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Original article

Improving growth and productivity of faba bean (*Vicia faba* L.) using chitosan, tryptophan, and potassium silicate anti-transpirants under different irrigation regimes

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A B S T R A C T

This work aims to study the effect of foliar spraying of three anti-transpirants i.e., A_1: tryptophan (Tri), A_2: potassium silicate (KS), A_3: chitosan (Chi) as well as A_0: control (Tap water) under three irrigation regimes, I_1: 2400, I_2: 3600, and I_3: 4800 m^3ha^{-1} on the quality and production of faba bean crop and its nutrient contents. The study was carried out during two successive winter seasons of 2018/2019 and 2019/2020. Drought stress affected the average performance of all studied traits as it reduced seed yield and traits, as a result of the decrease in chlorophyll related to photosynthesis, protein, carbohydrates, total phenols, amino acids, macronutrients (N, P, and K), micronutrient contents (Fe, Mn, and Zn) and their absorption. The single foliar spraying of faba bean with tryptophan 75 ppm, potassium silicate at 100 ppm, or chitosan at 750 ppm significantly increased all studied traits and reduced the drought stress compared to control under different irrigation systems. We recommended using a foliar spray of chitosan (750 ppm) on faba bean plants under an irrigation level of 4800 m^3 led to an improvement in the physiological properties of the plant, i.e., plant height, the number of branches/plants, and the number of plants, pods $plant^{-1}$, the number of seed $pods^{-1}$, the weight of 100 seeds and seed yield ha^{-1} increased with relative increase about 42.29, 89.47, 28.85, 75.91, 24.43, and 306.48% compared to control. The quality properties also improved, as the total chlorophyll, protein, carbohydrates, total phenols, and amino acids were higher than the control with a relative increase of 63.83, 29.58, 27.72, 37.54, and 64.19%. Additionally, an increase in the contents and uptake of macronutrients (N, P, and K), and micronutrients (Fe, Mn, Zn) and their absorption. The increase was estimated with 29.41, 75.00, 16.56, 431.17, 630.48, 72.68%, 22.37, 35.69, 42.33, 397.63, 452.58, and 485.94% about the control. This was followed by potassium silicate (100 ppm), then tryptophan (75 ppm) compared to the control, which recorded the minimum values in plant traits.

1. Introduction

Faba bean (*Vicia faba* L.) is a source of protein, providing a renewable nitrogen input to crops and soils (Saad et al., 2015). The crop can provide the soil with 100 to 200 kg N ha^{-1} (Jensen et al., 2010). The bean crop is usually irrigated in Egyptian agriculture. Great attention was paid to increase the bean crop productivity. The agricultural strategies should focus on using the resistant varieties to biotic and abiotic stress, considering the water content

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in the region (Varga et al., 2015). Beans are grown in Egypt in sandy soils, which draining large amounts of water, and negatively impacted the plant properties by drought (Hag and Dalia, 2017). Drought stress badly affects plants' physiology and their productivity, leading to the deficiency of food security and economic losses (El-Saadony et al., 2021a). If a plant is grown in sandy soil with prolonged irrigation, it stimulates its defense system to reduce transpiration or adapt to drought. The plant defense system is not sufficient to resist drought; so, the anti-transpirants must be applied externally to enhance the drought resistance and reduce transpiration through the plant stomata. Chitosan reduces the drought stress in wheat, improving its morphological, quality, and yield properties (Malerba and Cerana, 2020). The addition of amino acids such as tryptophan reduces the effect of drought stress in wheat and affects the physiological processes of plants after absorption (Khalid et al., 2006; Jamil et al., 2018). L-tryptophan is a valuable amino acid. It may act as an osmolyte, an ion transport regulator that modulates stomatal opening and detoxifies harmful effects of heavy metals (Orabi et al., 2014). Furthermore, the tryptophan pathway plays a defensive role in plants (Hussein et al., 2014).

The majority of water absorbed by the crop has been lost through transpiration (Davenport et al., 1972). Anti-transpirant materials are compounds that reduce transpiration through the plant stomata.

Chitosan is a ubiquitous polysaccharide biopolymer, commercially extracted from shrimp and crab shells (Hein, 2004). It is a low toxic and inexpensive compound that is biodegradable and ecofriendly with various applications in agriculture (New et al., 2004). The coating with chitosan can form a semi-permeable film which may modify the internal atmosphere and decrease the transpiration loss of the leaves (Olivas and Barbosa-Cánovas, 2005). Furthermore, enhancing germination (Guan et al., 2009) and plant nutrients mineralization (Bolto et al., 2004). Many other beneficial effects of chitosan on strawberry (Abdel-Mawgoud et al., 2010); Shehata et al. (2012) on cucumber; Abd El-Gawad and Bondok (2015) on tomato. Abu-Muriefah (2013) found that foliar application of chitosan (100–125 mg L^{-1}) received a positive response in all common bean traits, yield, and the mineral content plant.

The foliar spray of banana peel extract or tryptophan on quinoa plants was tested under drought conditions. The application leads to an increase in auxins, following by an increase in photosynthesis and the contents of carbohydrates, proteins, flavonoids, and antioxidant in grains. The banana extract was more efficient than tryptophan because it is rich in vitamins, flavonoids, and amino acids such as tryptophan. It also reduces the amount of water consumed in irrigation (Bakry et al., 2016). The silicate belongs to the Anti-transpirant where its importance is represented in depositing on the leaves, forming a double layer that reduces transpiration in maize plants (Liang et al., 2005; Freitas et al., 2011). The study showed that adding the optimal concentration of silicate to the plant helps in resisting drought. The utilization of sodium silicate or potassium silicate as a source of silicate to combat transpiration is not economical. The use of agricultural wastes and natural compounds is cost-effective (El-Saadony et al., 2021; Saad et al., 2021), therefore, it is possible to use rice and sugarcane residues as a source of silicates.

The present study aims to assess the effect of chitosan, tryptophan, potassium silicate as anti-transpirants on decreasing the amount of water needed for the Faba bean crop grown in three irrigation regimes under Egyptian conditions.

2. Material and methods

Two field experiments were conducted on faba bean (*Vicia faba* L.) cv. Giza 843, The study was carried out during two consecutive winter seasons of 2018/2019 and 2019/2020 in the Agricultural Research Station Farm, Ismailia Governorate, Egypt, (30° 35′30″N, 32°14′50″E) to determine the effect of three anti-transpirants i.e. A_1: tryptophan at (75 ppm), A_2: potassium silicate (100 ppm), A_3: chitosan (750 ppm) compared to A_0: control (Tap water) on the quality and productivity of faba bean crop and its nutrient contents. The anti-transpirants were prepared and sprayed on the plants' leaves by using a hand pump pressure sprayer (20 L) until the leaves were wet to run off. The experiments were conducted under three irrigation regimes i.e. I_1: 2400, I_2: 3600, and I_3: 4800 m^3ha^{-1} (representing 75, 100, and 150%, respectively of the regime adopted by farmers). All foliar treatments were applied three times at an interval of 30, 45, and 60 days after sowing. The soil was analyzed chemically according to the procedures described by Page et al. (1982) and Klute (1986). The used soil was a sandy loam and its properties showed in Table 1.

2.1. Experimental design

The experimental design was a split plot with three replicates. The plot area was 20 m^2 (4 × 5 m). Irrigation regimes were applied in the main plots, while the anti-transpirants were applied to the subplots. Each plot included eight rows spaced 50 cm, one plant per hill, and a distance of 20 cm between hills. The drip irrigation system was used with drip laterals spaced 50 cm, and the space between emitters along the polyethylene pipelines was 30 cm. Each irrigation sector had a valve and pressure gauge to maintain the operating pressure at 1 bar and emitter flow rate of 4 L/h. A flow meter was used to measure the amount of targeted irrigation water at each irrigation level. Sowing was occurred on the 20th and 25th November in both seasons, respectively. Harvest happened on 26^{th} and 29^{th} April in both seasons, respectively. The recommended practices of faba bean production were followed.

2.2. Biochemical parameters of faba bean

After 65 days of sowing, 50 g of leaves samples were dried, powdered, and 10 g of the powder was homogenized in 300 mL of ethanol (70%) and stirred for 3 h. The solvent was evaporated with BUCHI rotary evaporator, Germany, the residues was mixed with distilled water and is ready for the following analysis (Saad et al., 2020).

2.2.1. Total polyphenols estimation

The phenolic compounds were estimated according to Chen et al. (2015) with some modifications. In brief, 100 μL of faba leaves extracts were mixed with 50 μL of diluted Folin-Ciocalteu reagent and 50 μL Na_2CO_3 (7.5%) in microtiter plate. The absorbance was read at 760 nm after 1 h using microtiter plate reader (BioTek Elx808, USA). The total polyphenols content was presented as mg gallic acid equivalent/mL of extract.

2.2.2. Determination of total carbohydrates and protein

The leaves samples were hydrolyzed by HCl 6 N at 120 °C for 24 h, then the acid was evaporated and the residues were dissolved in methanol. Total carbohydrates were estimated by phenol sulfuric acid method according to Saad et al. (2021a). 100 μL leaves hydrolysate was mixed with 50 μL phenol (5%) and 50 μL sulfuric acid (conc.). The absorbance (y) was read at 490 nm after 30 min using microtiter plate reader (BioTek Elx808, USA). The total carbohydrates concentration (x) mg glucose/mL sample was calculated using the following linear equation, $y = 0.0053x - 0.0193$, $R^2 = 0.9884$. Total nitrogen was estimated by Kjeldahl method and the protein percentage was calculated by multiply % N in 6.25 (AOAC, 2005).

Table 1

Property Particle size distribution		Value	Property		Value
Clay %		12.59	Soluble ions (mmolc L^{-1})		
Silt %		7.88	Na^+		6.88
Sand %		79.53	K^+		0.82
Texture		Sandy loam	Ca^{++}		5.26
EC (dSm^{-1}in paste extract)		1.56	Mg^{++}		2.60
			Cl^-		5.13
pH [Soil suspension 1:2.5]		7.88	HCO_3^-		1.02
Organic matter (g kg^{-1})		6.41	SO_4^{--}		9.41
$CaCO_3$ (g kg^{-1})		13.4	CO_3^{--}		0.00
Available nutrients (mg kg^{-1} soil)					
N	P	K	Fe	Mn	Zn
34.1	5.2	125	1.9	3.2	0.6

(1) Available nutrient extractants: NH_4HCO_3-DTPA (for P, K, Fe, Mn, and Zn), KCl (for N).
(2) Texture using the International Texture Triangle.

2.2.3. Determination of total chlorophyll and mineral content

The total chlorophyll (a + b) determination as per El-Saadony et al. (2021b). On the other hands, the minerals content was estimated by using the Atomic Absorption Spectrophotometer (AAS model GPC A932 ver. 1.1) according to Lukić et al. (2020).

2.3. Growth and yield attributes

At maturity, the middle three rows of each plot were harvested and air-dried to determine plant height, number of branch plant^{-1}, number of pods plant^{-1}, number of seeds podt^{-1}, 100-seed weight, and Seed yield (ton ha^{-1}) (El-Saadony et al., 2021b).

2.4. Soil sample analysis after harvest

Top soil samples (0–30 cm) were collected at the maximum growth phases from all of the experimental plots, air dried, crushed, and sieved through a 2 mm sieve, and evaluated for soil EC, pH, and accessible N, P, and K contents using some of the same methods (Page et al., 1982) used to examine the initial soil.

2.5. Statistical analysis

The data obtained from each trial were subjected to the analysis of variance of split-plot design using the computer program MSTAT-C as described by Snedecor and Cochran (1981). A combined analysis was made for data means of the two seasons. The differences between means were compared using Duncan's multiple range test (Duncan, 1955).

3. Results

3.1. Seed yield and its attributes

Data in Table 2 showed that plant height, the number of branches/plants, the number of pods plant^{-1}, the number of seeds pod-1, 100-seed weight, and seed yield ha^{-1} were significantly increased with the increasing amount of applied irrigation water up to the highest level at 4800 m^3 ha^{-1}. Generally, severe drought reduced seed yield by 81.55% comparing with the highest level of irrigation. Moreover, single foliar spray faba beans with Tryptophan (Tri) at 75 ppm, Potassium silicate (KS) at 100 ppm, or Chitosan (Chi) at 750 ppm was significantly increased most above-mention traits compared to control (spraying with tap water) under different irrigation regimes.

Chitosan spray (750 ppm) gave the tallest plants and recorded the maximum values of above-mention traits. Such treatment gave increases of 28.89, 67.99, 15.93, 36.51, 16.94, and 129.17%, followed by Potassium silicate at 100 ppm, which gave increases of 23.97, 49.53, 8.72, 22.82, 13.45, and 77.78. In addition, Tryptophan spray (75 ppm) achieves relative increments of 11.08, 23.36, 4.31, 12.86, 6.85, and 38.89% as compared to control (spraying with tap water) for plant height, number of branches/plants, number of pods plant-1, number of seeds pod^{-1}, 100 seed weight, and Seed yield ha^{-1}, respectively.

The interaction between irrigation levels and anti-transpirants was significant for plant height, the number of seeds pod^{-1} 100 seed weight, and seed yield ha^{-1} (Table 2). The results showed that spraying faba bean plants with anti-transpiration materials increased the mean performance of all studied traits under the different irrigation levels compared with the non-treated treatment. Meanwhile, spraying faba bean plants with chitosan at 750 ppm under an irrigation level of 4800 m^3 ha^{-1} recorded the highest values with increases of about 42.29, 89.47, 28.85, 75.91, 24.43, and 306.48% for plant height, number of branches/plant, number of pods plant-1, number of seeds pod^{-1}, 100 seed weight and seed yield ha^{-1} followed by spray with Chitosan at 750 ppm under irrigation level of 3600 m^3 ha^{-1} with increases about 80.95, 23.37, 20.76 and 200.0% for the number of branches plant^{-1}, number of pods plant^{-1}, 100 seed weight and seed yield ha^{-1}. The foliar spray with Potassium silicate at 100 ppm under the irrigation level 4800 m^3 ha^{-1} increased the plant height and the number of seeds pod^{-1} with a relative increase of about 35.70 and 54.55% compared to control treatment (spray with tap water) × Irrigation Level at 2400 m^3 ha^{-1} which recorded the minimum values of above-mention traits, respectively.

3.2. Yield quality and its components

The contents of total chlorophyll, protein, carbohydrate, total phenols, and amino acids as affected by irrigation regimes, anti-transpiration materials, and their interaction over two growing seasons are shown in Table 3.

The carbohydrate, total phenols, and amino acids were significantly increased with increasing the amount of applied irrigation water up to the highest level at 4800 m^3 ha^{-1} by 4.24, 8.73, and 20.32%, respectively, comparing with the control.

Moreover, the single application of Tri (75 ppm), KS (100 ppm), or Chi (750 ppm) on faba bean was significantly increased most above-mention traits compared to control (spraying with tap water) under different irrigation regimes.

Table 2
Plant height, number of branches^{-1} plant, pod weight plant^{-1}, seed weight plant^{-1}, 100-seed weight, pod yield and seed yield as affected by irrigation regimes, anti-transpiration materials and their interaction over two growing seasons.

Irrigation Levels m^3ha^{-1} (I)	Anti-Transpiration (A)	Plant height (cm)	No. of branches plant^{-1}	Number of pods plant^{-1}	Number of seeds/pod	100-seed weight (g)	Seed yield (ton ha^{-1})
I_1	A_0	75.9i	3.99f	10.40 g	2.20 g	79.0 g	1.08 g
	A_1	83.7 g	4.55def	11.10eg	2.40 fg	83.4f	1.50f
	A_2	88.3e	5.20cde	11.6def	2.57 ef	87.4de	1.88e
	A_3	93.5d	6.79ab	12.37abe	2.77de	88.1d	2.29 cd
I_2	A_0	77.4i	4.18ef	11.03 fg	2.37 fg	79.7 g	1.35 fg
	A_1	86.4f	5.40 cd	11.73cdef	2.63 e	85.7e	1.92de
	A_2	97.7c	6.80ab	12.13bcde	2.90d	91.5c	2.49c
	A_3	98.2c	7.22a	12.83abc	3.23bc	95.4b	3.24b
I_3	A_0	79.3 h	4.66def	12.00bcdef	2.67 e	82.4f	1.90e
	A_1	88.5e	5.89bc	12.00bcdef	3.13c	88.3d	2.59c
	A_2	103b	7.20a	12.57abcd	3.40b	94.3b	3.11b
	A_3	108a	7.56a	13.40a	3.87a	98.3a	4.39a
Irrigation (I)	I_1	85.35c	5.13b	11.37b	2.48c	84.47c	1.68c
	I_2	89.93b	5.90a	11.93ab	2.78b	88.05b	2.25b
	I_3	94.68a	6.33a	12.48a	3.67a	90.85a	3.05a
Anti-Transpiration (A)	A_0	77.6 d	4.28 d	11.13c	2.41d	80.3 d	1.44d
	A_1	86.2c	5.28c	11.61bc	2.72c	85.8c	2.00c
	A_2	96.2b	6.40b	12.10b	2.96b	91.1b	2.56b
	A_3	100.0 a	7.19 a	12.87a	3.29a	93.9 a	3.30a
ANOVA	I	<0.001	0.02	0.052	<0.001	<0.001	<0.001
	A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	I × A	<0.001	0.3255	0.959	0.052	<0.001	0.002

Notes: 1. Anti-transpiration sources: A_0, A_1, A_2 and A_3 are; Non-Treated, Tryptophan, Potassium Silicate and Chitosan used as foliar spray, respectively. 2. Irrigation regimes: I_1, I_2 and I_3 are; 2400, 3600 and 4800 m^3 ha^{-1} respectively.

Table 3
Total chlorophyll, protein, carbohydrate, total phenols and amino acids as affected by irrigation regimes, anti-transpiration materials and their interaction over two growing seasons.

Irrigation Levels m^3ha^{-1} (I)	Anti-Transpiration (A)	Total Chlorophyll (a + b) (mg g fw^{-1})	Protein (g kg^{-1})	Carbohydrate (mg g^{-1})	Total phenols (µg g^{-1} fw)	Amino acids (mg g^{-1})
I_1	A_0	4.23e	180.33d	150.33 g	38.63 g	22.37f
	A_1	5.63 cd	210.00abcd	166.33e	44.20e	25.13e
	A_2	5.94abcd	213.67abcd	175.33 cd	47.33 cd	27.40d
	A_3	6.37abc	222.00abc	182.67b	48.53c	31.40c
I_2	A_0	4.85de	183.33 cd	154.33f	39.87 fg	23.67ef
	A_1	5.77bcd	210.00abcd	169.33e	45.63de	28.20d
	A_2	6.12abc	223.67abc	177.00c	48.33c	28.10d
	A_3	6.88ab	226.33a	185.67b	49.20bc	33.17bc
I_3	A_0	4.96de	185.67bcd	155.00f	41.20f	24.40ef
	A_1	5.88abcd	214.00abcd	173.00d	48.63c	32.13c
	A_2	6.44abc	225.67ab	183.33b	51.33ab	34.67b
	A_3	6.93a	233.67a	192.00a	53.13a	36.73a
Irrigation (I)	I_1	5.54b	204.75a	168.67c	44.68b	26.58c
	I_2	5.91ab	210.83a	171.58b	45.76b	28.28b
	I_3	6.05a	214.75a	175.83a	48.58a	31.98a
Anti-Transpiration (A)	A_0	4.68c	183.11b	153.22d	39.9c	23.48d
	A_1	5.76b	209.00a	169.56c	46.16b	28.49c
	A_2	6.17 ab	221.00a	178.56b	49.00a	30.06b
	A_3	6.73 a	227.33a	186.78a	50.29a	33.77a
ANOVA	I	0.070	0.464	<0.001	0.001	<0.001
	A	<0.001	0.004	<0.001	<0.001	<0.001
	I × A	0.993	0.999	0.190	0.719	0.003

Notes: 1. Anti-transpiration sources: A_0, A_1, A_2 and A_3 are; Non-Treated, Tryptophan, Potassium Silicate and Chitosan used as foliar spray, respectively. 2. Irrigation regimes: I_1, I_2 and I_3 are; 2400, 3600 and 4800 m^3 ha^{-1} respectively.

As shown in Table 3, spraying faba bean with Chi at 750 ppm increased the carbohydrates, total phenols, and amino acid contents by 21.90, 26.04, and 43.82% followed by KS at 100 ppm with increases of 16.54, 22.81, and 28.02% then Tri at 75 ppm which gave increases of 169.56, 46.16 and 28.49, respectively, comparing with control. Similarity, the total chlorophyll increased with the application of anti-transpirants levels.

Regarding the interaction between irrigation levels and anti-transpirants, the results indicated that spraying faba bean plants with anti-transpiration materials increased the mean performance of all studied traits under the different irrigation levels compared with the non-treated treatment. Meanwhile, spraying faba bean plants with chitosan at 750 ppm under the highest irrigation level 4800 m^3ha^{-1} recorded the highest values of total chlorophyll, protein, carbohydrate, total phenols, and amino acids i.e., 63.83, 29.58, 27.72, 37.54, and 64.19%. In addition, the spraying with Chitosan at 750 ppm under irrigation level at 3600 m^3ha^{-1} with increases about 62.65, 25.51, and 23.51% for total chlorophyll, protein, and carbohydrate. Furthermore, the spray with Potassium silicate at 100 ppm under the highest irrigation level 4800 m^3ha^{-1} with about 32.88 and 54.98% for total phenols and amino acids comparing with control treatment (spray with tap water) × irrigation level at 2400 m^3ha^{-1}, which recorded the minimum values of above-mention traits, respectively.

3.3. Macronutrients (N, P and K) and micronutrients (Fe, Mn and Zn) contents and uptake

Drought stress significantly decreased the contents and uptake of all minerals except N content. Furthermore, the reduction in these minerals content was more pronounced in the severe compared with the moderate and well-watered conditions. The combined ANOVA for all evaluated traits indicated that the effects of irrigation regime, anti-transpirants, and their interaction were significant for uptake of all minerals, except the irrigation regime impacts on N content and the interaction effect on N, P, K, Fe, Mn, and Zn contents (Tables 4 and 5). On the other hand, the application of anti-transpirants spray demonstrated a significant increase in the abovementioned macro and micronutrients compared with control under different irrigation levels.

The Chi spray (750 ppm) was exhibited the maximum values of minerals content, i.e., 24.13, 42.82, 9.20, 180, 12.0, 229.06, and 49.20%, and uptake of 11.86, 26.17, 20.90, 156.75, 191.91, and 174.13% followed by KS spray (100 ppm) and Tryptophan at 75 ppm compared with control (spraying with tap water) for macronutrients (N, P, and K) and micronutrients (Fe, Mn, and Zn), respectively.

Regarding the interaction between irrigation levels and anti-transpirants, the results indicated that spraying faba bean plants with chitosan at 750 ppm under the highest irrigation level of 4800 m3ha-1 recorded the highest values with increases about 29.41, 75.00, 16.56, 431.17, 630.48, and 72.68% and 22.37, 35.69, 42.33, 397.63, 452.58 and 485.94% compared to control (spraying with tap water) under the lowest level of irrigation for macronutrients (N, P, and K) and micronutrients (Fe, Mn, and Zn) contents and uptake, respectively.

3.4. Soil pH and salinity, available nutrients after plant harvest

Data in Table 6 showed that all anti-transpirants treatments were decreased the soil pH, which ranging from 7.88 to 7.84 for the I_1 treatments; 7.87 to 7.80 for the I_2 and 7.87 to 7.80 for the I_3. The lowest pH of 7.79 was observed in Chi treatment combined with I_2. The EC decreased due to applying anti-trispirants. Lowest EC of 1.14 dSm^{-1} was recorded by I_2 × Chi. Anti-transpiration increased the contents of available nutrients in soil. Soil treated I_3 gave the highest available nutrients. Sharp (2013) mentioned that chitosan has the ability to chelate the plant nutrients.

4. Discussion

Drought stress is one of the foremost affecting variables that seriously modify the plant physiology, definitely leading to the decline of crop productivity. In plants, it causes a set of morpho-anatomical, physiological, and biochemical changes. Drought stress adversely influences crop performance and weakens food security (El-Saadony et al., 2021a).

Biotic stresses, i.e., heavy metals, salinity, and drought have an impact on the mean performance of all studied characters as it reduced seed yield and its attributes, resulting in a decrease of chlorophylls related to photosynthesis, protein, carbohydrate, total phenols, amino acids, macronutrients (N, P, and K) and micronutrients (Fe, Mn, and Zn) contents and uptake (Desoky et al, 2020a; Desoky et al, 2020b; Desoky et al, 2020c; Elrys et al, 2019; Elrys et al, 2020). The reduction in these attributes was related to the degree of stress, phonological development, physiological and biochemical processes; therefore, plant productivity is adversely affected by drought exposure (Hag and Dalia, 2017). According to

Table 4
Macronutrients' content and uptake as affected by irrigation regimes, anti-transpiration materials and their interaction over two growing seasons.

Irrigation Levels m^3ha^{-1} (I)	Anti-Transpiration (A)	Macronutrients content ($mg\ kg^{-1}$)			Macronutrients uptake ($kg\ ha^{-1}$)		
		N	P	K	N	P	K
I_1	A_0	28.90d	3.60e	21.13 g	30.83 g	3.74 h	22.84f
	A_1	32.20abcd	4.20cde	21.50 fg	50.07ef	6.57fgh	32.34e
	A_2	34.20abcd	4.50cde	22.30def	65.15de	8.61ef	41.96d
	A_3	35.50abc	4.80bcd	22.80bcde	80.82 cd	10.88de	52.06c
I_2	A_0	29.30 cd	3.80de	21.83efg	40.15 fg	5.15gh	29.55ef
	A_1	33.60abcd	4.70bcde	22.37cdef	65.02de	8.86ef	43.02d
	A_2	35.80ab	4.90bcd	23.37bc	89.95c	12.21 cd	58.26c
	A_3	36.20a	5.30abc	23.77ab	117.28b	17.18b	76.93b
I_3	A_0	29.70bcd	4.10cde	22.23def	58.02ef	7.93efg	42.69d
	A_1	34.20abcd	5.20abc	23.00bcd	88.89c	13.42 cd	59.57c
	A_2	36.10ab	5.90ab	23.73ab	120.64b	19.63b	78.58b
	A_3	37.40a	6.30a	24.63a	163.76a	27.32a	107.96a
Irrigation (I)	I_1	32.78a	4.28b	21.93c	56.72c	7.45c	37.30c
	I_2	33.73a	4.68b	22.53b	78.1b	10.85b	51.94b
	I_3	34.35a	5.38a	23.40a	107.88a	17.08a	72.20a
Anti-Transpiration (A)	A_0	29.3b	3.83c	21.73b	43.06d	5.61d	31.69d
	A_1	33.43a	4.70b	22.29b	67.99c	9.62c	44.98c
	A_2	35.37a	5.10ab	23.13a	91.91b	13.48b	59.60b
	A_3	36.37a	5.47a	23.73a	120.62a	18.46a	78.97a
ANOVA	I	0.470	0.028	<0.001	<0.001	0.001	<0.001
	A	0.004	<0.001	<0.001	<0.001	<0.001	<0.001
	I × A	0.999	0.872	0.973	0.007	0.001	<0.001

Notes: 1. Anti-transpiration sources: A_0, A_1, A_2 and A_3 are; Non-Treated, Tryptophan, Potassium Silicate and Chitosan used as foliar spray, respectively. 2. Irrigation regimes: I_1, I_2 and I_3 are; 2400, 3600 and 4800 $m^3\ ha^{-1}$ respectively.

Table 5
Micronutrients' content and uptake as affected by irrigation regimes, anti-transpiration materials and their interaction over two growing seasons.

Irrigation Levels m^3ha^{-1} (I)	Anti-Transpiration (A)	Micronutrients content (mg kg^{-1})			Micronutrient uptake (g ha^{-1})		
		Fe	Mn	Zn	Fe	Mn	Zn
I_1	A_0	61.37 g	39.87e	27.00d	66.26 h	42.83 g	28.81 h
	A_1	63.43 fg	42.37e	31.20bcd	95.52 fg	62.89f	46.66fgh
	A_2	65.33cdefg	43.87bcde	32.17abcd	122.82ef	82.30e	62.01efg
	A_3	67.47cdef	45.97bcd	34.20abc	153.92 cd	105.16d	77.89de
I_2	A_0	63.87efg	40.67e	29.53 cd	86.37gh	54.81 fg	39.79gh
	A_1	65.73cdef	43.90bcde	33.53abcd	125.52de	84.21e	65.17ef
	A_2	68.13bcd	46.53bc	34.67abc	170.01c	115.89 cd	86.41d
	A_3	69.33bc	54.67a	34.97abc	224.44b	176.97b	113.17bc
I_3	A_0	64.20defg	42.10cde	32.53abcd	123.16ef	80.09e	62.69ef
	A_1	68.13bcdf	47.53b	36.53ab	175.59c	123.14c	94.44 cd
	A_2	72.13ab	52.63a	37.67ab	239.23b	174.48b	125.06b
	A_3	75.10a	54.10a	38.43a	329.73a	236.67a	168.81a
Irrigation (I)	I_1	64.40b	43.02c	31.14b	109.63c	73.29c	53.84c
	I_2	66.77b	46.44b	33.18ab	151.58b	107.97b	76.13b
	I_3	69.89a	49.09a	36.29a	217.18a	153.6a	112.75a
Anti-Transpiration (A)	A_0	63.14c	40.88d	29.67b	91.93d	59.24d	43.76d
	A_1	65.77b	44.60c	33.76a	132.54c	90.08c	68.76c
	A_2	68.53a	47.68b	34.83a	177.35b	124.22b	91.16b
	A_3	70.63a	51.58a	35.87a	236.03a	172.93a	119.96a
ANOVA	I	0.011	<0.001	0.059	0.001	<0.001	<0.001
	A	<0.001	<0.001	0.009	<0.001	<0.001	<0.001
	I × A	0.509	0.112	0.999	<0.001	<0.001	0.031

Notes: 1. Anti-transpiration sources: A_0, A_1, A_2 and A_3 are; Non-Treated, Tryptophan, Potassium Silicate and Chitosan used as foliar spray, respectively. 2. Irrigation regimes: I_1, I_2 and I_3 are; 2400, 3600 and 4800 m^3 ha^{-1} respectively.

Table 6
Soil pH, EC as well as available macro and micronutrients content in the soil after faba bean harvest as affected by irrigation regimes, anti-transpiration materials and their interaction over two growing seasons.

Irrigation Levels m^3ha^{-1} (I)	Anti-Transpiration (A)	pH (1:2.5)	EC (dSm^{-1})	Available macronutrients ($mgkg^{-1}$)			Available micronutrients ($mgkg^{-1}$)		
				Fe	Mn	Zn	Fe	Mn	Zn
I_1	A_0	7.88	1.35 a	36.70d	5.89	128.0f	1.98	3.55f	0.58d
	A_1	7.87	1.28bc	37.20 cd	6.04	133.0de	1.92	3.59def	0.62bcd
	A_2	7.87	1.26bcd	37.80 cd	6.12	136.0 cd	1.94	3.63bcdef	0.64abcd
	A_3	7.85	1.21d	38.10bcd	6.21	142.0ab	1.97	3.66abcde	0.67abcd
I_2	A_0	7.84	1.32b	37.90bcd	5.90	130.0ef	1.91	3.58ef	0.59 cd
	A_1	7.85	1.24cde	39.37abcd	6.10	134.0de	1.94	3.62cdef	0.64abcd
	A_2	7.83	1.20de	40.30abcd	6.16	138.0bc	1.95	3.68abcd	0.68abcd
	A_3	7.82	1.14e	41.53abc	6.25	144.0a	1.98	3.72ab	0.72abc
I_3	A_0	7.82	1.20d	39.60abcd	5.97	133.0de	1.93	3.59def	0.62bcd
	A_1	7.84	1.25 cd	41.20abc	6.13	138.67bc	1.96	3.64bcdef	0.69abcd
	A_2	7.80	1.14e	42.30ab	6.23	144.0a	1.98	3.69abc	0.73ab
	A_3	7.79	1.07f	43.0a	6.34	142.67a	2.04	3.74a	0.77a
Irrigation (I)	I_1		1.28a	37.45b	6.10	134.75b	1.93	3.61	0.63b
	I_2		1.23a	39.78ab	6.10	136.50ab	1.95	3.65	0.66ab
	I_3		1.15b	41.53a	6.17	139.58a	1.98	3.67	0.70a
Anti-Transpiration (A)	A_0		1.26a	38.10b	5.92	130.33d	1.91	3.57c	0.60b
	A_1		1.26a	39.26ab	6.10	135.22c	1.94	3.62bc	0.65ab
	A_2		1.20b	40.13ab	6.17	139.33b	1.96	3.67ab	0.68a
	A_3		1.14c	40.88a	6.27	142.89a	2.00	3.71a	0.72a
ANOVA	I		0.007	0.034	0.851	0.040	0.751	0.117	0.034
	A		0.011	0.121	0.584	0.001	0.407	<0.001	0.034
	I × A		<0.001	0.989	1.000	0.065	0.999	0.995	0.997

Notes: 1. Anti-transpiration sources: A_0, A_1, A_2 and A_3 are; Non-Treated, Tryptophan, Potassium Silicate and Chitosan used as foliar spray, respectively. 2. Irrigation regimes: I_1, I_2 and I_3 are; 2400, 3600 and 4800 m^3 ha^{-1} respectively.

Reddy et al. (2003), water stress reduces photosynthesis by reducing stomatal conductance and decreasing leaf area; stomata close as a mechanism to minimize transpiration as moisture stress increases. As a result, the amount of carbon dioxide entering the atmosphere is diminished. If any crop is grown under adverse conditions such as the conditions of this study (irrigation interval-prolonging and sandy soil conditions), the plant stimulates its endogenous anti-transpiration system to develop or adapt against these conditions, but that is not enough; therefore, external anti-transpiration must be applied to increase the plant's ability to protect itself under such conditions. Among this anti-transpiration, chitosan, tryptophan, and potassium silicate has been applied to many stressed crops. The foliar spray of faba bean with tryptophan, potassium silicate, and chitosan single or combined significantly reduced the transpiration and increased the yield quality and quantity properties. The coating with chitosan can form a semi-permeable film which may modify the internal atmosphere and decrease the transpiration loss of the leaves (Olivas and Barbosa-Cánovas, 2005). Also, chitosan has been found to exhibit potent antioxidant and antimicrobial activity (Ramírez et al., 2010; Abd El-Hack et al., 2020). Foliar application of chitosan can increase stomatal conductance and reduce transpiration or be applied as a coating material in seeds as SeNPs effect on wheat (El-Saadony et al., 2021b). Moreover, it can be effective in promoting chitinolytic microorganisms and prolonging storage life through post-harvest treatments, or benefit nutrient delivery to plants as it may prevent leaching and improve the slow release of nutrients in fertilizers (Shahrajabian et al., 2021). Mondal et al. (2012) and Abu-Muriefah (2013) applied chitosan through foliar spray (100–125 mg L^{-1}) and obtained a positive response in nearly all plant traits as well as yield and plant N, P and K. This report achieved an enhancement in faba bean morphology, physiology, biochemistry, and productivity under drought stress. The beneficial effects of chitosan on plant growth can be linked to increased critical enzyme activity in nitrogen metabolism and improved nitrogen transit in functioning leaves, resulting in improved plant growth, quality, and water efficiency (Al-ahmadi, 2015; Górnik et al., 2008). This shows the effect of anti-transpirants in improving water efficiency under semi-arid conditions on pea-green yield (Lolicato 2011; Maamoun and Hassan, 2013). El Nagar et al. (2012) noted that spraying with chitosan at a rate of 1% increased vegetable growth, yield, and component. Chitosan increased all growth properties of okra when applying anti-respirants (Ramadan and El Mesairy 2015; Hidangmayum et al., 2019; Rendina et al., 2019; El Amerany et al., 2020).

The effect of chitosan on nutrients may be attributed to the increase in numbers of microbial populations in soil, and the transformation of organic nutrients into inorganic nutrients that are absorbed easily by plant roots (Abu-Muriefah, 2013; Bolto et al., 2004; Shehata et al., 2012). Also, the binding surface of chitosan can chelate ions containing N in compost (El Amerany et al., 2020). Chitosan application increased nutrient uptake in coffee seedlings (Minh and Anh, 2013). Romanazzi et al. (2017) stated that chitosan increased polyphenols in many fruits by activating relevant enzymes in the phenol production pathway, such as phenylalanine ammonia-lyase (PAL). Rahman et al. (2018) noted that the application of chitosan (1000 ppm) increased the total flavonoid content in strawberry fruits. In addition, Salachna and Zawadzińska (2014) reported that spraying leaves of *Freesia refracta* with chitosan led to increases of N, P, and K of plants. The utilizing of chitosan can be maximized by converting to nano form by using the biological pathways, i.e., plant extract (Saad et al., 2021b) and microbial synthesis of nanomaterials (El-Saadony et al., 2020; Abd El-Hack et al., 2021; El-Saadony et al., 2021b; El-Saadony et al., 2021c). These pathways produce eco-friendly and cost-effective nanomaterials of small sizes with valuable biological activity (El-Saadony et al., 2021d; El-Saadony et al., 2021e; El-Saadony et al., 2021f). Therefore, the amount of chitosan is reduced and maximized.

5. Conclusion

Drought stress badly affects plants' physiology and productivity, leading to the deficiency of food security and economic losses. In addition, the increasing transpiration in the faba bean reduces the yield quality and quantity. The self-defense system of the plant is not sufficient to reduce the external or internal drought. The foliar application of extra anti-transpirants like chitosan, tryptophan, and potassium silicate improve the resistance of plants against biotic and abiotic stresses. Based on the obtained results, we recommended spraying faba bean plants with chitosan at 750 ppm under an irrigation level of 4800 m3 to improve plant quality and quantity.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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