Influence of Zeolite, Kaolin, and Chitosan on the Growth and Productivity of Strawberry

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Although chemical fertilizers increase crop productivity, they have undesirable effects on the environment, soil fertility, and negatively influence fruit shelf life and quality. Therefore, the application of plant biostimulants and biostimulant-like substances has become necessary to improve the availability and absorption of nutrients, enhance growth, yield, quality, and tolerance to abiotic and biotic stresses, and serve as an alternative to mineral fertilizers. Therefore, this study investigated the influence of zeolite, kaolin (KL), and chitosan (Cs) in alleviating abiotic stress and improving productivity and quality of strawberry plants. Strawberry plants were soil fertilized by zeolite at 0, 2, and 3 kg and then they were sprayed with 2% g/L KL + 500 ppm Cs, 4% KL + 1000 ppm Cs, and 6% KL + 1500 ppm Cs. The individual application of zeolite improved the performance of strawberry plants, and its influence greatly increased with the combination spraying of different combinations from KL + Cs. The highest increments resulted from the application of 3 and 2 kg of zeolite combined with the spraying of 4% KL + 1000 ppm Cs and 6% KL + 1500 ppm Cs compared to non-treated plants.

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INTRODUCTION

Strawberry is one of the most important berry fruits that is highly consumed and accepted by people worldwide (D'Urso *et al*. 2015). It has an attractive taste, fine flavor, distinctive aroma, bright red colour, sweetness, and juicy texture, making it a delightful fruit. Moreover, strawberry is rich in essential minerals such as K, Ca, and P, phytochemicals, fiber, antioxidants, and vitamins, particularly vitamins C and B9. Thus, it is beneficial to human health (Fernandes *et al*. 2012). It can be eaten fresh, and is used for preparing jelly, ice cream, juice, chocolates, and wine (Kumar *et al*. 2017). In Egypt, strawberry is one of the most important export crops; the cultivated area is 15.836 hectares and the production is 638.842 tons (FAO 2022). However, it is sensitive to high temperature.

Chemical fertilizers are simpler to apply than organic fertilizers; however, they negatively impact naturally occurring soil microorganisms that boost soil fertility (Verma *et al.* 2014). The overuse of chemical fertilizers has caused significant environmental impacts and increased production costs (Wang *et al.* 2018; Fang *et al.* 2021). Besides, they pollute the undersoil water, increase air pollution, and raise soil acidification, which in turn decreases the organic compounds in the soil (Havlin *et al.* 2005).

Reducing chemical fertilizer use while increasing organic fertilizers represents a forward-looking strategy for balanced agricultural management, and this approach regulates nutrient supply to the soil, enhancing both soil productivity and crop quality (Chen 2006). Sustainable agricultural practices prioritize the health of both soil components and crop plants, along with beneficial microbes (Narula and Dudeja 2013).

Using organic fertilizers can enhance soil nutrient levels and boost soil enzyme activity (Kilic *et al*. 2021). The usage of organic fertilizers has numerous advantages such as reducing the cost, improving the soil construction, texture, and airing, enhancing the soil water holding capacity and improving the growth root system (Liu *et al.* 2010), increasing soil organic matter, and consequently improving the soil fertility (Moe *et al*. 2017; Jin *et al.* 2022). Additionally, organic fertilizers affect the physicochemical properties of orchard soils and the sugar, acid, and solid content of fruit (Yadav *et al.* 2016).

Zeolite-coated fertilizers possess a greater capacity to absorb and hold water and retard the rates of nutrient release from the soil, particularly sandy and sandy loam soil (Syukur and Sunarminto 2013). Additionally, natural zeolites are effective soil-improving substances and have a good capacity to hold water and nutrients, and they improve the rates of infiltration, conductivity, cation exchange capacity, and prevent water losses from profound leaking (Enamorado-Horrutiner *et al*. 2016), and they could be utilized as fertilizer and chelating agents (Tsintskaladze *et al*. 2016). Moreover, natural zeolites markedly enhance fertilizer efficiency and reduce the environmental impact of chemical fertilizers in agriculture due to their high surface area, porosity, ion exchange capacity, and ability to retain and gradually release nutrients and water (Lahori *et al.* 2020).

Kaolin (KL) particle film technology has been developed as an efficient, eco-friendly solution to mitigate heat and light stress, reduce water deficits, and promote the cultivation of high-quality fruits and vegetables (Boari *et al*. 2015) by reflecting solar radiation off the tree canopy surface (Gullo *et al*. 2020; Ali *et al*. 2021). Moreover, it is believed to work as an anti-transpirant, enhancing water use efficiency (Brillante *et al.* 2016), effectively lowering temperature and sunburn, which in turn enhances productivity and improves both the physical and chemical qualities of fruit across various tree species compared to the control (Khalifa *et al*. 2021). Spraying of KL forms a white film of particles on the leaves, leading to the activation of the photosynthetic rate (Torres-Quezada *et al*. 2018). KL is a mineral compound characterized by a high amount of kaolinite, and it has been used for alleviating environmental stresses such as heat and drought in different crops. It is also a non-toxic and eco-friendly natural antitranspirant that enhances growth traits, yield, and its components, meanwhile, it can help mitigate the adverse effects of water deficiency, although it may increase leaf temperature if the plant is not under drought stress (Mphande *et al.* 2020).

Appling of chitosan (Cs) has been demonstrated as a strategy to alleviate the negative effect of abiotic stress, stimulate plant growth, and improve the yield and quality of crops (Jabeen and Ahmad 2013). It also can improve plant tolerance to abiotic stresses such as salt, drought, and low temperatures (Hassan *et al*. 2021; Kocięcka and Liberacki 2021; Wang *et al*. 2021). The impact of Cs may be attributed to the release of nitrogen, which is then utilized in the synthesis of components for the photosynthetic system (Shangguan *et al*. 2000). It acts as a growth promoter by enhancing nutrient absorption capacity in plants (Malekpoor *et al*. 2016; Balal *et al*. 2017). Additionally, Cs is a natural, low toxic, and economical compound, consisting of an amino polysaccharide obtained by alkaline deacetylation from chitin and other decomposable substances of crabs and shrimp shells. Therefore, it is considered an eco-friendly product (Mohamed *et al*. 2018). Cs is favored for its various properties; water-soluble (Golkar *et al.* 2019), bioactive (Turk 2019; Bakhoum *et al.* 2020), antimicrobial (Gerami *et al.* 2020), and non-toxic characteristics (Sen *et al.* 2020) to enhance stress tolerance and boost plant performance by activating multiple stress-related enzymes. Therefore, this study focused on studying the influence of zeolite combined with different combinations of KL + Cs as to improve the growth, productivity, and fruit quality attributes of strawberry.

EXPERIMENTAL

Applied Treatments, Location, and Experimental Design

The experiments were conducted using a split-plot design with three plots (replicates) on the festival strawberry variety, where each plot contained ten plants. The plants were cultivated in rows. The distance between rows was 40 cm and between plants in the same row 25 cm under drip irrigation. Strawberry plants were planted at the start of October 2022 and 2023 seasons in a private orchard in the Nubaria region, Beheira governorate, Egypt. Each plot was fertilized with zeolite with 0, 2, and 3 kg at the start of the plantation as the main factor, then they were sprayed with the combinations of 2% g/L KL + 500 ppm Cs, 4% KL + 1000 ppm Cs, and 6% KL + 1500 ppm Cs as a submain factor compared to untreated trees as a control (Table 1). The plants were sprayed four times: mid-November 2022 (vegetative growth and flowering period), December 01, 2022 (flowering and fruiting period), March 01, 2023 (fruiting period), and April 01, 2023 (fruiting period). The same treatments were performed again in the second season of 2023/2024, where the total volume of the spraying solution was 2 L. Physical and chemical analysis of the experimental soil is given in Table 2, and the weather data in Table 3.

Table 1. The Applied Treatments

Treatments	Soil Application	Foliar Spray
T1	0 kg Zeolite	0 KL + 0 Cs
T2	0 kg Zeolite	2% KL + 500 ppm Cs
T3	0 kg Zeolite	4% KL + 1000 ppm Cs
T4	0 kg Zeolite	6% KL + 1500 ppm Cs
T5	2 kg Zeolite	0 KL + 0 Cs
T6	2 kg Zeolite	2% KL + 500 ppm Cs
T7	2 kg Zeolite	4% KL + 1000 ppm Cs
T8	2 kg Zeolite	6% KL + 1500 ppm Cs
T9	3 kg Zeolite	0 KL + 0 Cs
T10	3 kg Zeolite	2% Kl + 500 ppm Cs
T11	3 kg Zeolite	4% KL + 1000 ppm Cs
T12	3 kg Zeolite	6% KL + 1500 ppm Cs

Table 2. Soil Analysis

Mechanical Analysis (0 to 30 cm depth)							
Sand (%)	Silt (%)	Clay (%)	Textural Class	pH (1:2)	EC (1:2, Water Extract) (dS/m)	O.M	Ca CO_3
80.32	2.00	17.68	Loamy sand	7.8	0.8	1.3	3.13

Soluble Cations (meq/L)				Soluble Anions (meq/L)			Available Nutrients (mg/kg)		
Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	N	P	K
2.0	4.0	1.8	0.4	3.6	2.2	2.3	93.4	15.6	450

O.M: organic matter

Table 3. Weather Data During the Experimental Period 2022/2023 to 2023/2024

Year	Months	Temperature (°C)		Average Relative Humidity (%)	Total Precipitation (mm)
		Minimum	Maximum		
	2022 to 2023				
2022	September	23.07	33.34	60.56	1.10
	October	20.48	28.77	62.91	3.00
	November	16.99	24.41	63.58	2.70
	December	14.35	22.83	68.75	23.80
2023	January	11.89	20.35	72.73	31.70
	February	10.61	18.87	68.77	48.70
	March	12.75	23.43	63.57	19.00
	April	14.39	26.33	59.06	16.00
	May	17.36	29.53	59.56	0.40
Year	2023 to 2024				
2023	September	24.05	34.80	60.11	0.60
	October	21.30	30.15	65.05	4.30
	November	18.05	26.89	63.62	5.00
	December	14.87	22.79	69.42	6.80
2024	January	12.20	19.84	66.87	28.20
	February	11.50	20.46	69.66	23.60
	March	12.71	23.51	62.56	2.50
	April	15.72	27.96	63.55	4.20
	May	18.27	30.19	55.32	0.80

Vegetative Growth Attributes

After 120 days from transplanting throughout the two experimental seasons, in the two growing seasons, plant height (cm), number of leaves per plant, and leaf area were measured. Leaf chlorophyll content was measured in fresh leaves by taking an average of ten readings. The flower number and the number of crowns were estimated.

Fruit Yield

The yield per plant (g) was determined as the weight of all harvested fruits from each plot during February and March over the harvested season up to mid May, and then the total yield per hectare was calculated.

Fruit Quality

Fruit physical characteristics

The average fruit weight was calculated as the average of 40 fresh fruits. Fruit firmness was measured using a Chatillon Pressure Meter Equipped with a Plunger (Hongqi Instrument (Changxing) Company, Zhejiang, China). Fruit length and diameter were measured using a digital Vernier caliper.

Fruit chemical characteristics

Twenty ripe fruits were chosen randomly from each experimental plot at a full ripe stage to measure the percentage of total soluble solids content (TSS) using the hand refractometer. Titratable acidity (TA%), samples of 100 g fruits from each experimental plot at a full ripe stage were randomly chosen to determine the titratable acidity of juice by titration with 0.1 NaOH solution, according to the method described in (AOAC 2005). The content of vitamin C (mg/ 100 mL juice) was determined by titration using 2,6-dichloro phenol indophenol (Nielsen 2017). Anthocyanin content (mg/100 g F.W.) was determined according to Nangle *et al*. (2015). The phenol-sulfuric acid method was used to estimate the total sugars using 1.0 mL of sample treated with 1.0 mL of 5% phenol and 5.0 mL of concentrated H_2SO_4 and measured at 485 nm, while reduced sugars were estimated using the 3,5-dinitro salicylic acid (DNS) method using 2.0 mL of the sample and 1.5 mL of DNS at 80 °C for 10 min and measuring at 510 nm (Lam *et al*. 2021). Non-reduced sugars were the difference between them.

Mineral Content in the Leaves

At the end of seasons 2022/2023 and 2023/2024 seasons, 40 leaves from each plot (Arrobas *et al*. 2018) were dried at 70 °C until constant weight and then ground and digested using H_2SO_4 and H_2O_2 until the solution became clear to determine nitrogen content using the micro Kjeldahl method (Wang *et al*. 2016), phosphorus content using the Vanadomolybdo method (Wieczorek *et al*. 2022), and potassium content was determined using a flame photometer (Asch *et al*. 2022). Micronutrients, such as iron, manganese, and zinc, were determined using atomic absorption spectrophotometry.

Statistical Analysis

The results were statistically analyzed by using a Split Plot Design in three replicates, where soil addition of zeolite was the main factor and spraying of KL + Cs combination was the submain factor using CoHort Soft-ware 6.311 (Pacific Grove, CA, USA). The least significant difference at 0.05% ($LSD_{0.05}$) was applied to compare the treatment means (Snedecor and Cochran 2021).

RESULTS AND DISCUSSION

Vegetative Growth Parameters

Spraying strawberry plants with the combination of KL + Cs solely or combined with the soil addition of zeolite greatly improved the leaf chlorophyll content, numbers of flowers, and crowns compared to untreated plants (Fig. 1). Additionally, the results significantly improved the leaf chlorophyll content by the addition of 3 kg of zeolite combined with 6 % KL + 1500 ppm Cs, which is the superior treatment rather than the other treatments. Numbers of flowers and crowns were statistically improved by the addition of 3 or 2 kg zeolite to the soil combined with the exogenous spraying of 6% KL + 1500 ppm Cs, 4% KL + 1000 ppm Cs, and 2% KL + 500 ppm Cs compared to untreated plants.

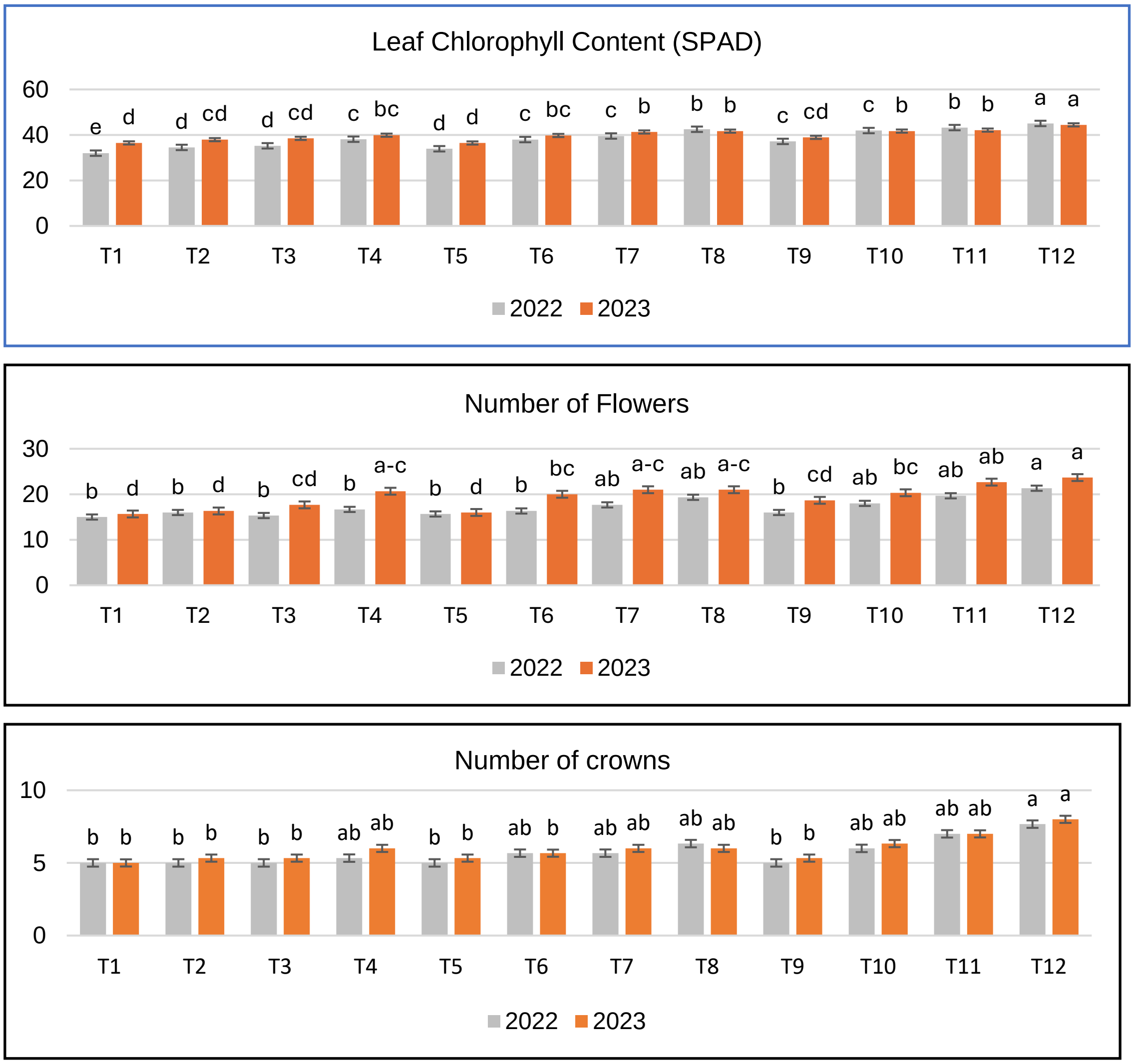

Fig. 1. Effect of the zeolite soil addition combined with the spraying of KL and Cs on the leaf chlorophyll, flower number and crown number of strawberry

The addition of zeolite to the soil singly and with the spraying of KL and Cs greatly improved the leaf number per plant, leaf area, and plant height over untreated trees (Table 4). The addition of 3 or 2 kg of zeolite combined with the spraying of 6% KL + 1500 ppm Cs and 4% KL + 1000 ppm Cs greatly enhanced the number of leaves per plant, plant height, and leaf area compared to the control plants. Additionally, the spraying of 6% KL + 1500 ppm Cs was also effective in improving these parameters. Moreover, the highest increments in these parameters were noted by the soil addition of 3 kg zeolite combined with 6% KL + 1500 ppm Cs, which is the superior treatment during the experimental period.

Table 4. Effect of the Zeolite Soil Addition Combined with the Spraying of KL and Cs on the Leaf Number, Plant Height, and Leaf Area of Strawberry

Soil Application	Foliar Spray	Leaf Number/Plant		Plant Height (cm)		Leaf Area (cm^2)	
		2022	2023	2022	2023	2022	2023
0 kg Zeolite	0 KL + 0 Cs	17.00d ±1.00	16.00d ±1.00	17.98d ±0.65	18.47f ±0.91	2.83c ±0.15	3.00d ±0.1
	2% KL + 500 ppm Cs	17.00d ±2.64	16.33d ±1.53	18.33d ±0.91	19.90f ±0.43	2.97bc ±0.21	3.09d ±0.38
	4% KL + 1000 ppm Cs	21.33bc ±1.53	19.33cd ±1.15	21.97bc ±1.48	22.90cde ±1.95	3.33bc ±0.23	3.29d ±0.19
	6% KL + 1500 ppm Cs	23.67b ±1.52	24.33b ±1.15	22.93bc ±1.70	23.60cd ±2.05	3.47b ±0.15	4.18bc ±0.02
2 kg Zeolite	0 KL + 0 Cs	17.67cd ±1.53	16.67d ±2.08	20.50cd ±2.01	20.50ef ±1.21	3.07bc ±0.21	3.03d ±0.21
	2% KL + 500 ppm Cs	18.67cd ±1.53	19.33cd ±1.15	22.17bc ±1.50	21.17def ±1.00	3.37bc ±0.21	3.12d ±0.22
	4% KL + 1000 ppm Cs	23.33b ±1.53	24.33b ±1.53	23.23bc ±1.48	24.17cd ±1.30	3.47b ±0.15	3.96c ±0.36
	6% KL + 1500 ppm Cs	23.67b ±1.53	24.67b ±2.08	23.33bc ±1.01	25.33bc ±1.68	3.48b ±0.12	4.40abc ±0.09
3 kg Zeolite	0 KL + 0 Cs	18.33cd ±1.53	18.00cd ±1.00	20.90bc ±0.79	22.80c-e ±2.36	3.27bc ±0.25	3.19d ±0.08
	2% KL + 500 ppm Cs	23.33b ±1.53	21.67bc ±1.52	22.90bc ±.46	23.10cde ±1.41	3.37bc ±0.15	3.46d ±0.20
	4% KL + 1000 ppm Cs	24.00b ±1.00	25.00b ±2.00	24.20b ±1.59	26.87b ±1.65	3.99a ±0.34	4.57ab ±0.08
	6% KL + 1500 ppm Cs	28.33a ±1.53	28.67a ±1.15	26.37a ±1.01	29.37a ±0.85	4.18a ±0.15	4.81a ±0.18
$LSD_{0.05}$		2.75	2.75	2.11	2.03	0.36	0.38

Note: Treatments with the same letter in each column indicate no significant differences between them.

Fruit Weight and Fruit Yield

The results showed that there was an improvement in individual fruit weight, fruit yield were obviously improved by the soil addition of zeolite at 3 or 2 kg combined with the spraying of 6% KL + 1500 ppm Cs or 4% KL + 1000 ppm Cs respectively, compared to untreated plants (Fig. 2). Additionally, the spraying of 6% KL + 1500 ppm Cs and 4% KL + 1000 ppm Cs also were more effective in improving the same parameters than the spraying of 2% KL + 500 ppm Cs compared to untreated trees. The results indicated that the most efficient treatment was the application of 3 kg of zeolite to the soil combined with the spraying of 6% KL + 1500 ppm Cs compared to the other applied treatments.

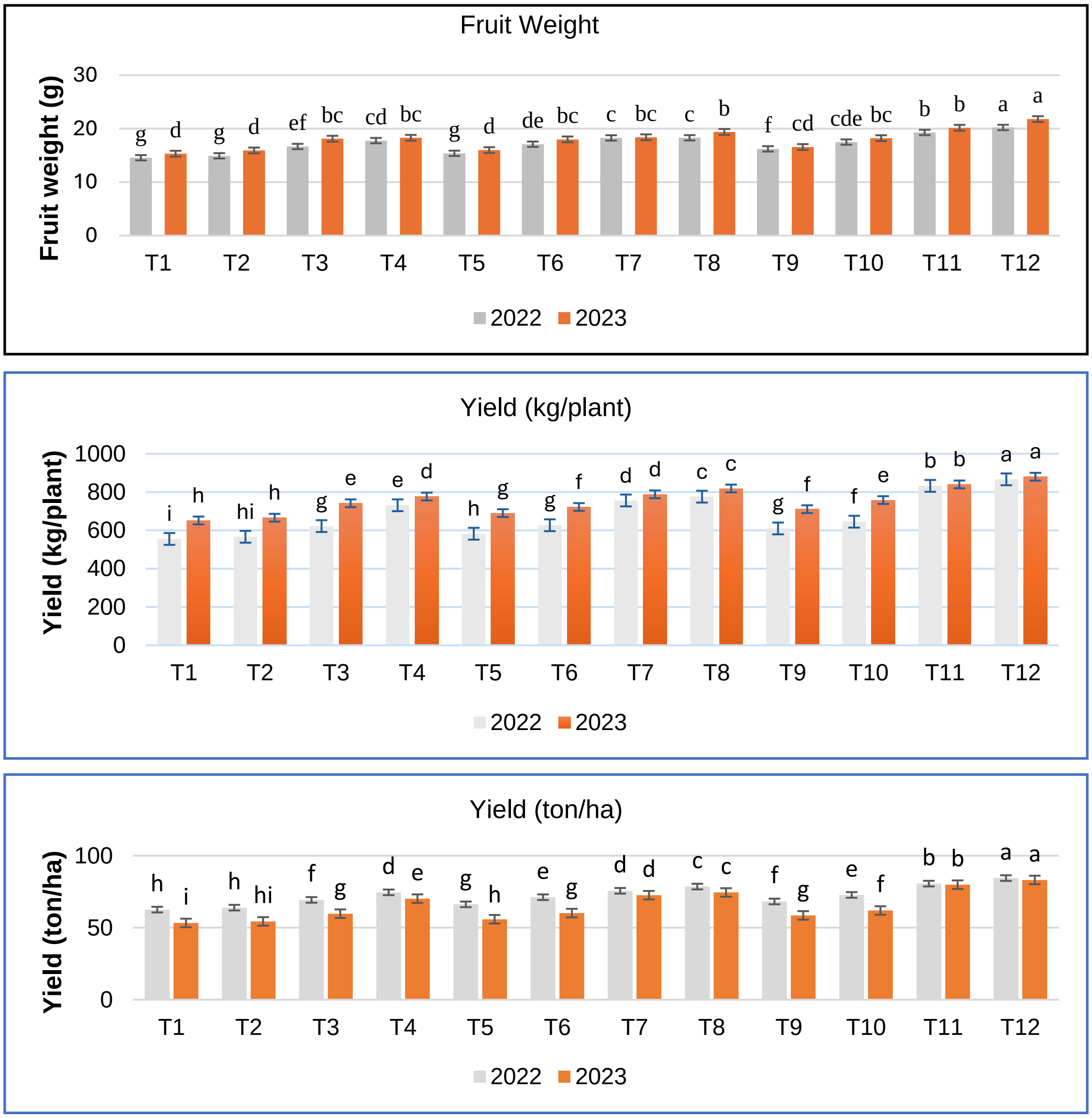

Fig. 2. Effect of the zeolite soil addition combined with the spraying of KL and Cs on fruit weight and fruit yield (kg per plant) and (ton/ha) of strawberry

Fruit Physical Characteristics

Spraying strawberry plants fertilized with zeolite by the mixture of KL + Cs positively increased the fruit length, fruit diameter, and fruit firmness compared to nontreated plants (Table 5). The best results in fruit length, fruit diameter, and fruit firmness were noted by the addition of 3 kg zeolite and spraying the plants with the 6% KL + 1500 ppm Cs. Additionally, the fruit length and fruit diameter were also greatly improved with the addition of 3 kg zeolite combined with the spraying of 4% zeolite + 1000 ppm Cs in the two experimental seasons.

Table 5. Effect of the Zeolite Soil Addition Combined with the Spraying of KL and Cs on the Fruit Length, Diameter, and Fruit Firmness of Strawberry

Soil Application	Foliar Spray	Fruit Length (cm)		Fruit Diameter (cm)		Fruit Firmness (kg/cm^2)	
		2022	2023	2022	2023	2022	2023
0 kg Zeolite	0 KL + 0 CS	2.60e ±0.10	2.66g ±0.13	2.39d ±0.04	2.53e ±0.09	1.40e ±0.02	1.47d ±0.02
	2% KL + 500 ppm Cs	2.68e ±0.12	2.81fg ±0.04	2.44d ±0.06	2.65de ±0.10	1.44d ±0.01	1.47d ±0.01
	4% KL + 1000 ppm Cs	3.04d ±0.03	3.02de ±0.14	2.76c ±0.08	2.81d ±0.04	1.45d ±0.01	1.49cd ±0.01
	6% KL + 1500 ppm Cs	3.28c ±0.08	3.22cd ±0.05	3.13b ±0.12	3.06c ±0.05	1.49b ±0.02	1.52bc ±0.02
2 kg Zeolite	0 KL + 0 CS	2.69e ±0.09	2.82fg ±0.04	2.49d ±0.04	2.70d ±0.04	1.40e ±0.02	1.48cd ±0.01
	2% KL + 500 ppm Cs	3.06d ±0.06	3.13cd ±0.03	2.81c ±0.04	3.01c ±0.06	1.46cd ±0.01	1.49cd ±0.01
	4% KL + 1000 ppm Cs	3.28c ±0.08	3.26c ±0.04	3.15b ±0.05	3.07c ±0.06	1.50b ±0.01	1.52bc ±0.02
	6% KL + 1500 ppm Cs	3.46b ±0.07	3.30c ±0.06	3.29ab ±0.04	3.13c ±0.03	1.50b ±0.01	1.52bc ±0.02
3 kg Zeolite	0 KL + 0 CS	2.76e ±0.05	2.88ef ±0.07	2.53d ±0.04	2.74d ±0.05	1.43de ±0.01	1.48cd ±0.03
	2% KL + 500 ppm Cs	3.24c ±0.04	3.20cd ±0.11	2.81c ±0.04	3.06c ±0.05	1.48bc ±0.01	1.51bcd ±0.02
	4% KL + 1000 ppm Cs	3.51b ±0.04	3.50b ±0.02	3.35a ±0.05	3.37b ±0.03	1.52b ±0.02	1.54b ±0.02
	6% KL + 1500 ppm Cs	3.69a ±0.10	3.80a ±0.18	3.46a ±0.03	3.54a ±0.14	1.55a ±0.01	1.58a ±0.02
$LSD_{0.05}$		0.14	0.16	0.15	0.13	0.03	0.03

Note: Treatments with the same letters in each column indicate no significant differences between them

Fruit Chemical Characteristics

Spraying of 6% KL + 1500 ppm Cs and 4% KL + 1000 ppm Cs greatly increased the fruit content from TSS %, anthocyanin, and vitamin C, and their effect was greatly increased by the soil addition of zeolite at 3 or 2 kg. Meanwhile, they greatly reduced the fruit content from acidity compared to untreated trees (Fig. 3). Additionally, the results demonstrated that the most positive influence was obtained by the 3 kg zeolite combined with 6% KL + 1500 ppm Cs, which is the best treatment compared to nontreated plants during the testing period. Moreover, the spraying of 6% KL + 1500 ppm Cs was more effective in improving these parameters than the spraying of 4% KL + 1000 ppm Cs or 2% KLl + 500 ppm Cs.

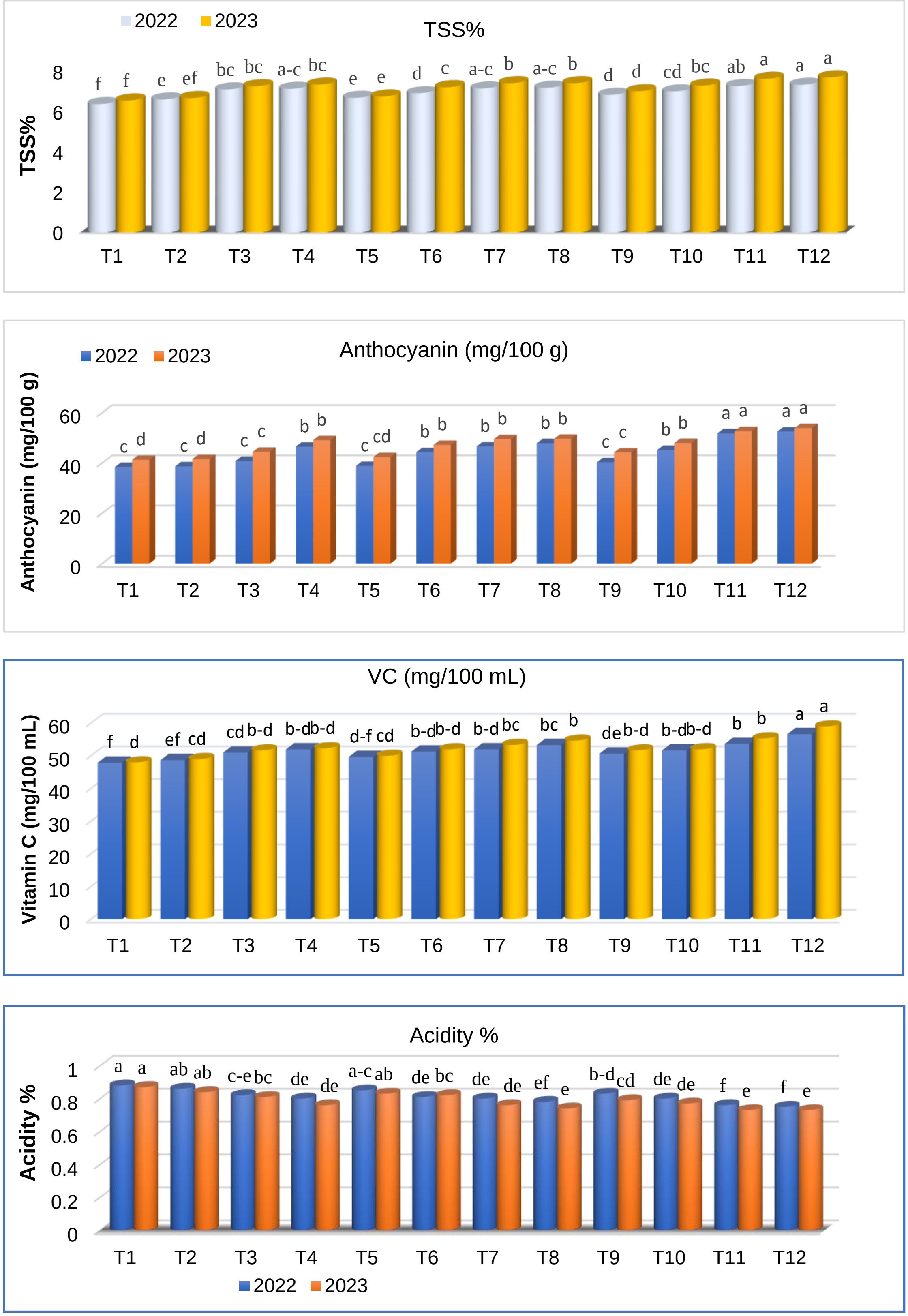

Fig. 3. Effect of the zeolite soil addition combined with the spraying of KL and Cs on TSS, anthocyanin, vitamin C, and acidity in strawberry

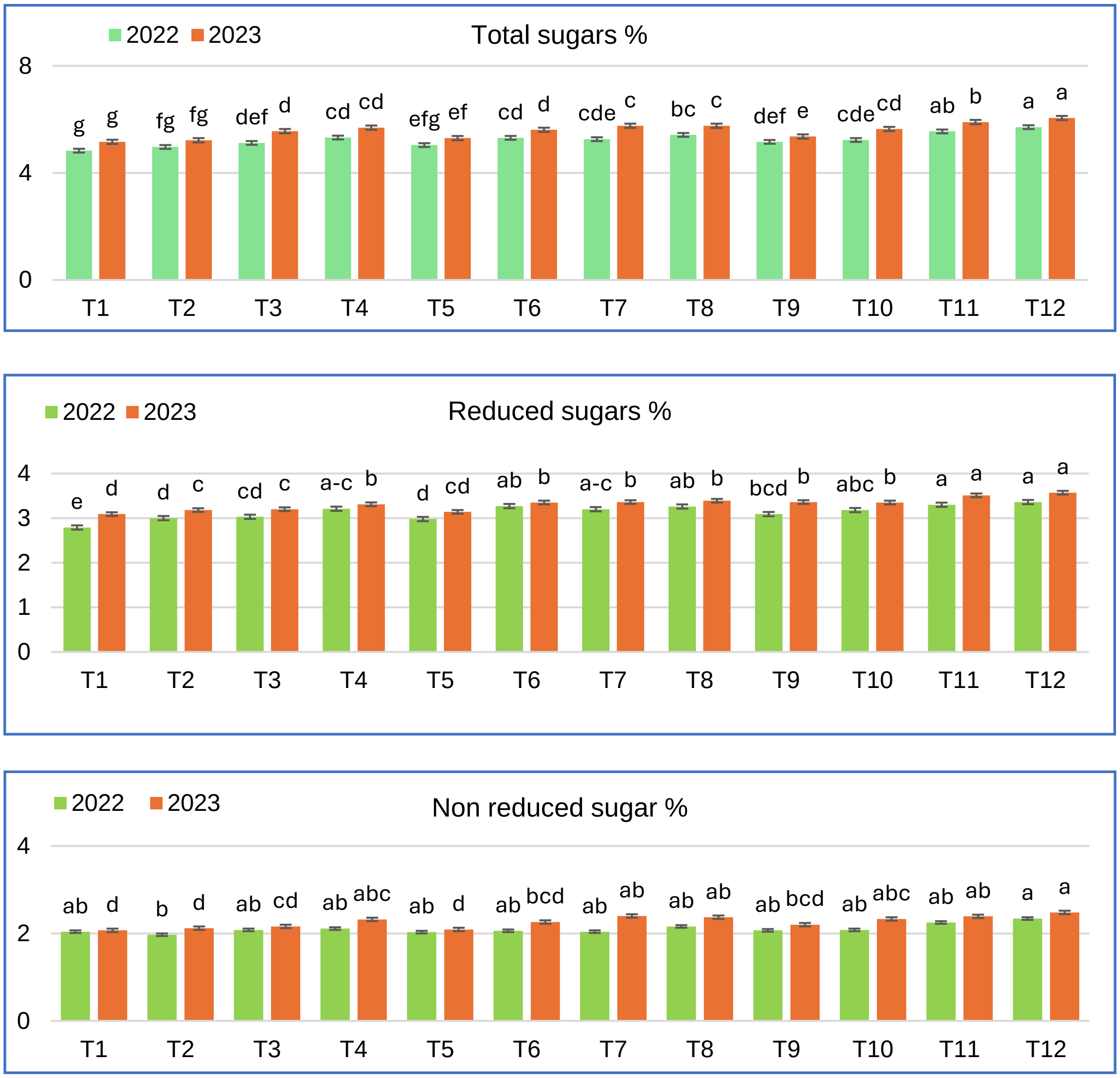

Fig. 4. Effect of zeolite soil addition combined with the spraying of KL and Cs on the fruit content: total, reduced, and non-reduced sugars in strawberry

The soil addition of 3 or 2 kg from zeolite combined with the spraying of 4% KL + 1000 ppm Cs and 6% KL + 1500 ppm Cs improved the total, reduced, and non-reduced sugars compared to untreated plants (Fig. 4). The spraying of 6% KL + 1500 ppm Cs was higher in its effect than the spraying of 4% KL + 1000 ppm Cs or 2% KL + 500 ppm Cs. The soil addition of 3 kg from zeolite was more effective than the usage of 2 kg. The combined application of zeolite with the spraying of KL + Cs was more effective than the sole application of each one of them.

Nutritional Status

The data in Tables 6 and 7 indicate that the soil addition of zeolite of 3 or 2 kg combined with the foliar spraying of 6% KL + 1500 ppm Cs and 4% KL + 1000 ppm Cs significantly improved the leaf content of nitrogen, phosphorous, potassium, iron, manganese, and zinc compared to untreated plants. Additionally, the results showed that the individual spraying of 6% KL + 1500 ppm Cs was more effective in its positive effect than the spraying of 4% KL + 1000 ppm Cs or 2% KL + 500 ppm Cs compared to untreated plants.

Table 6. Effect of the Zeolite Soil Addition Combined with the Spraying of KL and Cs on Leaf Content of Nitrogen, Phosphorous, and Potassium in Strawberry

Soil Application	Foliar Spray	N (%)		P (%)		K (%)	
		2022	2023	2022	2023	2022	2023
0 kg Zeolite	0 KL + 0 Cs	2.14e ±0.02	2.30f ±0.06	0.33c ±0.01	0.38e ±0.01	2.23f ±0.03	2.28h ±0.05
	2% KL + 500 ppm Cs	2.15e ±0.05	2.34f ±0.01	0.34c ±0.01	0.38e ±0.01	2.26f ±0.04	2.31h ±0.06
	4% KL + 1000 ppm Cs	2.38cd ±0.02	2.54d ±0.01	0.37bc ±0.01	0.40cde ±0.02	2.28f ±0.01	2.59f ±0.03
	6% KL + 1500 ppm Cs	2.52b ±0.05	2.69c ±.04	0.37bc ±0.01	0.42bcd ±0.01	2.47cd ±0.04	2.77d ±0.04
2 kg Zeolite	0 KL + 0 Cs	2.20e ±0.02	2.40e ±0.01	0.35bc ±0.01	0.39de ±0.01	2.35e ±0.01	2.33h ±0.05
	2% KL + 500 ppm Cs	2.42c ± 0.02	2.55d ±0.04	0.36bc ±0.01	0.41bcde ±0.01	2.44d ±0.03	2.44g ±0.04
	4% KL + 1000 ppm Cs	2.54ab ±0.03	2.75bc ±0.02	0.37bc ±0.01	0.43bcd ±0.02	2.53c ±0.05	2.86c ±0.06
	6% KL + 1500 ppm Cs	2.55ab ±0.04	2.78b ±0.01	0.38bc ±0.02	0.43bc ±0.01	2.64b ±0.05	3.05b ±0.03
3 kg Zeolite	0 KL + 0 Cs	2.34d ±0.04	2.51d ±0.01	0.36bc ±0.01	0.40cde ±0.02	2.40de ±0.01	2.54f ±0.02
	2% KL + 500 ppm Cs	2.54ab ±0.03	2.57d ±0.04	0.37bc ±0.01	0.42bcd ±0.01	2.51c ±0.06	2.67e ±0.03
	4% KL + 1000 ppm Cs	2.58ab ±0.02	2.81b ±0.04	0.39b ±0.02	0.44b ±0.01	2.65b ±0.01	3.08b ±0.01
	6% KL + 1500 ppm Cs	2.62a ±0.03	2.88a ±0.02	0.43a ±0.02	0.48a ±0.01	2.80a ±0.09	3.20a ±0.06
LSD$_{0.05}$		0.06	0.06	0.03	0.02	0.06	0.07

Note: Treatments with the same letters in each column indicate no significant differences between them

DISCUSSION

The soil application of zeolite positively affected soil fertility, which improved the vegetative growth, yield, and fruit quality of strawberry. Previous authors have stated that the addition of zeolites to the light texture of soil minimizes the bulk density, which improves the soil air porosity (Ramesh and Reddy 2011). Zeolite addition to sandy soil increased the water- holding capacity by at least 10% and the available water to plants by 15% (de Campos Bernardi *et al*. 2013), or by 50% (Sangeetha and Baskar 2016) and delayed reaching the permanent wilting point (Torkashvand and Shadparvar 2013).

Table 7. Effect of the Zeolite Soil Addition Combined with the Spraying of KL and Cs on the Leaf Content from Iron, Zinc, and Manganese in Strawberry

Soil Application	Foliar Spray	Fe (ppm)		Zn (ppm)		Mn (ppm)	
		2022	2023	2022	2023	2022	2023
0 kg Zeolite	0 KL + 0 Cs	142.33e ±1.53	152.33h ±2.08	43.70i ±0.98	47.93h ±2.18	47.73e ±1.96	50.50f ±1.50
	2% KL + 500 ppm Cs	143.67e ±1.53	156.33g ±1.53	45.00i ±1.00	48.57h ±1.25	49.47e ±0.80	52.00f ±1.00
	4% KL + 1000 ppm Cs	155.00c ±1.00	164.00e ± 1.00	52.93g 0.90	56.17f ±1.76	63.10c ± 2.80	54.00f ±1.00
	6% KL + 1500 ppm Cs	160.00b ±2.00	166.00de ±1.00	56.00f ±1.00	63.90d ±1.64	64.33c ±1.55	58.67e ±1.53
2 kg Zeolite	0 KL + 0 Cs	147.67d ±1.53	159.00f ±1.00	47.87h ±0.81	52.13g ±1.89	49.90e ±1.70	52.67f ±2.08
	2% KL + 500 ppm Cs	153.67c ±1.53	166.67de ±1.15	54.33fg ±1.53	61.30e ±1.65	62.07c ±1.62	54.00f ±1.00
	4% KL + 1000 ppm Cs	161.67b ± 2.00	167.00de ±1.00	60.00e ±2.00	67.47c ±1.00	70.10b ±1.30	62.67d ±0.58
	6% KL + 1500 ppm Cs	163.67b ±0.6	170.33bc ±2.53	66.87c ±1.29	70.43bc ±1.89	71.90b ±2.57	74.67b ±1.53
3 kg Zeolite	0 KL + 0 Cs	151.67c ±1.53	159.67f ±1.53	54.27fg ±1.42	54.47fg ±2.40	57.13d ±1.42	53.33f ±1.53
	2% KL + 500 ppm Cs	161.00b ±2.00	168.33cd ±1.53	63.43d ±1.50	70.10bc ±1.44	70.87b ±2.57	70.67c ±1.53
	4% KL + 1000 ppm Cs	168.00a ±2.00	171.67b ±1.51	68.90b ±1.29	72.83b ±2.08	72.73b ±0.80	76.00b ±1.00
	6% KL + 1500 ppm Cs	170.67a ±2.51	176.33a ±1.53	70.83a ±1.43	76.10a ±1.15	76.53a ±0.90	78.67a ±1.53
$LSD_{0.05}$		3.00	2.39	1.68	2.49	3.04	2.51

Note: Treatments with the same letters in each column indicate no significant differences between them.

Zeolites act as fertilizers and chelating agents, enhancing soil properties by reducing water leaching, improving water efficiency through increased soil water-holding capacity, and supporting a slow, consistent release of essential nutrients like nitrogen, potassium, calcium, and magnesium, which boosts crop growth, enhances nutrient efficiency, and reduces fertilizer costs across growing seasons (Eroglu *et al.* 2017; Cataldo *et al*. 2021). In addition, zeolite promotes rapid rewetting and lateral water distribution throughout the root zone during irrigation, reducing the time needed for water application, and enhancing the soil moisture retention for extended periods, especially during dry times, helping to alleviate drought stress and enable the plants to endure dry conditions (Nakhli *et al*. 2017). Additionally, it improves the usage of fertilizers and water efficacy and minimizes the pollution of the environment by lessening the leaching of nitrate and emissions of nitrous oxides and ammonia, thereby significantly improving crop growth, productivity, and quality (Mondal *et al*. 2021). Zeolites enhance plant yield by serving as fertilizers with high cation exchange capacity, large reactive surface area, effective water retention, and strong adsorption properties, gradually releasing key nutrients such as nitrogen and potassium to meet crop needs, improve phosphorus availability, and boost nitrogen uptake (Bibi *et al*. 2024). This addition of zeolite at 1, 2, and 3 kg to mango cv. ‘Ewaise’ positively improved the soil characteristics, which led to improving the tree trunk thickness, shoot length and thickness, inflorescence number, fruit set and fruit retention percentages, fruit number, fruit yield, fruit weight, fruit dimensions, fruit size, fruit firmness, peel and pulp weights, fruit content of TSS, VC, carotene, total, reduced and non-reduced sugars, as well as the minerals content in the leaves, including N, P, K, Fe, Zn, Mn, Cu, Mo, and B compared to nontreated trees. Additionally, these applied treatments minimized the percentages of fruit drop and fruit content from the acidity (Harhash *et al*. 2022).

The results showed the positive influence of KL in mitigating the undesirable influence of heat on strawberry and improving the growth, productivity, and fruit quality. These results are in harmony with the findings of many authors, who have stated that KL is a natural clay mineral that serves as a reflective agent and antitranspirant, enhancing plant performance by reducing stomatal conductance under abiotic stress in some plant species, reflecting solar radiation to lower plant temperature, improving gas exchange and photosynthetic efficiency, and providing a protective barrier against disease by hindering pathogen penetration (Ramírez-Godoy *et al.* 2018; Brito *et al.* 2019a; Luciani *et al.* 2020). Moreover, it can reduce leaf temperature by up to 6.7 °C, inducing the opening of stomata, and this improves the process of photosynthesis and raises the plant adaptation to excessive light and temperatures (Abreu *et al.* 2022). The foliar application of K releases nutrients and helps retain soil moisture, enhances growth parameters, reflects radiation, reduces leaf temperature and significantly minimizes water loss from cells, promoting cell expansion and elongation (Vani *et al.* 2023). Additionally, KL reduces the negative impacts of combined stress by minimizing leaf damage and abscission and inhibiting carotenoid degeneration. Meanwhile, it increases the proline content, the physiological and gas exchange percentage, chlorophyll content, and regulates the levels of hormones such as abscisic, salicylic, indole-3-acetic, and jasmonic acids, which raise the plant stress tolerance (Terán *et al.* 2024). KL concentrations of 2 to 4% are recommended for improving the rates of photosynthesis and transpiration and protecting fruits from sunburn in apples (Glenn, 2010), grapevines (Dinis *et al.* 2016), and olive trees (Brito *et al.* 2019b). Segura-Monroy *et al*. (2015) reported that the application of KL on cape gooseberry noticeably boosted plant height, dry weight, and water-use efficiency, and improved the opening rates of stomata under stresses. Meanwhile, it lessened the rates of transpiration, the temperature of the leaves, and leaf thickness. Applying KL greatly improved the fruit quality, such as total soluble solids, color, and fruit size in mango (Baiea *et al*. 2018), and reduced the fruit drop, sunburn, and cracking percentages in Persian walnut (Gharaghani *et al*. 2018). Spraying of KL at 2, 4, and 6% greatly improved the fruit set percentages, productivity, fruit weight and firmness, and reduced the fruit sunburn percentage in pomegranate (Al-Saif *et al*. 2022), leaf surface area, tree volume, photosynthesis process, chlorophyll, and carotenoids content in the leaves, productivity, and the fruit quality in mango, meanwhile these treatments significantly reduced the sunburned fruits number, and 6% was the most recommended concentration (Hamdy *et al*. 2022).

The applied treatments from Cs effectively reduced the heat stress and consequently improved the growth and yield of strawberry. These results are in the same trend as those obtained by many studies that reported that applying Cs to the aerial parts of plants, such as leaves, stems, and fruits has been shown to increase the nitrogen content in the fruits. This increase could be due to the release of nitrogen from Cs (polysaccharides-NH_2) by promoting the growth of xylem vessels, which enhances nutrient absorption and improves the plant’s nutritional status, particularly in nitrogen for amino acid synthesis (Khan *et al.*

2015; El Amerany *et al*. 2020). Studies have reported that the application of Cs has increased the indole-3-acetic acid concentration, which induces cell division (Saharan and Pal 2016; Lopez-Moya *et al*. 2017) and enhances the rates of ascorbic acid and sugars (Moha *et al*. 2021). Additionally, Cs application to shoots affects fruit metabolome by raising the rates of sucrose and minimizing the rates of organic acids, particularly citrate (Choudhary *et al*. 2017). Shaheen *et al* (2017) reported that spraying onion with Cs at 5 cm/L three times at 15-day intervals greatly increased the proportion of large mother bulbs, resulting in a higher weight of onion seeds. Ahmad *et al.* (2019) reported that foliar application of Cs at a concentration of 0.75 mg mL^{-1} enhanced growth, number and area of leaves, and the fresh and dry weights of shoots and this improvement is because of improving the chloroplast function, leading to increased O_2 production and CO_2 fixation compared to untreated plants (Ahmad *et al*. 2019). The application of Cs stimulates carbon and nitrogen metabolism and enhances nitrogen and phosphorus uptake, leading to increased sucrose production, and it also influences various plant processes like stomatal conductance, division and developing of cells, ripeness of fruits, intake of elements, and defense responses. It also increases the accumulation of chlorophyll, and nutrient uptake (Ahmed *et al*. 2020; Maluin and Hussein 2020) and improves chlorophyll fluorescence, increases CO_2 assimilation, and boosts the plant's photosynthetic activity (El Amerany *et al*. 2022). Additionally, Cs is quite effective at promoting plant development, and this could be connected to how it affects the osmotic pressure in cells and stimulates the absorption of water and vital minerals (Chakraborty *et al*. 2020). Applying nano Cs at 50 ppm to onion remarkably raised the growth attributes, yield, and yield components compared to untreated plants (Geries *et al.* 2020). Additionally, Cs improves the productivity and agro-environmental sustainability by boosting plant defense systems against biological and environmental stresses, acting as an inducer the plant growth by increasing stomatal opening rates and reducing the rates of transpiration, aiding nutrient delivery by preventing leaching and enabling slow nutrient release, and improving soil properties and plant resistance to both abiotic and biotic stresses (Shahrajabian *et al.* 2021). Applying nano Cs to bean at 50 ppm improved the vegetative growth, parameters, bulb weight, marketable bulbs percentage and productivity, bulb diameter and TSS%, compared to the control (Khalil *et al.* 2022; Bayar *et al.* 2024).

CONCLUSIONS

1. The results of the present study showed that the soil addition of zeolite positively improved the vegetative growth of strawberry plants, productivity, fruit physical and chemical characteristics, and leaf mineral content from macro and micronutrients, and the positive influence was greatly increased by the spraying of KL and Cs, in particular 6% KL + 1500 ppm Cs and 4 % KL + 1000 ppm Cs.
2. The best results were obtained by 3 kg zeolite combined with 6% KL + 1500 ppm Cs followed by 2 kg zeolite combined with 4% KL + 1000 ppm Cs in the experimental period compared to untreated plants or the other treatments.

Data Availability Statement

All the required data are included in the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

REFERENCES CITED

Abreu, D. P. de, Roda, N. M., Abreu, G. P. de, Bernado, W. P. de, Rodrigues, W. P., Campostrini, E., and Rakocevic, M. (2022). "Kaolin film increases gas exchange parameters of coffee seedlings during transference from nursery to full sunlight," *Frontiers in Plant Science* 12, article 784482. DOI:10.3389/fpls.2021.784482

Ahmad, B., Jaleel, H., Shabbir, A., Khan, M. M. A., and Sadiq, Y. (2019). "Concomitant application of depolymerized chitosan and GA_3 modulates photosynthesis, essential oil and menthol production in peppermint (*Mentha piperita* L.)," *Scientia Horticulturae* 246, 371-379. DOI: 10.1016/j.scienta.2018.10.031

Ahmed, K. B. M., Khan, M. M. A., Siddiqui, H., and Jahan, A. (2020). "Chitosan and its oligosaccharides, a promising option for sustainable crop production – A review," *Carbohydrate Polymers* 227, article ID 115331. DOI: 10.1016/j.carbpol.2019.115331

Ali, M. M., Anwar, R., Yousef, A. F., Li, B., Luvisi, A., De Bellis, L., Aprile, A., and Chen, F. (2021). "Influence of bagging on the development and quality of fruits," *Plants* 10(2), article 358. DOI: 10.3390/plants10020358

Al-Saif, A. M., Mosa, W. F., Saleh, A. A., Ali, M. M., Sas-Paszt, L., Abada, H. S., and Abdel-Sattar, M. (2022). "Yield and fruit quality response of pomegranate (*Punica granatum*) to foliar spray of potassium, calcium and kaolin," *Horticulturae* 8(10), article 946. DOI: 10.3390/horticulturae8100946

Arrobas, M., Afonso, S., and Rodrigues, M. Â. (2018). "Diagnosing the nutritional condition of chestnut groves by soil and leaf analyses," *Scientia Horticulturae* 228, 113-121. DOI: 10.1016/j.scienta.2017.10.027

Asch, J., Johnson, K., Mondal, S., and Asch, F. (2022). "Comprehensive assessment of extraction methods for plant tissue samples for determining sodium and potassium *via* flame photometer and chloride *via* automated flow analysis," *Journal of Plant Nutrition and Soil Science* 185(2), 308-316. DOI: 10.1002/jpln.202100344

Association of Analytical Chemists (AOAC) (2005). *Official Methods of Analysis of the Association of Analytical Chemists International*, AOAC, Gaithersburg, MD, USA.

Baiea, M., El-Gioushy, S., and El-Badawy, H. (2018). "Efficacy of kaolin and screen duo spraying on fruit sunburn, yield and fruit quality of Keitt mango fruits," *Journal of Plant Production* 9(12), 1013-1020. DOI: 10.21608/jpp.2018.36619

Bakhoum, G. S., Sadak, M. S., and Badr, E. A. E. M. (2020). "Mitigation of adverse effects of salinity stress on sunflower plant (*Helianthus annuus* L.) by exogenous application of chitosan," *Bulletin of the National Research Centre* 44(79), 1-11. DOI:10.1186/s42269-020-00343-7

Balal, R. M., Shahid, M. A., Javaid, M. M., Iqbal, Z., Liu, G. D., Zotarelli, L., and Khan, N. (2017). "Chitosan alleviates phytotoxicity caused by boron through augmented polyamine metabolism and antioxidant activities and reduced boron concentration in *Cucumis sativus* L.," *Acta Physiologiae Plantarum* 39, 1-15. DOI: 10.1007/s11738-016-2335-z

Bayar, J., Shah, S., Khan, W., Bayar, J., Shah, S., Khan, W., Okla, M. K., Alwasel, Y. A., Saleh, I. A., AbdElgawad, H., *et al.* (2024). "Boron foliar application improves growth, yield and grain quality of maize," *Polish Journal of Environmental Studies* 33(3), 3079-3089. DOI: 10.15244/pjoes/177183

Bibi, S., Tariq-Khan, M., Hamid, A., Jamil, M., and Shafqat, M. (2024). "Interactive impact of zeolite with nitrogen sources on garlic yield under temperate agro-ecosystem of Azad Jammu and Kashmir," *Journal of Pure and Applied Agriculture* 9(1).

Boari, F., Donadio, A., Schiattone, M. I., and Cantore, V. (2015). "Particle film technology: A supplemental tool to save water," *Agricultural Water Management* 147, 154-162. DOI: 10.1016/j.agwat.2014.07.014

Brillante, L., Belfiore, N., Gaiotti, F., Lovat, L., Sansone, L., Poni, S., and Tomasi, D. (2016). "Comparing kaolin and pinolene to improve sustainable grapevine production during drought," *PLoS One* 11(6), article ID e0156631. DOI: 10.1371/journal.pone.0156631

Brito, C., Dinis, L.T., Moutinho-Pereira, J., Correia, C. (2019a). "Kaolin, an emerging tool to alleviate the effects of abiotic stresses on crop performance. *Scientia Horticulturae* 250, 310-316. DOI: 10.1016/j.scienta.2019.02.070.

Brito, C., Dinis, L.T., Luzio, A., Silva, E., Gonçalves, A., Meijon, M., Escandon, M., Arrobas, M., Rodrigues, M. A., Moutinho-Pereira, J., and Correia, C. M. (2019b). "Kaolin and salicylic acid alleviate summer stress in rainfed olive orchards by modulation of distinct physiological and biochemical responses," *Scientia Horticulturae* 246, 201-211. DOI: 10.1016/j.scienta.2018.10.059.

Cataldo, E., Salvi, L., Paoli, F., Fucile, M., Masciandaro, G., Manzi, D., Masini, C. M., and Mattii, G. B. (2021). "Application of zeolites in agriculture and other potential uses: A review," *Agronomy* 11(8), 1547

Chakraborty, M., Hasanuzzaman, M., Rahman, M., Khan, M. A. R., Bhowmik, P., Mahmud, N. U., Tanveer, M., and Islam, T. (2020). "Mechanism of plant growth promotion and disease suppression by chitosan biopolymer," *Agriculture* 10(12), article 624. DOI: 10.3390/agriculture10120624

Chen, J. H. (2006). "The combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility," in: *International Workshop on Sustained Management of the Soil-rhizosphere System for Efficient Crop Production and Fertilizer Use* 16(20), 1-11. Land Development Department Bangkok Thailand.

Choudhary, R. C., Joshi, A., Kumari, S., Kumaraswamy, R., and Saharan, V. (2017). "Preparation of Cu-chitosan nanoparticle and its effect on growth and enzyme activity during seed germination in maize," *Journal of Pharmacognosy and Phytochemistry* 6(4), 669-673.

de Campos Bernardi, A. C., Oliviera, P. P. A., de Melo Monte, M. B., and Souza-Barros, F. (2013). "Brazilian sedimentary zeolite use in agriculture," *Microporous and Mesoporous Materials* 167, 16-21. DOI: 10.1016/j.micromeso.2012.06.051

Dinis, L.T., Ferreira H., Pinto G., Bernardo S., Correia C. M. and Moutinho-Pereira J. (2016). "Kaolin-based, foliar reflective film protects photosystem II structure and function in grapevine leaves exposed to heat and high solar radiation," *Photosynthetica* 54, 47-55. DOI: 10.1007/s11099-015-0156-8

D'Urso, G., d'Aquino, L., Pizza, C., and Montoro, P. (2015). "Integrated mass spectrometric and multivariate data analysis approaches for the discrimination of organic and conventional strawberry (*Fragaria ananassa* Duch.) crops," *Food Research International* 77, 264-272. DOI: 10.1016/j.foodres.2015.04.028

El Amerany, F., Rhazi, M., Balcke, G., Wahbi, S., Meddich, A., Taourirte, M., and Hause, B. (2022). "The effect of chitosan on plant physiology, wound response, and fruit quality of tomato," *Polymers* 14(22), article 5006. DOI: 10.3390/polym14225006

El Amerany, F., Rhazi, M., Wahbi, S., Taourirte, M., and Meddich, A. (2020). "The effect of chitosan, arbuscular mycorrhizal fungi, and compost applied individually or in combination on growth, nutrient uptake, and stem anatomy of tomato," *Scientia Horticulturae* 261, article ID 109015.

Enamorado-Horrutiner, Y., Villanueva-Tagle, M., Behar, M., Rodríguez-Fuentes, G., Ferraz Dias, J., and Pomares-Alfonso, M. (2016). "Cuban zeolite for lead sorption: Application for water decontamination and metal quantification in water using nondestructive techniques," *International Journal of Environmental Science and Technology* 13, 1245-1256. DOI: 10.1007/s13762-016-0956-9

Eroglu, N., Emekci, M., and Athanassiou, C. G. (2017). "Applications of natural zeolites on agriculture and food production," *Journal of the Science of Food and Agriculture* 97(11), 3487-3499. DOI: 10.1002/jsfa.8312

Fang, P., Abler, D., Lin, G., Sher, A., and Quan, Q. (2021). "Substituting organic fertilizer for chemical fertilizer: Evidence from apple growers in China," *Land*. 10, 858. DOI: 10.3390/land10080858.

FAO (2022). "Food and Agriculture Organization of the United Nations. FAO Statistical Databases," FAO, (https: //www.fao.org/faostat/), Accessed 22 Aug 2022.

Fernandes, V. C., Domingues, V. F., de Freitas, V., Delerue-Matos, C., and Mateus, N. (2012). "Strawberries from integrated pest management and organic farming: Phenolic composition and antioxidant properties," *Food Chemistry* 134(4), 1926-1931. DOI: 10.1016/j.foodchem.2012.03.130

Gerami, M., Majidian, P., Ghorbanpour, A., and Alipour, Z. (2020). "*Stevia rebaudiana* Bertoni responses to salt stress and chitosan elicitor," *Physiology and Molecular Biology of Plants* 26(5), 965-974.

Geries, L. S. M., Hashemb, O. S. M. and Mareya, R. A. (2020). "Soaking and foliar application with chitosan and nano-chitosan to enhance growth, productivity and quality of onion crop," *Plant Archives* 20(2), 3584-3591.

Gharaghani, A., Javarzari, A. M., and Vahdati, K. (2018). "Kaolin particle film alleviates adverse effects of light and heat stresses and improves nut and kernel quality in Persian walnut," *Scientia Horticulturae* 239, 35-40. DOI: 10.1016/j.scienta.2018.05.024

Glenn, D. M. (2010). "Canopy gas exchange and water use efficiency of 'Empire' apple in response to particle flm, irrigation, and microclimatic factors," *Journal of the American Society for Horticultural Science* 135, 25-32. DOI: 10.21273/jashs.135.1.25

Golkar, P., Taghizadeh, M., and Yousefian, Z. (2019). "The effects of chitosan and salicylic acid on elicitation of secondary metabolites and antioxidant activity of safflower under in vitro salinity stress," *Plant Cell, Tissue and Organ Culture* 137, 575-585. DOI: 10.1007/s11240-019-01592-9

Gullo, G., Dattola, A., Vonella, V., and Zappia, R. (2020). "Effects of two reflective materials on gas exchange, yield, and fruit quality of sweet orange tree *Citrus sinensis* (L.) Osb," *European Journal of Agronomy* 118, article ID 126071. DOI: 10.1016/j.eja.2020.126071

Hamdy, A. E., Abdel-Aziz, H. F., El-Khamissi, H., AlJwaizea, N. I., El-Yazied, A. A., Selim, S., Tawfik, M. M., AlHarbi, K., Ali, M. S., and Elkelish, A. (2022). "Kaolin improves photosynthetic pigments, and antioxidant content, and decreases sunburn of mangoes: Field study," *Agronomy* 12(7), article 1535. DOI: 10.3390/agronomy12071535

Harhash, M. M., Ahamed, M. M., and Mosa, W. F. (2022). "Mango performance as affected by the soil application of zeolite and biochar under water salinity stresses," *Environmental Science and Pollution Research* 29(58), 87144-87156. DOI: 10.1007/s11356-022-21503-4

Hassan, F., Ali, E., Gaber, A., Fetouh, M., and Mazrou, R. (2021). "Chitosan nanoparticles effectively combat salinity stress by enhancing antioxidant activity and alkaloid biosynthesis in *Catharanthus roseus* (L.) G. Don," *Plant Physiology and Biochemistry* 162, 291-300. DOI: 10.1016/j.plaphy.2021.03.004

Havlin, J. L., Beaton, J. D., Tisdale, S. L., and Nelson, W. L. (2005). "Soil fertility and fertilizers, an introduction to nutrient management," Upper Saddle River New Jersey.

Islam, M. A., Ferdous, G., Akter, A., Hossain, M. M., and Nandwani, D. (2017). "Effect of organic, inorganic fertilizers and plant spacing on the growth and yield of cabbage," *Agriculture* 7(4), article 31. DOI: 10.3390/agriculture7040031

Jabeen, N., and Ahmad, R. (2013). "The activity of antioxidant enzymes in response to salt stress in safflower (*Carthamus tinctorius* L.) and sunflower (*Helianthus annuus* L.) seedlings raised from seed treated with chitosan," *Journal of the Science of Food and Agriculture* 93(7), 1699-1705. DOI: 10.1002/jsfa.5953

Jin, N., Jin, L., Wang, S., Li, J., Liu, F., Liu, Z., Luo, S., Wu, Y., Lyu, J., and Yu, J. (2022). "Reduced chemical fertilizer combined with bio-organic fertilizer affects the soil microbial community and yield and quality of lettuce," *Frontiers in Microbiology* 13, article 863325. DOI: 10.3389/fmicb.2022.863325

Khalifa, S. A., Shedid, E. S., Saied, E. M., Jassbi, A. R., Jamebozorgi, F. H., Rateb, M. E., Du, M., Abdel-Daim, M. M., Kai, G.-Y., and Al-Hammady, M. A. (2021). "Cyanobacteria – From the oceans to the potential biotechnological and biomedical applications," *Marine Drugs* 19(5), article 241. DOI: 10.3390/md19050241

Khalil, H. A., Abdelkader, M. F. M., Lo'ay, A. A., *et al.* (2022). "The combined effect of hot water treatment and chitosan coating on mango (*Mangifera indica* L. cv. Kent) fruits to control postharvest deterioration and increase fruit quality," *Coatings* 12(1), article 83. DOI: 10.3390/coatings12010083

Khan, M. I. R., Trivellini, A., Fatma, M., Masood, A., Francini, A., Iqbal, N., Ferrante, A., and Khan, N. A. (2015). "Role of ethylene in responses of plants to nitrogen availability," *Frontiers in Plant Science* 6, article 927. DOI: 10.3389/fpls.2015.00927

Kilic, N., Burgut, A., Gündesli, M. A., Nogay, G., Ercisli, S., Kafkas, N. E., Ekiert, H., Elansary, H. O., and Szopa, A. (2021). "The effect of organic, inorganic fertilizers and their combinations on fruit quality parameters in strawberry," *Horticulturae* 7(10), article 354. DOI: 10.3390/horticulturae7100354

Kocięcka, J., and Liberacki, D. (2021). "The potential of using chitosan on cereal crops in the face of climate change," *Plants* 10(6), article 1160. DOI: 10.3390/plants10061160

Kumar, U. J., Bahadur, V., Prasad, V., Mishra, S., and Shukla, P. (2017). "Effect of different concentrations of iron oxide and zinc oxide nanoparticles on growth and yield of strawberry (*Fragaria x ananassa* Duch) cv. Chandler," *International Journal of Current Microbiology and Applied Sciences* 6(8), 2440-2445. DOI: 10.20546/ijcmas.2017.608.288

Lahori, A. H., Mierzwa-Hersztek, M., Demiraj, E., Sajjad, R. U., Ali, I., Shehnaz, H., ... and Zhang, Z. (2020). "Direct and residual impacts of zeolite on the remediation of harmful elements in multiple contaminated soils using cabbage in rotation with corn," *Chemosphere* 250, article 126317. DOI: 10.1016/j.chemosphere.2020.126317 (2020).

Lam, H.-H., Dinh, T.-H., and Dang-Bao, T. (2021). "Quantification of total sugars and reducing sugars of dragon fruit-derived sugar-samples by UV-Vis spectrophotometric method," *IOP Conference Series: Earth and Environmental Science, IOP Publishing,* 947(1), article ID 012041. DOI: 10.1088/1755-1315/947/1/012041

Liu, X., Zhang, X., Wang, Y., Sui, Y., Zhang, S., Herbert, S., and Ding, G. (2010). "Soil degradation: A problem threatening the sustainable development of agriculture in Northeast China," *Plant, Soil and Environment* 56 (2), 87-97.

Lopez-Moya, F., Escudero, N., Zavala-Gonzalez, E. A., Esteve-Bruna, D., Blázquez, M. A., Alabadí, D., and Lopez-Llorca, L. V. (2017). "Induction of auxin biosynthesis and WOX5 repression mediate changes in root development in *Arabidopsis* exposed to chitosan," *Scientific Reports* 7(1), article ID 16813. DOI: 10.1038/s41598-017-16874-5

Luciani, E., Palliotti, A., Frioni, T., Tombesi, S., Villa, F., Zadra, C., and Farinelli, D. (2020). "Kaolin treatments on Tonda Giffoni hazelnut (*Corylus avellana* L.) for the control of heat stress damages," *Scientia Horticulturae* 263, article 109097 DOI: 10.1016/j. scienta.2019.109097

Malekpoor, F., Pirbalouti, A. G., and Salimi, A. (2016). "Effect of foliar application of chitosan on morphological and physiological characteristics of basil under reduced irrigation," *Research on Crops* 17(2), 354-359. DOI: 10.5958/2348-7542.2016.00060.7

Maluin, F. N., and Hussein, M. Z. (2020). "Chitosan-based agronanochemicals as a sustainable alternative in crop protection," *Molecules* 25(7), article 1611. DOI: 10.3390/molecules25071611

Moe, K., Mg, K.W., Win, K.K., and Yamakawa, T. (2017). "Effects of combined application of inorganic fertilizer and organic manures on nitrogen use and recovery efficiencies of hybrid rice (Palethwe-1)," *American Journal of Plant Sciences* 8, 1043-1064. DOI: 10.4236/ajps.2017.85069

Moha, T., Said, W., Abdelilah, M., and Mohammed, R. (2021). "Use of metabolomics data analysis to identify fruit quality markers enhanced by the application of an aminopolysaccharide," *RSC Advances* 11(56), 35514-35524. DOI: 10.1039/d1ra05865g

Mohamed, F. H., El-sissi, A. F., Ismail, S. A., Ismail, S. A., and Hashem, A. M. (2018). "The potentiality of using chitosan and its enzymatic depolymerized derivative chito-oligosaccharides as immunomodulators," *Journal of Applied Pharmaceutical Science* 8(12), 132-139. DOI: 10.7324/JAPS.2018.81215

Mondal, M., Biswas, B., Garai, S., Sarkar, S., Banerjee, H., Brahmachari, K., Bandyopadhyay, P. K., Maitra, S., Brestic, M., Skalicky, M., *et al.* (2021). "Zeolites enhance soil health, crop productivity and environmental safety," *Agronomy* 11(3), article 448. DOI: 10.3390/agronomy11030448

Mphande, W., Kettlewell, P. S., Grove, I. G., and Farrell, A. D. (2020). "The potential of antitranspirants in drought management of arable crops: A review," *Agricultural Water Management* 236, article 106143. DOI: 10.1016/j.agwat.2020.106143

Nakhli, S. A. A., Delkash, M., Bakhshayesh, B. E., and Kazemian, H. (2017). "Application of zeolites for sustainable agriculture: A review on water and nutrient retention," *Water, Air, and Soil Pollution* 228, 1-34. DOI: 10.1007/s11270-017-3649-1

Nangle, E. J., Gardner, D. S., Metzger, J. D., Rodriguez-Saona, L., Guisti, M. M., Danneberger, T. K., and Petrella, D. P. (2015). "Pigment changes in cool-season turfgrasses in response to ultraviolet-B light irradiance," *Agronomy Journal* 107, 41-50. DOI: 10.2134/agronj14.0249

Narula, S., Anand, R. C., and Dudeja, S. S. (2013). "Beneficial traits of endophytic bacteria from field pea nodules and plant growth promotion of field pea," *Journal of Food Legumes* 26(3-4), 73-79

Nielsen, S. S. (2017). "Vitamin C determination by indophenol method," in: *Food Analysis Laboratory Manual. Food Science Text Series*, Springer, Cham, Switzerland, pp. 143-146. DOI: 10.1007/978-3-319-44127-6_15

Ramesh, K., and Reddy, D. D. (2011). "Zeolites and their potential uses in agriculture," *Advances in Agronomy* 113, 219-241. DOI: 10.1016/B978-0-12-386473-4.00004-X

Ramírez-Godoy, A., Puentes-Peréz, G., and Restrepo-Díaz, H. (2018). "Evaluation of the effect of foliar application of kaolin clay and calcium carbonate on populations of *Diaphorina citri* (Hemiptera: liviidae) in Tahiti lime," *Crop Protection* 109, 62-71. DOI: 10.1016/j.cropro.2018.01.012.

Saharan, V., and Pal, A. (2016). "Biological activities of chitosan-based nanomaterials," in: *Chitosan Based Nanomaterials in Plant Growth and Protection, Springer Briefs in Plant Science*, Springer, New Delhi, India, pp. 33-41. DOI: 10.1007/978-81-322-3601-6_4

Sangeetha, C., and Baskar, P. (2016). "Zeolite and its potential uses in agriculture: A critical review," *Agricultural Reviews* 37(2), 101-108. DOI: 10.18805/ar.v0iof.9627

Segura-Monroy, S., Uribe-Vallejo, A., Ramirez-Godoy, A., and Restrepo-Diaz, H. (2015). "Effect of kaolin application on growth, water use efficiency, and leaf epidermis characteristics of *Physalis peruviana* seedlings under two irrigation regimes," *Journal of Agriculture, Science and Technology* 17(6), 1585-1596. http://jast.modares.ac.ir/article-23-2523-en.html

Sen, S. K., Chouhan, D., Das, D., Ghosh, R., and Mandal, P. (2020). "Improvisation of salinity stress response in mung bean through solid matrix priming with normal and nano-sized chitosan," *International Journal of Biological Macromolecules* 145, 108-123. DOI: 10.1016/j.ijbiomac.2019.12.170

Shaheen, A. M., Rageb, M. E., Fatma A., *et al.* (2017). "Amelioration of onion seed production via bulb size and growth active substances," *Middle East Journal of Agriculture Research*, 6(4).

Shahrajabian, M. H., Chaski, C., Polyzos, N., Tzortzakis, N., and Petropoulos, S. A. (2021). "Sustainable agriculture systems in vegetable production using chitin and chitosan as plant biostimulants," *Biomolecules* 11(6), article 819. DOI: 10.3390/biom11060819

Shangguan, Z., Shao, M., and Dyckmans, J. (2000). "Effects of nitrogen nutrition and water deficit on net photosynthetic rate and chlorophyll fluorescence in winter wheat," *Journal of Plant Physiology* 156(1), 46-51. DOI: 10.1016/S0176-1617(00)80271-0

Snedecor, G. C., and Cochran, W. G. (2021). *Statistical Methods,* Iowa State University Press, 8th Ed., Ames, IA, USA.

Syukur, A., and Sunarminto, B. H. (2013). "Zeolite and hucalcia as coating material for improving quality of NPK fertilizer in costal sandy soil," *Journal of Tropical Soils* 16(2), 99-106. DOI: 10.5400/jts.2011.v16i2.99-106

Terán, F., Vives-Peris, V., López-Climent, M. F., Gómez-Cadenas, A., and Pérez-Clemente, R. M. (2024). "Palliative effects of kaolin on citrus plants under controlled stress conditions of high temperature and high light intensity," *Journal of Plant Growth Regulation* 43(2), 486-499. DOI: 10.1007/s00344-023-11103-y

Torkashvand, A. M., and Shadparvar, V. (2013). "Effect of some organic waste and zeolite on water holding capacity and PWP delay of soil," *Current Biotica* 6(4), 459-465.

Torres-Quezada, E. A., Zotarelli, L., Whitaker, V. M., Darnell, R. L., Santos, B. M., and Morgan, K. T. (2018). "Planting dates and transplant establishment methods on early-yield strawberry in west-central Florida," *HortTechnology* 28(5), 615-623. DOI: 10.21273/HORTTECH04079-18

Tsintskaladze, G., Eprikashvili, L., Urushadze, T., Kordzakhia, T., Sharashenidze, T., Zautashvili, M., and Burjanadze, M. (2016). "Nanomodified natural zeolite as a fertilizer of prolonged activity," *Annals of Agrarian Science* 14(3), 163-168. DOI: 10.1016/j.aasci.2016.05.013

Turk, H. (2019). "Chitosan-induced enhanced expression and activation of alternative oxidase confer tolerance to salt stress in maize seedlings," *Plant Physiology and Biochemistry* 141, 415-422. DOI: 10.1016/j.plaphy.2019.06.025

Vani, B. R. D., Ramesh, N., Manimaran, S., and Thangavel, P. (2023). "Effect of organic mulches and kaolin clay foliar spray on growth, yield attributes and yield of dry land maize (*Zea mays*)," *Crop Research* 58(1 and 2), 29-33. DOI: 10.31830/2454-1761.2023.CR-868

Verma, R., Maurya, B. R., and Meena, V. S. (2014). "Integrated effect of bio-organics with chemical fertilizer on growth, yield and quality of cabbage (*Brassica oleracea* var capitata)," *Indian Journal of Agricultural Sciences* 84(8), 914-919.

Wang, A., Li, J., Al-Huqail, A. A., Al-Harbi, M. S., Ali, E. F., Wang, J., Ding, Z., Rekaby, S. A., Ghoneim, A. M., and Eissa, M. A. (2021). "Mechanisms of chitosan nanoparticles in the regulation of cold stress resistance in banana plants," *Nanomaterials* 11(10), article 2670. DOI: 10.3390/nano11102670

Wang, H., Pampati, N., McCormick, W. M., and Bhattacharyya, L. (2016). "Protein nitrogen determination by Kjeldahl digestion and ion chromatography," *Journal of Pharmaceutical Sciences* 105(6), 1851-1857. DOI: 10.1016/j.xphs.2016.03.039

Wang, Y., Zhu, Y., Zhang, S., and Wang, Y. (2018). "What could promote farmers to replace chemical fertilizers with organic fertilizers?," *Journal of Cleaner Production,* 199, 882-890. DOI: 10.1016/j.jclepro.2018.07.222.

Wieczorek, D., Żyszka-Haberecht, B., Kafka, A., and Lipok, J. (2022). "Determination of phosphorus compounds in plant tissues: From colorimetry to advanced instrumental analytical chemistry," *Plant Methods* 18(1), article 22. DOI: 10.1186/s13007-022-00854-6

Yadav, S. K., Khokhar, U., Sharma, S. D., and Kumar, P. (2016). "Response of strawberry to organic versus inorganic fertilizers," *Journal of Plant Nutrition* 39, 194-203. DOI: 10.1080/01904167.2015.1109115

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