H_2O_2) and scavenged harmful ROS, reducing toxic influence and maintaining the integrity of the faba bean plant's cell membranes and physiological structure. In other words, the increased antioxidant activity in the faba bean plant tissues irrigated with agricultural wastewater is an adaptive response to oxidative stress. In contrast, freshwater provided a more suitable growth environment with lower salt and pollutant concentrations, enhancing the efficiency of vital processes such as photosynthesis and protein synthesis while reducing oxidative damage. This reduced the need for faba bean plants to increase their self-production of antioxidant enzymes. This also explains the lower MDA levels in plants irrigated with freshwater.

As for the improvements achieved by biochar, especially in its acidified form, it can be said that it may have mitigated the damage caused by irrigation with agricultural drainage water. This is due to biochar's high porosity and large surface area, which enable it to absorb and retain a portion of salts and heavy metals and reduce their access to the faba bean root zone. Biochar also may have played other roles in improving soil properties, such as aeration, water retention, and cation exchange capacity. All of this may have helped improve nutrient balance and reduce the agricultural drainage water stress. The obtained results are in harmony with those of (Huang *et al*. (2019); Ashour *et al.* (2021).

Concerning the effect of natural plant extracts, the grape seed extract came in the first order in terms of mitigating the harmful effect of irrigation with agricultural drainage water, followed by the green tea extract then the turmeric extract . This ranking can be explained as follows:

Grape seed extract is very rich in proanthocyanidins (polymers of flavonoids) that have a very high antioxidant capacity, higher than vitamins C and E. Its proanthocyanidin content protects the higher plant tissues from oxidative damage while simultaneously maintaining plant cell integrity. Grape seed extract also contains flavonoids such as quercetin and kaempferol, which stimulate plant defense enzymes. It also contains gallic acid and ellagic acid, which play a role in combating microbes and reducing damage caused by pollution. It also contains vitamins E and C, and small amounts of vitamin K. It also contains a significant amount of nutrients such as magnesium, iron, and zinc (Memar *et al.* 2019; Elsherif *et al.* 2024).

Green tea extract contains high levels of catechins, flavonoids, and vitamin C. It also contains vitamin E, which enhances the stability of plant cell membranes. It is also rich in the amino acid such as L-theanine, which reduces stress in higher plants. It also contains a high percentage of caffeine, which plays a unique role in plant metabolism (Çavuşoğlu, 2020). It also contains saponins, which have properties that enhance higher plant immunity. Saponins make this extract antifungal and antibacterial. It also contains macro- and micronutrients, which contribute to the nutrition of plants and improve their vital functions (Ibrahim & Al-Sereh, 2019).

Turmeric extract contains curcumin, demethoxycurcumin, and bisdemethoxycurcumin, all of which are powerful antioxidants. It also contains other compounds such as turmerone, atlantone, and zingiberene, which have antimicrobial properties (Maizura *et al.* 2011; Ejimofor, 2022). However, their water solubility is relatively low, which may limit their rapid distribution within plant tissues compared to the other two extracts.

CONCLUSION

According to the results obtained, the maximum values of growth criteria , chemical , photosynthetic pigments quantitative and qualitative yield as well as the minimum values of oxidation indicators were recorded when the faba been plants were irrigated with fresh water in conjunction with addition of biochar and grape seeds extract. On the other hand, applying the biochar combined with the grape seed extract under irrigation with agricultural drainage water had a non-significant effect on the faba bean performance compared to the irrigation with fresh water without any studied substances. Generally, it can be recommended to incorporate this approach into the management of low-quality irrigation water.

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تحسين إنتاجية وجوده محصول الفول البلدي المروي بمياه الصرف الزراعي باستخدام البيوشار والمستخلصات الطبيعية الغنية بمضادات الاكسدة

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الملخص

في مصر حاليًا، لا مفر من استخدام مياه الصرف الزراعي في أغراض الري كبديل جزئي أو كلي للمياه العذبة. لذلك، يجب إيجاد نهج من شأنه خفض تاثيرها الضار والمحافظة على الإنتاجية دون حدوث انخفاض كبير. لذلك، تم تنفيذ تجربة حقلية خلال موسمين متتاليين (٢٠٢٣/٢٤ و٢٠٢٤/٢٥) لتقييم إضافه الفحم الحيوي المحسن مع المستخلصات الطبيعية على الفول البلدي المروي بمياه الصرف الزراعي. تمت دراسة ثلاثة عوامل في تصميم قطع منشقة مرتين، حيث كان العامل الرئيسي هو نوع مياه الري (مياه عذبة و مياه الصرف الزراعي)، بينما كان العامل المنشق الاول هو اضافة البيوشار [مضاف بمعدل ٢,٤ طن / هكتار أو لم يتم اضافته]. كما تم ترتيب أربع معاملات رش ورقي (الكنترول ومستخلصات الشاي الأخضر والكركم و بذور العنب بمعدل ١٠,٠ سم٣/ لتر لكل مستخلص) في القطع المنشقة الثانية. تم تقييم مدلولات النمو (مثل الوزن الطازج والجاف)، والصفات الكمية والنوعية (مثل محصول البذور، الكربوهيدرات والبروتين) للفول البلدي. كانت قيم المدلولات التي تم تقيمها تحت الري بالمياه العذبة أعلى من تلك تحت الري بمياه الصرف الزراعي. بالإضافة إلى ذلك، أدى استخدام الفحم الحيوي إلى تحسينات في جميع المدلولات المدروسة. وكان المستخلص الطبيعي الأفضل هو مستخلص بذور العنب، يليه مستخلص الشاي الأخضر ثم مستخلص الكركم. علي جانب أخر، كان لاستخدام الفحم الحيوي مع مستخلص بذور العنب تحت الري بمياه الصرف الزراعي تأثير غير معنوي على أداء الفول البلدي مقارنةً بمعاملة الري بالمياه العذبة دون أي مواد مدروسة . لذلك نوصي بدمج هذا النهج في إدارة مياه الري منخفضة الجودة.