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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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...
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 (Malera 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. A₁: tryptophan at (75 ppm), A₂: potassium silicate (100 ppm), A₃: chitosan (750 ppm) compared to A₀: 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. I₁: 2400, I₂: 3600, and I₃: 4800 m³ha⁻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 m² (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 26th and 29th 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 through transpiration (Davenport et al., 1972). Anti-transpirant materials are compounds that reduce transpiration through the plant stomata. 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.

2.2.1. 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 Na₂CO₃ (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, R² = 0.9884. Total nitrogen was estimated by Kjeldahl method and the protein percentage was calculated by multiply % N in 6.25 (AOAC, 2005).
2.2.4. 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, 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 m³ ha⁻¹. Generally, severe drought reduced seed yield by 81.55% compared 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.

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 m³ ha⁻¹ by 42.29, 89.47, 28.85, 75.91, 24.43, and 306.48% 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 m³ 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/plants, number of pods plant⁻¹, number of seeds pod⁻¹, 100 seed weight and Seed yield ha⁻¹, respectively.

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 1

| Property                          | Value | Property                           | Value |
|----------------------------------|-------|------------------------------------|-------|
| Clay %                           | 12.59 | Soluble ions (mmol c⁻¹ L⁻¹)        | 6.88  |
| Silt %                           | 7.88  | Na⁺                                | 0.82  |
| Sand %                           | 79.53 | K⁺                                 | 5.26  |
| Texture                          | Sandy loam | Ca²⁺                       | 2.60  |
| EC (dSm⁻¹ in paste extract)      | 1.56  | Mg²⁺                               | 5.13  |
| pH [Soil suspension 1:2.5]       | 7.88  | Cl⁻                                 | 1.02  |
| Organic matter (g kg⁻¹)          | 6.41  | HCO₃⁻                               | 9.41  |
| CaCO₃ (g kg⁻¹)                   | 13.4  | SO₄²⁻                               | 0.00  |
| Available nutrients (mg kg⁻¹ soil) |       |                                    |       |
| N                                | 34.1  |                                    |       |
| P                                | 5.2   |                                    |       |
| K                                | 125   |                                    |       |
| Fe                               | 1.9   |                                    |       |
| Mn                               | 3.2   |                                    |       |
| Zn                               | 0.6   |                                    |       |

(1) Available nutrient extractants: NH₄HCO₃-DTPA (for P, K, Fe, Mn, and Zn), KCl (for N).
(2) Texture using the International Texture Triangle.

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, 43.1, 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.
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 m³ ha⁻¹ recorded the highest values of total chlorophyll, pro-
tein, 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 m³ ha⁻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 m³ ha⁻¹ with about 32.88 and 54.98% for total phenols and amino acids comparing with control treatment (spraying with tap water) × irrigation level at 2400 m³ ha⁻¹, which recorded the minimum values of abovemention 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 23.51% 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 m³ ha⁻¹ recorded the highest values with increases about 29.41, 75.00, 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 I₁ treatments; 7.87 to 7.80 for the I₂ and 7.87 to 7.80 for the I₃. The lowest pH of 7.79 was observed in Chi treatment combined with I₂. The EC decreased due to applying anti-trispirants. Lowest EC of 1.14 dS m⁻¹ was recorded by I₂ × Chi. Anti-transpiration increased the contents of available nutrients in soil. Soil treated I₂ 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, phonomological development, physiological and biochemical processes; therefore, plant productivity is adversely affected by drought exposure (Hag and Dalia, 2017). According to

Table 4

| Irrigation Levels m³ ha⁻¹ (I) | Anti-Transpiration (A) | Macronutrients content (mg kg⁻¹) | Macronutrients uptake (kg ha⁻¹) |
|-----------------------------|------------------------|---------------------------------|---------------------------------|
|                            | N | P | K | N | P | K |
| I₁                          |    |    |    | 28.90d | 3.60e | 21.13 g | 30.83 g | 3.74 h | 22.84f |
| I₂                          |    |    |    | 32.20abcd | 4.00cde | 21.50 fg | 50.07ef | 6.57gh | 32.34e |
| I₃                          |    |    |    | 34.20abcd | 4.50cde | 22.30def | 65.15de | 8.61ef | 41.96d |
| I₁                          |    |    |    | 35.50abc | 4.80bdc | 22.80bcde | 80.82 cd | 10.88de | 52.06c |
| I₂                          |    |    |    | 36.30abcd | 4.70bdc | 23.70bdc | 89.95c | 12.21cd | 58.26c |
| I₃                          |    |    |    | 37.40a | 5.30abbc | 23.77ab | 117.28b | 17.18b | 76.93b |
| I₁                          |    |    |    | 38.20abcd | 4.10cde | 23.80gde | 120.64b | 19.63b | 78.58b |
| I₂                          |    |    |    | 39.30a | 5.30abcd | 24.63a | 163.76a | 27.32a | 107.96a |
| I₃                          |    |    |    | 40.30a | 5.40abc | 24.63a | 163.76a | 27.32a | 107.96a |

Notes: 1. Anti-transpiration sources: A₀, A₁, A₂ and A₃ are; Non-Treated, Tryptophan, Potassium Silicate and Chitosan used as foliar spray, respectively. 2. Irrigation regimes: I₁, I₂ and I₃ are; 2400, 3600 and 4800 m³ 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-

| Irrigation Levels m³ ha⁻¹ (I) | Anti-Transpiration (A) | Micronutrients content (mg kg⁻¹) | Micronutrient uptake (g ha⁻¹) |
|-------------------------------|------------------------|---------------------------------|-------------------------------|
|                               |                        | Fe     | Mn    | Zn    | Fe     | Mn    | Zn    |
| I₁                            | A₀                     | 61.37  | 39.87e| 27.00d| 66.26  | 42.83 | 28.81 |
|                               | A₁                     | 63.43f| 42.73e| 31.20bcd| 95.52  | 62.89f| 46.60f|
|                               | A₂                     | 65.33cdef| 43.87bcd| 32.17abcd| 122.82e| 82.30e| 62.01ef|
|                               | A₃                     | 67.47defg| 45.97bcde| 34.20abc| 153.92cd| 105.16d| 77.89de|
| I₂                            | A₀                     | 63.87fg| 40.67e| 29.53cd| 86.37gh| 54.81f| 39.79gh|
|                               | A₁                     | 65.73cdef| 43.90bcd| 33.53abcd| 125.52de| 84.21e| 65.17ef|
|                               | A₂                     | 68.13bcd| 46.53b| 34.67abc| 170.01c| 115.89cd| 86.41d|
|                               | A₃                     | 69.33b| 47.64a| 35.87a| 224.44b| 176.97b| 113.17bc|

**Table 5**

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

| Irrigation Levels m³ ha⁻¹ (I) | Anti-Transpiration (A) | pH (1:2.5) | EC (dSm⁻¹) | Available macronutrients (mg kg⁻¹) | Available micronutrients (mg kg⁻¹) |
|-------------------------------|------------------------|------------|------------|-----------------------------------|-----------------------------------|
|                               |                        | Fe     | Mn    | Zn    | Fe     | Mn    | Zn    |
| I₁                            | A₀                     | 7.88   | 1.35a  | 36.70d| 5.89  | 128.0f| 1.98  | 3.55f |
|                               | A₁                     | 7.87   | 1.28bcd| 37.20cd| 6.04  | 133.0de| 1.92  | 3.59def|
|                               | A₂                     | 7.87   | 1.26bcd| 37.80cd| 6.12  | 136.0cd| 1.94  | 3.63bcdef|
|                               | A₃                     | 7.85   | 1.21d  | 38.10bcd| 6.21  | 142.0ab| 1.97  | 3.66abcde|
| I₂                            | A₀                     | 7.84   | 1.32b  | 37.90bcd| 5.90  | 130.0ef| 1.91  | 3.58ef|
|                               | A₁                     | 7.85   | 1.24bcd| 39.37abcd| 6.10  | 134.0de| 1.94  | 3.62def|
|                               | A₂                     | 7.83   | 1.20de  | 40.30abcd| 6.16  | 138.0bc| 1.95  | 3.68abcd|
|                               | A₃                     | 7.82   | 1.14e  | 41.53abc| 6.25  | 144.0a| 1.98  | 3.72ab|

**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.

Notes: 1. Anti-transpiration sources: A₀, A₁, A₂ and A₃ are; Non-Treated, Tryptophan, Potassium Silicate and Chitosan used as foliar spray, respectively. 2. Irrigation regimes: I₁, I₂ and I₃ are; 2400, 3600 and 4800 m³ ha⁻¹ respectively.
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). Foil 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 chitooligosaccharide 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; Görnik et al., 2008). This shows the effect of anti-transpirants in improving water efficiency under semi-arid conditions on pea-green yield (Lollicato 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; Hidangayumay et al., 2019; Rendina et al., 2019; El Amanery 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 Amanery 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 utilization 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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