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POTENTIAL RESISTANCE OF SWEET PEPPER PLANTS TO HEAT AND INSECT STRESS AFFECTED BY GROWTH STIMULANTS AND ITS RELATIONSHIP TO ENZYMATIC ACTIVITY, GROWTH, AND YIELD

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ABSTRACT

Field experiments were carried out at Qaha farm, Qalyubia Governorate, Horticulture Research Institute, Agric. Res. cent., Egypt., to study the effect of 6 anti-stressor compounds on pepper under heat stress and insect infestation. Five anti-stresses were classified as good desirable effect sources on yield and polyphenol oxidase activity (PPO) enzyme activities in leaves. Three out of these 5 anti-stress showed an increase in peroxidase (POD) activity along with a high reduction in whitefly infestation. Two out of the three, namely aluminum silicate (AS) and potassium silicate (PS) exhibited significant positive effects for the reduction of Thrips and Spider mite infestations along with superiority for early and total yield as well as fruit quality, indicating the possibility of combining both high yield and good quality characters under various environmental conditions. Both compounds combined significant desirable effects for three or more key studied characters, including vegetative growth, quality of fruits in terms of flavonoid, TSS, pH, and vitamin C, as well as Total soluble protein. Additionally, AS had strong favorable versus PS in all vegetative traits, most fruit attributes, and the mean of combined infestation reduction. Results suggest that the mentioned anti-stress treatments may be crucial for maintaining good yields and/or some of the essential elements of traditional agricultural practices.

INTRODUCTION

Pepper (*Capsicum annum* L.), one of the major vegetable crops, is both highly nutritious and economically valuable. The growing and production of pepper are negatively affected by rising temperatures and stress brought on by global warming (**Wang *et al.*, 2021).** The ideal temperature ranges for growing sweet peppers are between 20 and 25°C. Temperatures below 15°C or above 30°C frequently result in slower growth and lower yields. One prominent element that adversely affects plant development and productivity is heat stress **(Seo-Young and Seok, 2019)**. It has been demonstrated that *Capsicum* cultivated in hot climates, it decreases fruit yield and increases the likelihood of fruit physiological illnesses such as blossom-end rot and sunscald, which resulting in a significant loss in growth and yield **(Taylor *et al.*, 2004; Olle, and Bende, 2009; Díaz-Pérez, 2014).** Vegetable production technology is always evolving, necessitating new approaches to pest control and protection against high temperatures with maintaining profitability and the environment. In

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vegetable farming, bio stimulants can be utilized to increase productivity and yield as well as plant health and stress tolerance. They do indeed benefit plant metabolism, both in ideal and unfavorable environmental situations **(Bulgari *et al*., 2019)**. The highest share is in Europe of biostimulants at around 45%, followed by North America and Asia at about 20% each, and Latin America at about 15% Spain, the top EU producers of bio-stimulants are France, Italy, and Spain, **Traon *et al*., 2022).** Regarding biostimulant research output, among the top 15 nations, Italy ranked first with 18%, Morocco came last at about 1%, and Egypt took the seventh spot with 4% **(Corsi *et al*., 2022).** Biostimulants are bioactive products that can boost crops' ability to use nutrients and water more effectively, encourage plant growth, and guard against abiotic stress **(Bulgari *et al*., 2019; Van Oosten *et al*., 2017; Yakhin *et al*., 2017).** Biostimulants are produced from organic raw materials and contain bioactive compounds. They include poly- and oligosaccharides, chitin, chitosan, vitamins, and minerals as well as humic acids, protein hydrolysates, rhizobacteria, and fungi that promote plant growth, and extracts from seaweeds **(Berlyn and Russo, 1990; Hamza and Suggars, 2001; Ertani *et al*., 2014; Du-Jardin, 2015)** used sparingly, they increase plant metabolism **(Zhang and Schmidt, 1999)**. Spirulina is a multicellular, filamentous blue-green alga with a very high protein content that ranges from 55 to 70% by dry weight. It is a complete protein that includes all nine essential amino acids, 1.5–2.0% essential fatty acids, vitamins B1, B2, B3, B6, B12, C, D, and E., Minerals: Spirulina contains significant amounts of potassium, calcium, chromium, copper, iron, magnesium, manganese, phosphorus, selenium, sodium, and zinc., and photosynthetic pigments such as Chlorophyll-a, xanthophylls, -carotene, echinenone, myxo xanthophyll, and the phycobiliproteins C-phycocyanin and all ophycocyanin **(Usharani *et al*., 2012)**. The application of exogenous amino acids has the benefit of delaying protein deterioration and conserving plant energy sources **(Korkmaz *et al*., 2010)**. In addition to stimulating the root tomato plant apparatus in both optimal and drought conditions, it also, showed that the biostimulants such as amino acids, polysaccharides, and organic acids as active applications boosted the yield and fruit quality of pepper plants **(Petrozza *et al*., 2013)**. The role of silica in enhancing plant tolerance to both biotic and abiotic stresses, the application of silicates either directly to crops or incorporated into the fertilizers applied, silica does not form a constituent of any cellular component but primarily deposits on the walls of the epidermis and vascular tissues conferring strength, rigidity, and resistance to pests and diseases **(Meena *et al*., 2013).** Humic substances consideration as biostimulants, they can increase plants' root growth, the uptake of nutrients, and enhance tolerance to abiotic stresses, the beneficial effects may be primarily ascribed to the hormone-like activity **(Canellas *et al*., 2015; Du-Jardin, 2015; Nardi *et al*., 2016).**

The purpose of this study is to assess some biostimulant materials to resist biotic and abiotic stresses and their impact on the growth, quality, and yield of sweet pepper plants under conditions of Qaha, Qalyubia Governorate, Egypt.

MATERIALS AND METHODS

The study took place at Qaha Farm, Qalyubia Governorate belongs to the Horticulture Research Institute, Agric. Res. Cent., Egypt. During two consecutive seasons of 2022 and 2023. The research-focused study assesses some biostimulant materials to resist the stresses of high temperatures and the infliction of insects and their impact on the growth, quality, and yield of sweet pepper plants on the local hybrid "Fares" of sweet pepper (*Capsicum annum* L.).

Plant Material

The sweet pepper local hybrid *cv* "Fares" seeds were planted in seedling trays during the first week of April, and the transplanting in the open field process took place on the first week of May during both 2022 and 2023 growing seasons.

The seedlings were transplanted adjacent to the drip irrigation lines, with 100 cm between each pair of drip lines. When the pepper plants were transplanted, they were spaced 40 cm apart in the same row along the drip line. 12 m^2 was the size of the plot (12 m long by 100 cm broad). In accordance with the Ministry of Agriculture and Land Reclamation's directives, conventional agricultural methods were used for pepper plants.

Experimental Design and Treatments

The treatments were arranged in a randomized complete block design with three replications. Six bio-stimulation substances were utilized as treatments, of which 5-treatments were foliar sprayed, namely spirulina algae "SP" (3 g/L), amino acid extract "AA" (750 ppm), potassium silicate "PS" (5 cm/L), aluminum silicate "AS" (20g/L) and boric acid "BA" (1g/L). However, the 6th treatment potassium humate "PH" was applied at 2 L/fed with irrigation. In addition to the aforementioned 6 treatments, tap water was sprayed in the control treatment "Co". In terms of foliar spraying, all experimental sweet pepper plants were sprayed from the bottom to the top, adhering to the commonly recommended protocol as a fine mist until runoff, ensuring comprehensive coverage of all plant organs. The treatments were administered four times, with the initial foliar spraying commencing 30 days after the seedlings were transplanted, at 15-day intervals throughout the sweet pepper plants' growing season except, potassium humate was applied *via* irrigation water after 30- and 60-days following transplantation.

Table 1 presents some physical and chemical properties of the experimental soil and the chemical analyses of irrigation water, according to methods described by **Ryan *et al.* (1999)**.

Data Recorded

Climate

Monthly data recorded to an average maximum, and minimum air temperatures and relative humidity in the two summer seasons of 2022 and 2023 issued by the Central Climate Laboratory, Agricultural Research Center, Giza, Egypt, presented in Table 2.

Vegetative Growth

The following vegetative growth properties were assessed in 5 randomly selected plants from each sub plot at 90 days after transplantation: plant height (cm), leaves number, fresh and dry weight of leaves (g), both total fresh and dry weight of plants (g), and leaf area (cm).

Insect and Mite Infestations

Procedures of insect infestations resistance

The experiment utilized the same treatments and recommended agricultural practices as mentioned earlier. However, in this case, deliberate avoidance of insecticide treatments was implemented. The plants were intentionally left unprotected, allowing them to be naturally exposed to insect infestations without any pesticide treatment. The primary objective was to evaluate the effect of the stimulating treatments on the plants' resistance to heat and insect infestations. Data was gathered to determine the prevalence and numerical density of white fly, thrips, and spider mites.

Table 1. Analyses of the experimental soil and irrigation water

Experimental soil					Irrigation water			
		Sand	**34.38**				**pH**	**7.82**
		Silt	**32.12**	**Clay loam**				
		Clay	**33.5**				**EC (dSm-1)**	**1.58**
Chemical analysis (soluble ion in (1:5 extract)								
Available mgl^{-1}		**N**	82.3		**Soluble ions(meq.l^{-1}/L)**	**Cations**	**Ca^{++}**	5.58
		P	5.6				**Mg^{++}**	2.51
		K	186.2				**Na^{+}**	7.91
meq.l^{-1}	**Cations**	**Ca^{++}**	2.71				**K^{+}**	0.61
		Mg^{++}	1.88			**Anions**	**Cl^{-}**	5.02
		Na^{+}	5.52				**HCO_3^{-}**	6.88
		K^{+}	3.31				**CO_3^{--}**	-
	Anions	**SO_4^{--}**	0.51				**SO_4^{--}**	4.71
		Cl-	9.8					
		HCO^{-}_3	0.91					
		$CaCo_3$	2.01					
ECe			1.0					
pH			7.75					
Organic matter (%)			1.8					

Sampling selection and timing

Samples were collected in accordance with the requirements for measuring insect and mite infestations, as well as the spray treatments used. Subsequently, the weekly population density for each of White fly, thrips, and spider mites was documented from June 15th until the second week of October, with data recording repeated every fifteen days throughout these periods. This was conducted in both the first season (2022) and the second season (2023) respectively.

Samples examination

Twenty fully expanded leaves (including the basal, middle, and upper parts) were randomly selected from five plants in each experimental unit. These leaves were carefully placed in plastic bags and immediately taken to the laboratory of the Plant Protection Department on the same day. In the laboratory, the pest infestations were evaluated by counting the number of whitefly nymphs, thrips individuals, and movable stages of the spider mite (*Tetranychus urticae* Koch.). The count of the movable stages of the spider mite was performed 24 hours before treatment and at 1, 3, 7, and 10 days after treatment. The percentage reduction was determined using the Henderson and Tilton formula **(Henderson and Tilton, 1955)**. Precise optical microscopy was utilized for thorough examination, and the count was conducted within a square inch area of each leaf.

Sample analysis and testing.

The reduction was calculated for each replicate in both the treated and untreated plots. To assess the impact of various treatments on sweet pepper at regular intervals (one week), the reduction of individuals in three replicates of each treatment was compared to that of the control group using the one-way analysis of least significant difference (LSD 0.05) to determine significant differences ($P<0.05$). The percent reduction of pests in the treated plots was calculated according to the equation proposed by **Henderson and Tilton (1955)**, is as follows:

Reduction (%) = [1- (n % in Co before treatment) X (n% T after treatment) ÷ (n % in Co. after treatment) X (n% in T before treatment)] × 100

Where:

n = Insect population, T= treated, Co = control

Analysis of Chlorophyll Content in the Leaves and Flavonoid Content in the Fruits.

The content of photosynthetic pigments (chlorophyll a, and b analyses (mg/ g F.W)) in leaves were extracted and limited to concentration after 75 days. According to method of **Moran (1982)**.

The flavonoid content of pepper fruits was determined as follows.

A suitable dilution of the extract was prepared by mixing 0.2 ml of the extract with 0.8 ml of distilled water. Then, 1 ml of a 2% $AlCl_3$ in methanol solution (containing 5% acetic acid in methanol) was added to the diluted extract. The mixture was allowed to react for 10 minutes, and the absorbance was measured at 430 nm against a blank sample without reactants. To create a calibration curve, quercetin was used as a standard. The total flavonoid content of the extracts was expressed as milligrams of quercetin equivalents (QE) per 100 grams of fresh pepper, determined using the method described by **Bonvehi *et al.* (2001).**

Antioxidant Enzyme Assay

To determine the antioxidant enzymes activity, 0.2 g of composite leaf tissues was homogenized in precooled 1.6 mL of 50 mM phosphate buffer (pH7.8) and centrifuged at 12,000_ g for 20 min at 4 _C, followed by collecting the supernatant.

The peroxidase activity (POD)

Was determined using the method described by **Chance and Maehly (1955).**

Polyphenol oxidase activity (PPO)

Was determined based on the method described by **Mayer and Harel (1979).**

Total soluble protein

Was determined using the method described by **Towbin *et al.* (1992).**

Fruit Physical Measurements

Ten fruits were randomly selected at the green ripe stage (which is the stage when the fruits are marketable or edible) of the third picking, and the following parameters were all measured using calipers.

a) Length of the fruits (cm).

b) Diameter of the fruits (cm).

c) Average weight of the fruits (g).

Fruit Quality

For quality trait analyses, a total of 10 fruits were randomly selected the third picking from each subplot during the green ripe stage, commonly known as the marketable or edible stage. The following analyses were conducted accordingly.

a) The concentration of ascorbic acid (Vitamin C) in the fruit juice was determined in milligrams per 100 milliliters of juice using 2,6-dichlorophenol indophenol method following the guidelines of the **AOAC (1990).**

b) The pH value of the juice was measured using a pH meter according to the **AOAC (1990)** standard.

c) The total soluble solids content in the fruit (TSS%) was determined using a hand refractometer as per the **AOAC (1990)** guidelines.

Yield and its Components

The calculation of fruit pepper yield was conducted as follows: fruit yield per plant (g), early yield per fed was determined, and the overall yield was divided into two categories: unmarketable yield (ton/fed), and marketable yield (ton/fed). The total yield was calculated from them.

Statistical Analysis

The data were statistically analyses using statistical analysis of variance in accordance with **Snedecor and Cochran (1980).** Using Duncan's multiple range tests, the means were compared (**Duncan, 1958**). For analysis, the M Stat C program was utilized.

RESULTS AND DISCUSSION

Data on Temperatures and Humidity

According to the presentation of Table 2, an increase in temperature is evident throughout the growth period of the sweet pepper plant in the study site at Qalyubia Governorate. The recorded where readings during the summer months indicate a rise in both average maximum and minimum temperatures, as well as a changes in relative humidity which are considered conditions that have a detrimental effect on plant growth, productivity, quality characteristics, and insect infestations. As a result, a comprehensive study of various widely available growth stimulants has been conducted to identify the most effective ones for utilization.

Plant Growth Parameters

Results presented in Table 3 demonstrates that all the substances utilized to enhance the growth of sweet pepper plants exhibited considerable improvements across all growth characteristics compared to the control treatment.

Aluminum silicate exhibited the highest values for each growth traits of sweet pepper plants by increase in plant height (89.72 and 91.83 cm), number of branches (5.23 and 5.65), as well as both the fresh (204.91 and 203.63) and dry (36.12 and 38.31 g) weights of the leaves; and both the fresh and dry weights of total plant organs (567.06 and 570.46; 205.89 and 207.88 g) in the first and second seasons, respectively. Additionally, the increase was attributed to the treatment with aluminum silicate, followed by amino acid extract, with no significant difference between them in the second season. These results were in agreement with the previous findings of **El-Sayed and Rady (2019), El-Gazzar *et al.* (2020) and Amro *et al.* (2023)** Aluminum silicate's ability to control physiological and biochemical processes associated with growth, photosynthesis, and antioxidant defense is the basis for its ability to reduce heat stress in pepper plants and aids in maintaining cellular homeostasis and reducing damage caused by heat stress, ultimately improving the growth performance and productivity of bell pepper plants **(Li *et al.*, 2015a; Wang *et al.*, 2021; Kumar *et al.*, 2023).** In addition to the above, it was noted that applying potassium silicate containing 10.25% K_2O may increase vegetative growth parameters, such as plant height (cm) and the number of branches per plant attributing to potassium's ability to regulate stomatal function and enhance photosynthesis efficiency. Additionally, potassium is believed to play a crucial role in promoting the growth of meristematic tissue therefore developing plant growth and productivity. These findings and discussion are according to **Amro *et al.* (2023)**.

Photosynthetic Pigments and Total Soluble Solids, pH, and Vitamin C (mg/100 ml juice in fruits)

The Results presented in Table 4 reveal that the utilization of stimulant materials resulted in a significant increase in the values of photosynthetic pigments *i.e.*, the content of chlorophyll in leaves mg/g f.w. (Fig.1), and fruit contents of total flavonoid $mg/100g^{-1}$, total soluble solids (TSS), pH, and vitamin C $mg/100^{-1}$ (Fig. 2). Boric acid, spirulina algae, and control were the lowest significant values on total soluble solids, pH, and vitamin C (V.C).

Table 2. Monthly the maximum, minimum air temperatures and relative humidity during growth sweet pepper plants in the two summers 2022 and 2023 seasons

Month	First season 2022			Second season 2023		
	Air temperature (˚C)		Relative humidity (%)	Air temperature (˚C)		Relative humidity (%)
	MAX	MIN		MAX	MIN	
April	30.07	11.73	52.90	32.93	13.94	45.34
May	38.20	17.96	40.42	34.72	17.17	44.73
June	38.02	19.83	44.12	38.70	21.52	45.29
July	40.52	22.86	45.33	39.58	22.07	46.09
August	41.06	23.38	47.09	39.26	23.26	49.90
Mean	37.57	19.15	45.97	37.04	19.59	46.27

* Data issued by the Central Climate Laboratory, Agricultural Research Center, Giza, Egypt.

Table 3. Effect of stimulant treatments on pepper plant growth during the 2022 and 2023 seasons

Parameter	Plant height	Branch number	Leaf fresh weight	Leaf dry weight	Plant Fresh weight	Plant dry weight	Leaf area/plant
Treatment	Cm		(g/plant)				(cm^2)
First season 2022							
Control	58.86c	3.56d	153.20e	19.43f	345.63g	84.56e	2559.06g
Spirulina algae	78.71ab	4.73ab	170.53cd	26.86d	466.21e	150.11c	2955.36e
Amino acids	73.91b	4.56a-c	164.83de	23.26e	444.52e	130.71d	2746.86f
Potassium silicate	86.83a	5.13a	186.81b	33.46ab	536.11b	192.20ab	3450.53b
Potassium humate	82.53ab	4.42bc	169.42cd	28.86cd	494.d	177.81b	3208.70cd
Aluminum silicate	89.72a	5.23a	204.91a	36.12a	567.06a	205.89a	3650.03a
Boric acid	73.23b	4.12cd	161.03de	21.50ef	415.50f	130.43d	3110.40d
Second season 2023							
Control	61.07c	3.76c	155.29e	24.05f	348.71d	86.91e	2567b
Spirulina algae	80.97ab	4.99ab	173.25cd	28.73de	468.88bc	153.27c	3022ab
Amino acids	76.64b	5.04ab	167.04c-e	25.68ef	450.17bc	132.72d	3460a
Potassium silicate	85.66ab	5.48ab	188.72b	36.25ab	472.66bc	195.81ab	2815ab
Potassium humate	85.10ab	4.96ab	171.71cd	30.86cd	491.48bc	180.99b	3278ab
Aluminum silicate	91.83a	5.65a	203.63a	38.31a	570.46a	207.88a	3384a
Boric acid	76.03b	4.71b	163.66de	23.02f	417.21cd	133.14d	3184ab

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

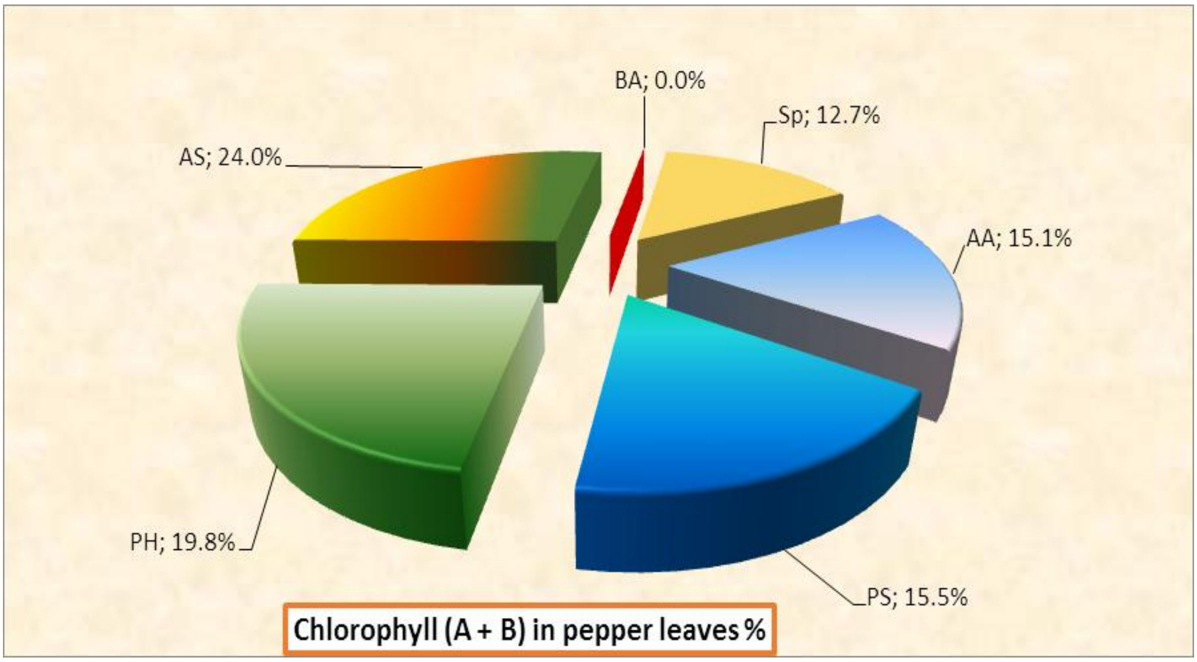


Fig. 1. Increment of leaf chlorophyll (a+b) as affected by stimulants average of both seasons. Treatments where, Sp: Spirulina algae, AA: Amino acids, Ps: Potassium silicate, PH: Potassium humate, As: Aluminum silicate, BA: Boric acid)

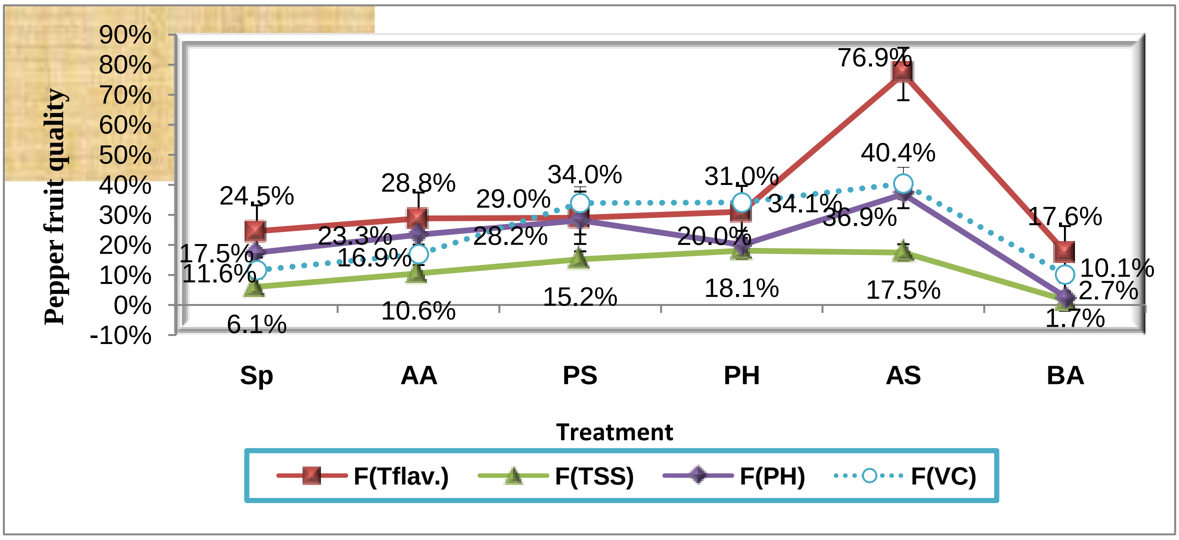


Fig. 2. Increment of fruit quality traits as affected by stimulants in average of both seasons.

Treatments where, Sp: Spirulina algae, AA: Amino acids, Ps: Potassium silicate, PH: Potassium humate, As: Aluminum silicate, BA: Boric acid). Fruit quality where, F(Tflav.): Total flavonoid, F(TSS): Total soluble solids, F(PH): Acidity, F(VC): Vitamin C.)

Foliar spraying of aluminum silicate resulted in high values for all the studied traits, including chlorophyll A + chlorophyll B (5.92, 7.01 mg/g and 24% incr.) in leaves as well as the contents of fruit as total flavonoids (131.44, 130.94 mg/100g and 76.9% incr.), TSS (4.79, 4.87% and 17.5% incr.), pH (6.36, 6.66 and 36.9% incr.), and V.C (150.24, 161.14mg/100g and 40.4% incr.) of the first and second season as well as increment percentage over the control, respectively.

The application of aluminum silicate had the highest effect on all measured fruit traits, indicating its effectiveness in mitigating the impact of heat stress on the photosynthetic pigment content in both pepper plant leaves and fruits. Photosynthesis, as a highly responsive physiological process, is significantly influenced by various stress factors that can impair its machinery and functionality **(Kim *et al.*, 2017; Rastogi *et al.*, 2020; Wang *et al.*, 2021)**. The application of silicon has demonstrated notable improvements in photosynthesis at multiple levels, including the protection of crucial photosynthetic structures, enhanced water use efficiency, improved electron transport within the photosynthetic system, effective safeguarding against reactive oxygen species (ROS), and the facilitation of essential physiological processes such as the absorption of macro and micronutrients, as well as phytohormones that directly impact photosynthetic activity **(Avila *et al.*, 2020; Hussain *et al.*, 2021 Rastogi *et al.*, 2021; Kumar *et al.*, 2023)** Regarding total acidity and V.C, consistent findings were reported by **Abdel-Aziz and Geeth (2018) and Kamal (2013)** They observed a significant enhancement in total acidity (%), and V.C (mg/100 g fresh weight) in pepper fruits when subjected to foliar application of varying rates of silicon sources and under heat stress conditions.

Fruit Length, Diameter and Average Fruit Weight

The results presented in Table 5 demonstrate that using stimulant materials positively impacted the length (cm), diameter (cm) compared to the control treatment. Remarkably the foliar spray application of aluminum silicate followed by potassium silicate significantly increased the fruit length (12.13, 11.75 and 10.12, 9.97), and diameter (7.73, 8.51 and 6.7, 7.80), of sweet pepper fruits in the first and second season respectively. Additionally, aluminum silicate achieved the highest values for average fruit weight (59.53 and 64.14). In general, the treatments involving aluminum silicate, potassium silicate demonstrated superior results compared to both the other treatments and the control treatment.

The results obtained from treating with aluminum and potassium silicate may be supplements to potassium's role, as stated **(Afzal *et al.*, 2015; Ibrahim *et al.*, 2105; El-Beltagi *et al.*, 2017; Abbas *et al.*, 2022)** potassium plays a crucial role in enhancing photosynthesis, activating enzymes, maintaining cell turgor, regulating plant water status, and promoting the synthesis of sugars and polysaccharides. Additionally, potassium is involved in various biochemical and physiological processes in plants. **Amro *et al.* (2023)** conducted a comparative study on the foliar application of potassium silicate and salicylic acid at different concentrations and found that using potassium silicate at concentrations of 4 and 8 mg/L increased fruit length, fruit diameter, and average fruit weight compared to the foliar application of salicylic acid at rates 8 and 16 mg/l). It is also noted that the significance and efficacy of foliar application of potassium fertilizer can enhance various parameters of vegetative growth. This improvement in hot pepper plants and their yield can be attributed to enhancements in photosynthesis, stimulation of vegetative growth, increased nitrogen levels, and the crucial role of potassium as an essential nutrient for facilitating the translocation of photo-assimilates during root growth, promoting root surface area, and subsequently enhancing water and mineral uptake by the roots **(Abdel-Aziz and Geeth, 2018; Amro *et al.*, 2023)**.

Table 4. Effect of stimulants treatments on flavonoid, chlorophyll (a+b) content and fruit quality of pepper plants during the 2022 and 2023 seasons

Parameter	Leaf	Fruits			
Treatment	**Chl. A+B (mg/g F.W.)**	**Total flavonoid (mg 100 g^{-1})**	**Total soluble solid**	**pH in juice**	**vitamin C (mg 100 g^{-1})**
		First season 2022			
Control	4.77de	73.00d	4.12c	4.76d	111.48d
Spirulina algae	5.16cd	90.93b	4.34b	5.58c	125.53bc
Amino acids	5.34bc	97.23b	4.68a	5.89bc	128.27b
Potassium silicate	5.43bc	95.33b	4.73a	6.19ab	143.27a
Potassium humate	5.62ab	95.65b	4.85a	5.77c	147.70a
Aluminum silicate	5.92a	131.44a	4.79a	6.36a	150.24a
Boric acid	4.67e	84.40c	4.17bc	4.76d	118.58cd
		Second season 2023			
Control	5.66c	75.33d	4.10d	4.75d	110.27e
Spirulina algae	6.59ab	93.72bc	4.38c	5.59bc	121.95de
Amino acids	6.66ab	93.76bc	4.41c	5.84bc	130.96cd
Potassium silicate	6.62ab	96.06bc	4.74ab	6.00b	153.80ab
Potassium humate	6.87a	98.65bc	4.86ab	5.64bc	149.66ab
Aluminum silicate	7.01a	130.94a	4.87a	6.66a	161.14a
Boric acid	5.76c	90.06c	4.19d	5.01d	125.58d

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

Table 5. Effect of stimulant treatments on physical fruits and average fruit weight of pepper plants during the 2022 and 2023 seasons

Parameter	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)
Treatment	**First season 2022**			**Second season 2023**		
Control	6.43f	4.43c	40.66c	6.26d	4.66d	47.11d
Spirulina algae	7.80e	5.73bc	46.11c	8.36bc	6.69a-c	51.06cd
Amino acids	7.51e	5.43bc	47.66bc	8.31c	5.82cd	54.28bc
Potassium silicate	10.12b	6.71ab	53.46ab	9.97b	7.80ab	64.44a
Potassium humate	8.91cd	5.93bc	53.33ab	9.27bc	6.44b-d	58.65ab
Aluminum silicate	12.13a	7.73a	59.53a	11.75a	8.51a	64.14a
Boric acid	8.02de	5.53bc	44.73c	8.78bc	6.08b-d	51.09cd

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

Yield and its Components

The effect of utilizing stimulant materials on enhancing yield and its components is presented in Table 6. The results indicate that the used materials had a significant impact on yield and its components compared to the control treatment, which yielded the lowest values. Particularly noteworthy is the significant effect of spraying with aluminum silicate followed by potassium silicate on yield and its components such as yield per plant (1180.75, 1319.30 and 1123.84, 1270.64 g/ plant) early yield (4.95, 4.15, and 4.72, 4.34 ton/fed.)., total yield (12.39, 13.85, and 11.81, 13.34 ton/fed.), and marketable yield (10.90, 12.21, and 11.03, 12.17 ton/fed.), in the first and second seasons respectively. In terms of marketable yield, no significant differences were observed between aluminum silicate and potassium silicate in the first season. Furthermore, the results indicated that there were no significant differences between aluminum silicate and potassium silicate treatments in the second season in the yield and its components (yield per plant, early yield, and total yield, except for marketable yield. Similarly, insignificant differences were found between aluminum silicate and potassium silicate in the second season.

The previous findings suggested there were no significant variations among certain growth-stimulating substances. Despite their superiority over other treatments, this similarity in performance could be attributed to their comparable roles, functions, and plant responses under heat-stressed conditions. Consequently, either aluminum silicate and potassium silicate can be utilized to enhance the growth of pepper plants and augment yield and its components.

The noteworthy outcomes observed in pepper plants can be attributed to the combined impact of aluminum silicate and potassium silicate, both representing the influence of silicon on vegetative growth characteristics (as demonstrated in Table 1). Ultimately, this influence affects yield and its components, including yield per plant, total yield per fed., and marketable yield per fed. Similar positive outcomes regarding the beneficial impact of aluminum and potassium silicate were observed, as reported by **Abd El-Aziz and Geeth (2018)** the use of foliar treatments, more especially the spraying of pepper plants with aluminum silicate followed by potassium silicate led to appreciable increases in fruit set (%), early and marketable overall yields. As compared to other treatments and the control group, it also resulted in a drop in unmarketable yield. Silicon possesses diverse properties that contribute to these effects. Silicon helps to strengthen cell walls. By encouraging erect growth, optimizing leaf angle and light interception, preventing excessive self-shading, increasing the structural integrity of plant tissues, minimizing lodging, and delaying senescence (**Gong and Chen, 2012**) in addition to the deposition of silica in stomatal guard cells can act as transparent windows, facilitating the passage of ample light through the plant's outer layer and into the photosynthetic tissues., thereby enhancing photosynthetic rates. This is due to the crucial role of the guarding stomata without negatively affecting photosynthesis, helping to slow down natural moisture loss without interfering with plant growth or respiration **(Yang *et al.*, 2021)**. Several studies have highlighted the significance and impact of putrescine substances material on plant growth and development. These include its role in mitigating stress and senescence, enhancing defense mechanisms against environmental stresses, acting as an antioxidant, and improving cellular membrane stability. Notably, in 'Comice' pear, putrescine has been found to benefit pollen tube ovule penetration and delay ovule senescence **(Crisosto *et al.*, 1992; Ahmed *et al.*, 2013; Khorshidi and Hamedi, 2014; Li *et al.*, 2015b; Ahmed, 2017; Kavuluko *et al.*, 2021; Sharma *et al.*, 2023).** Based on the evidence provided above regarding the functions of aluminum, potassium silicate, it is clear that using these

Table 6. Effect of stimulant treatments on yield and its components of pepper plants during the 2022 and 2023 seasons

Parameter	Yield (g /plant)	Early yield (ton/fed)	Total yield (ton/fed)	Marketable yield (ton/fed)	Yield (g /plant)	Early yield (ton/fed)	Total yield (ton/fed)	Marketable yield (ton/fed)
Trteatment	First season 2022				Second season 2023			
Control	580.54g	2.43e	6.09e	3.95e	713.72d	2.24d	7.49d	5.21c
Spirulina algae	858.97f	3.60cd	9.02cd	7.37cd	996.54bc	3.14bc	10.46bc	9.15b
Amino acids	820.69ef	3.44d	8.61d	7.71cd	998.83bc	3.14bc	10.48bc	9.48ab
Potassium silicate	1123.84ab	4.72ab	11.81ab	11.03a	1270.64a	4.34a	13.34a	12.17a
Potassium humate	950.68cd	3.99b-d	9.98b-d	8.32bc	1097.23a-c	3.45a-c	11.52a-c	10.00ab
Aluminum silicate	1180.57a	4.95a	12.39a	10.90a	1319.30a	4.15a	13.85a	12.28a
Boric acid	730.58fg	3.06de	7.67de	6.45d	843.57cd	2.65cd	8.86cd	7.16bc

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

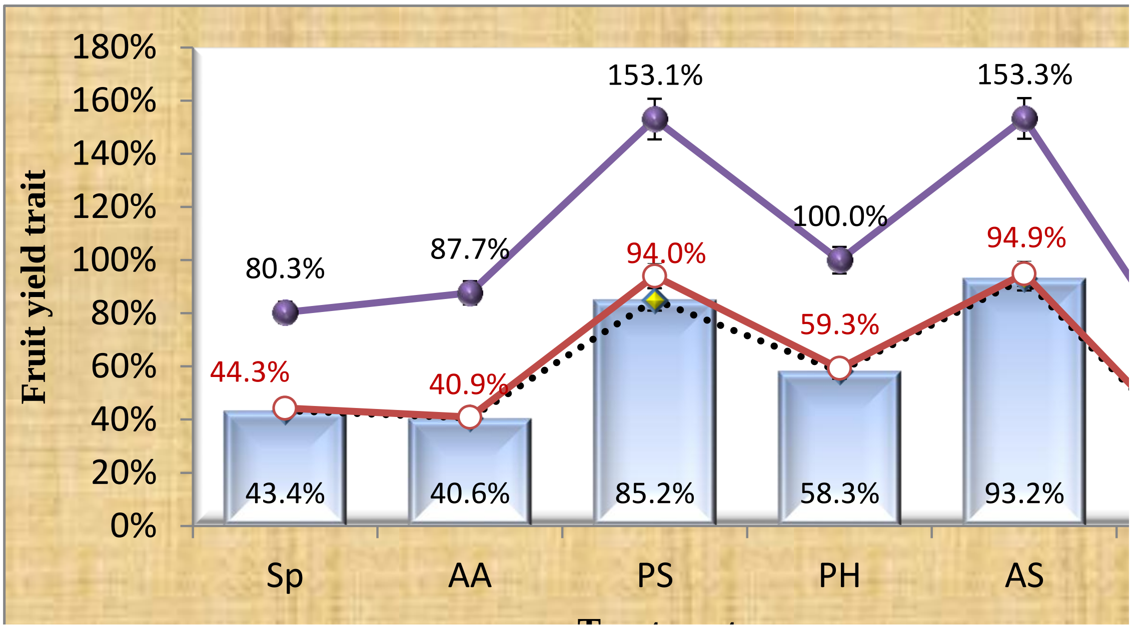


Fig. 3. Increment of yield traits as affected by stimulants in average of both seasons.

Treatments where, Sp: Spirulina algae, AA: Amino acids, Ps: Potassium silicate, PH: Potassium humate, As: Aluminum silicate, BA: Boric acid).

substances may reduce environmental stresses, particularly heat stress, which will have an impact on the Physiological and biological processes, photosynthesis, nutritional metabolism, water state of the plant, and evapotranspiration processes., All the above processes can affect positive play on vegetative growth, which in turn affects the yield and its components.

Protein Content (Pr.), Polyphenol Oxidase (PPO) and Peroxidase (POD)

The results presented in Table 7 and Fig. 4 indicate that boric acid, and amino acids exhibited significantly high protein content values in leaves during the first season (3.07, and 5.01 mg/g, respectively) and second season (3.32 and 3.16). Regarding sweet pepper fruits, in the first season, significantly increased protein content values were observed with the application of boric acid, and aluminum silicate, measuring 3.16, and 2.58 respectively. In the second season, significant values were obtained by applying boric acid, and potassium humate, with measurements of 3.22, and 2.64, respectively.

Furthermore, the results in Table 7 reveal that the foliar application of aluminum silicate, and amino acids resulted in significant higher enzymatic activity of the Polyphenol activity enzyme (PPO) in leaves compared to the control treatment. In the first season, aluminum silicate had values of 138.58, and amino acids showed values of 102.75. The control treatment had values of 18.63. In the second season, aluminum silicate had a value of 144.32, amino acids had a value of 103.78, and the control treatment had a value of 18.68. The application of amino acids, potassium silicate, and aluminum silicate *via* foliar spray resulted in an increase in the polyphenol peroxidase (PPO) content in pepper fruits, in the first season, the values were 460.35, 429.20, and 366.14, respectively. In the second season, the values were 460.33, 455.43, and 470.85. However, no significant differences were observed among these treatments in the second season alone.

Similarly, amino acids, potassium silicate, and aluminum silicate induced the highest enzymatic activity of the peroxidase enzyme (POD) in leaves. In the first season, amino acids exhibited values of 459.75, potassium silicate had values of 429.00, and aluminum silicate showed values of 363.75. In the second season, amino acids had values of 411.89, potassium silicate had values of 355.20, and aluminum silicate had values of 285.35.

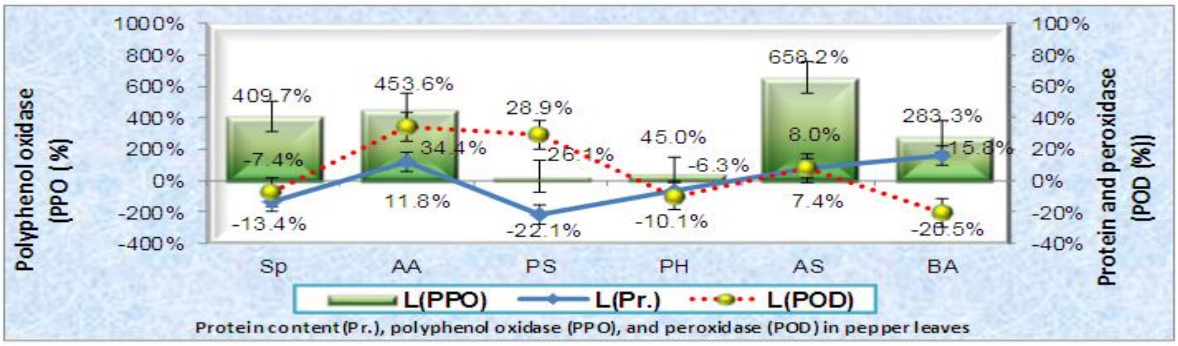
The application of amino acid, and aluminum silicate *via* foliar spray resulted in an increase in the peroxidase activity (POD) content in pepper fruits. In the first season, the values were 378.33, and 331.13, respectively. In the second season, the values were 411.89, and 355.20. The highest activity of enzymes was probably associated with a progressive incorporation of phenolic compounds within the cell wall, thus affecting the feeding of the tested inset. Amino acids, potassium silicate, and aluminum silicate are not only involved in mechanical restraints against heat stress or insect infestation but also with biochemical changes because there was a significant increase in polyphenol oxidase and peroxidase activity in pepper leaves after being exposed to heat stress and/or insect infestation when compared with the control over time during the 2022 and 2023 seasons.

As for PPO, the highest values were observed in the leaves of pepper plants treated with aluminum silicate and amino acid. This finding is consistent with a study by **Li *et al.* (2018)** found that the application of aluminum silicate increased the activity of PPO in cucumber plants. These findings suggest that the use of these substances may enhance the synthesis of PPO in pepper plants, which could help to improve the tolerance of plants to high-temperature stress and/or insect infestation. For POD, the highest values were observed in the leaves

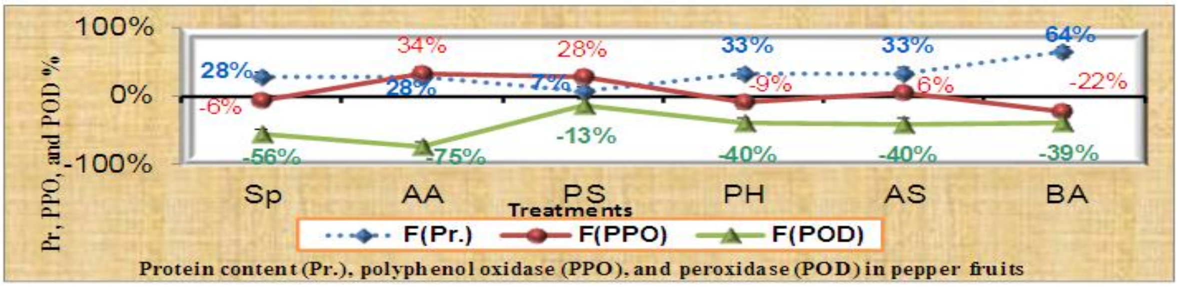
Table 7. Effect of stimulant treatments on protein content, polyphenol oxidase, and peroxidase in the leaves and fruits of pepper plants during the 2022 and 2023 Seasons

Parameter	Protein and enzymes in leaves			Protein and enzymes in fruits		
Treatment	Protein (mg/g)	polyphenol oxidase (PPO) µg/ mg protein	peroxidase (POD) µg/ mg protein	Protein (mg/g)	polyphenol oxidase (PPO) µg/mg protein	peroxidase (POD) µg/ mg protein
			First season 2022			
Control	2.71e	18.63h	342.00d	1.93de	342.12d	93.66e
Spirulina algae	2.36f	94.57c	316.53e	2.45c	317.25e	171.33d
Amino acids	3.01b	102.75b	459.75a	2.43c	460.35a	378.33a
Potassium silicate	2.05g	22.40g	429.00b	2.05d	429.20b	331.11b
Potassium humate	2.54ef	25.40g	303.75e	2.52c	304.52ef	225.66c
Aluminum silicate	2.85d	138.58a	363.75c	2.58bc	366.14c	231.13c
Boric acid	3.07a	69.67f	267.0g	3.16a	267.22g	231.21c
			Second season 2023			
Control	2.81c	18.68h	342.66c	1.96f	346.66b	104.11f
Spirulina algae	2.42e	95.61c	317.54d	2.52d	331.01b	174.33e
Amino acids	3.16b	103.78b	460.56a	2.53cd	460.33a	411.89a
Potassium silicate	2.25e	24.66g	453.74a	2.11e	455.43a	355.20b
Potassium humate	2.63cd	28.71g	311.46d	2.64b	319.23b	247.65d
Aluminum silicate	3.11b	144.32a	371.46b	2.61bc	470.85a	285.35c
Boric acid	3.32a	73.33e	277.57e	3.22a	269.30d	253.25cd

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



Protein content (Pr.), polyphenol oxidase (PPO), and peroxidase (POD) in pepper leaves



Protein content (Pr.), polyphenol oxidase (PPO), and peroxidase (POD) in pepper fruits

Fig. 4. Effect of stimulants treatments on protein content (Pr.), polyphenol oxidase (PPO), and peroxidase (POD) in the leaves (Upper) and fruits (Lower) of pepper plants in average of both seasons.

Treatments where, Sp: Spirulina algae, AA: Amino acids, Ps: Potassium silicate, PH: Potassium humate, As: Aluminum silicate, BA: Boric acid).

of pepper plants treated with amino acid, followed by aluminum silicate and potassium silicate. This result is consistent with a study by **Hasanuzzaman *et al.* (2013)**, which reported that the application of amino acids increased the activity of POD in pepper plants under heat stress conditions. Similarly, a study by **Jiang and Zhang (2021)** found that the application of aluminum silicate increased the activity of POD in tomato plants. These findings suggest that the use of these substances may enhance the synthesis of POD in pepper plants, which could help mitigate the negative effects of high-temperature stress on plant growth and productivity. A summary of these results indicates suggests that the effect of growth-promoting substances on POD activity in pepper plants may vary depending on the specific growth conditions and the type of stress applied. **Amith *et al.* (2021)** reviewed the responses of plants to high-temperature stress and highlighted the role of PPO and POD enzymes in plant stress tolerance. The high temperature leads to an increase in the activity of oxidizing enzymes and a decrease in the activity of reducing enzymes in plants, which negatively affects plant growth and productivity. PPO protects plants from thermal stress by breaking down harmful molecules and regulating plant growth, while POD converts harmful molecules into harmless substances and provides energy for plants. The use of growth-promoting substances increases the activity of PPO and POD enzymes, improving plant tolerance to high-temperature stress. Using growth-promoting substances could be an effective strategy for enhancing plant tolerance to thermal stress, which could improve the productivity of vegetable crops under challenging environmental conditions.

Reduction of Insects

In the present investigation, all the target populations collected from field locations were exposed to different bio-stimulant formulations at the corresponding rate shown in materials and methods, as shown in Table 8. It was observed that the population (*Bemisia tabaci* (Genm)), (*Thrips tabaci*), and the spider mite (*Tetranych usurticae* Koch) varied significantly among the various treatment applications on sweet pepper plants during the two growing seasons. Regarding the reduction of whiteflies, the results of the pepper crop's response to the bio-stimulant formulations showed that the aluminum silicate exhibited the highest significantly reducing the population of whitefly nymphs per plant. The reduction percentages were 52.3%, 52.9% and 52.6% in the 1st season, 2nd season and on average of both seasons, respectively, followed by Potassium humate (41.4%, 48.0% and 44.7%), Amino acids (43.85%, 42.90% and 43.4%), and Potassium silicate (45.85%, 40.15% and 43%) with no significant differences among them as well as Spirulina algae (41.05%,39.95% and 40.5%) and Boric acid (21.82%, 19.50% and 20.66%) in descending order in reducing whitefly populations in the 1st season, 2nd season and on average of both seasons, respectively (Fig. 5). The results indicated that it was more effective throughout the field investigation period.

When examining the reduction percentage of thrips populations under the application of the studied treatments in the same abovementioned Fig. 5, it was found that aluminum silicate and potassium humate were significantly effective in reducing the population of thrips nymphs on average in both seasons. The reduction percentages were 46.8%, and 42.4% in 1st season, and were 45.1% and 47.9% in 2nd one, respectively for aluminum silicate and potassium humate. Potassium silicate (44.6%, 41.9% and 43.2%), followed by spirulina algae (33.7%, 34.5% and 34.1%), Amino acid (31.6%, 31.5% and 31.6%) and in 1st, 2nd and average seasons, respectively with no significant difference between them. The significantly lowest effect was observed for boric acid, with reduction percentages of 17,5%. In addition, the results presented in Fig. 5 demonstrated the percentage of reduction in spider mite populations. The application of aluminum silicate had a significantly high effect in reducing the mite population, with reduction percentages of 45.4%, and 43.3% for the first and second seasons, respectively followed by potassium silicate (45.80% and 42.35%), potassium humate (40.57% and 39.60%), Amino acid (31.50% and 26.60%), Spirolina algae (28.40% and 29.45%), and Boric acid (18.80% and 20.85%) which had the significantly lowest effect in the first and second seasons compared to the control.

Relationships between reduced insect infestation, yield, and enzymes

Generally, combined infestation means reduction (IMR) overall insects was 47.6% coupled with an increment of total yield (93.2%) and marketable yield (153.3%) compared with the corresponding control (Fig. 6).

The previous results of stimulant treatments and their impact on protein content, polyphenol oxidase, and peroxidase in the leaves and fruits of pepper plants, as presented in Table 7, suggest a correlation between plant growth-promoting substances and enzymatic activity, insect population, and insect infestation. Therefore, it can be concluded that Amino acids, potassium silicate, and aluminum silicate not only provide mechanical protection against insect damage but also induce biochemical changes in plants. In pepper leaves, there was a significant increase in polyphenol oxidase and peroxidase activity after infestation compared to the control treatment during the two growing seasons 2022 and 2023. Among these treatments, amino acids and aluminum silicate showed the highest enzymatic activity of the polyphenol oxidase (PPO) enzyme, with values of (102.75 and 138.5) in the first season and (103.78 and 144.32) in the second season respectively, compared to the control treatment in which polyphenol oxidase was 18.63 and 18.68 in the first and the second seasons, respectively. Similarly, amino acids, potassium silicate, and aluminum silicate exhibited the highest enzymatic activity of the peroxidase (POD) enzyme in pepper plant leaves, *i.e.,* 459.75, 429.00, and 363.75 in the 1st season and 460.56, 453.74, and 371.46 in the 2nd season. The elevated enzyme activity may be attributed to the gradual incorporation of phenolic compounds into the cell wall, thereby impacting the feeding behavior of the tested insects. It is also possible for the transaction by amino acids, potassium silicate, and aluminum silicate to lead to improved activity of enzymes polyphenol oxidase and peroxidase compared to the control probably involved in the activation of defense mechanisms of sweet pepper against whitefly (*Bemisia tabaci*), trips (*thrips tabaci*) and spider mites (*Tetranychus urticae*). However, the linear regression results for the insect infestations affected by different anti-stressor treatments are shown in Fig. 7. Good fits were found between the linear model and experimental data for spider mite vs. both yield (Y-SpM) and marketable yield (My-SpM), combined infestation vs. yield (Y-IMR), or marketable yield (My-IMR) and whitefly vs. marketable yield (My-WhF). Their R2 values are 0.916 (Y-SpM), 0.885 My-SpM), 0.858 (Y-IMR), 0.847 (My-IMR) and 0.835 (My-WhF), respectively. On the other hand, somewhat acceptable fits were found between the linear model and experimental data for whitefly versus total (R2=0.793), or thrips versus both total yield (R2=0.763) and marketable yield (R2= 0.714). Also, the scattering of thrips infection points around the slope line (Fig.8) may be due to the level of thrips infestation and its lack of response rate to some different treatments combined with the genotype source resulting in the somewhat weak fits.

The role of exogenous silicon is of great importance because it can act as a modulator influencing the timing and extent of plant defense responses in a manner reminiscent of the role of secondary messengers in induced.

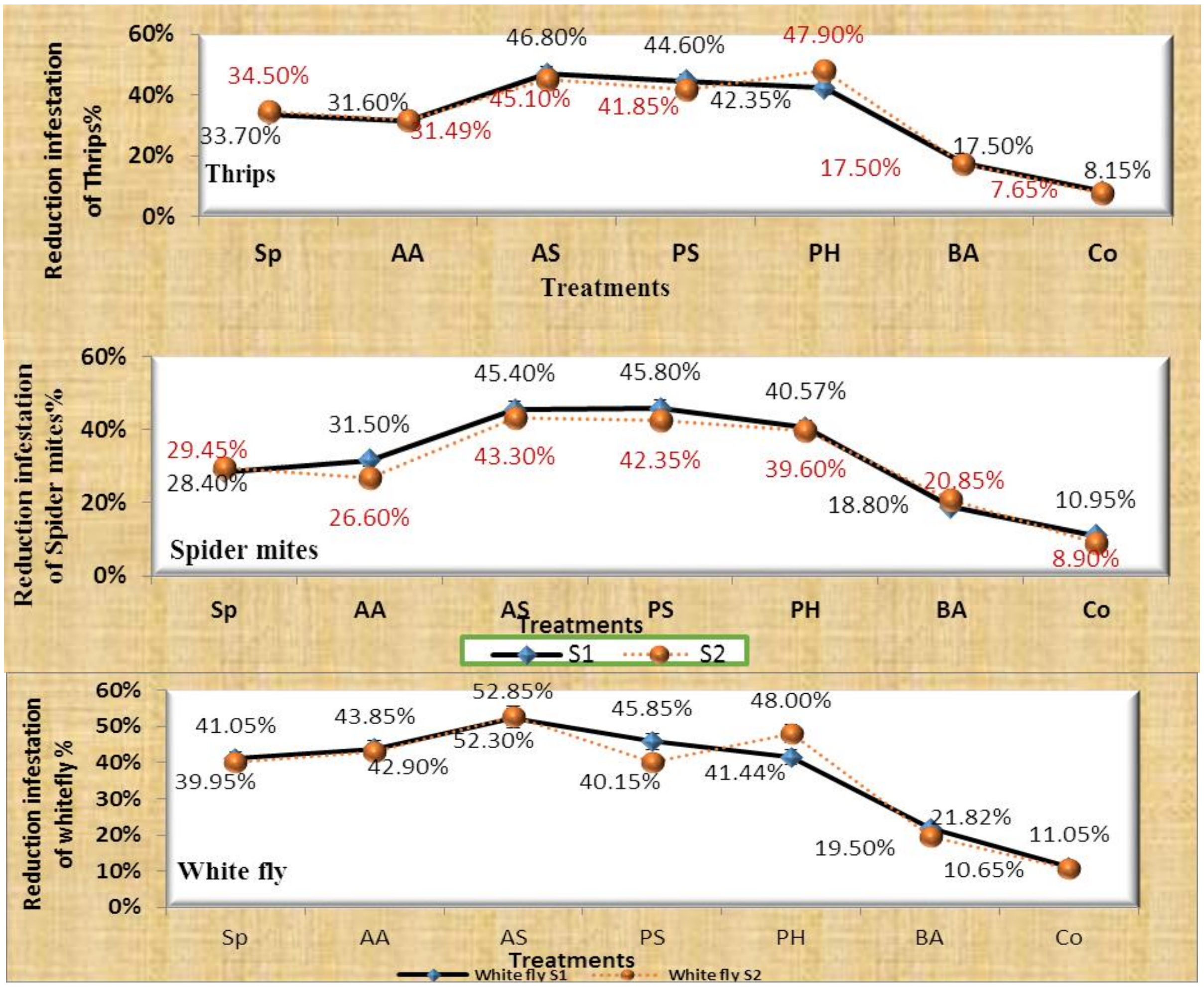


Fig. 5. Reduction percentage of whitefly, Thrips and spider mites as affected by different anti-stressor treatments in average of both seasons.

Treatments where, Co: Control, Sp: Spirulina algae, AA: Amino acids, Ps: Potassium silicate, PH: Potassium humate, As: Aluminum silicate, BA: Boric acid.

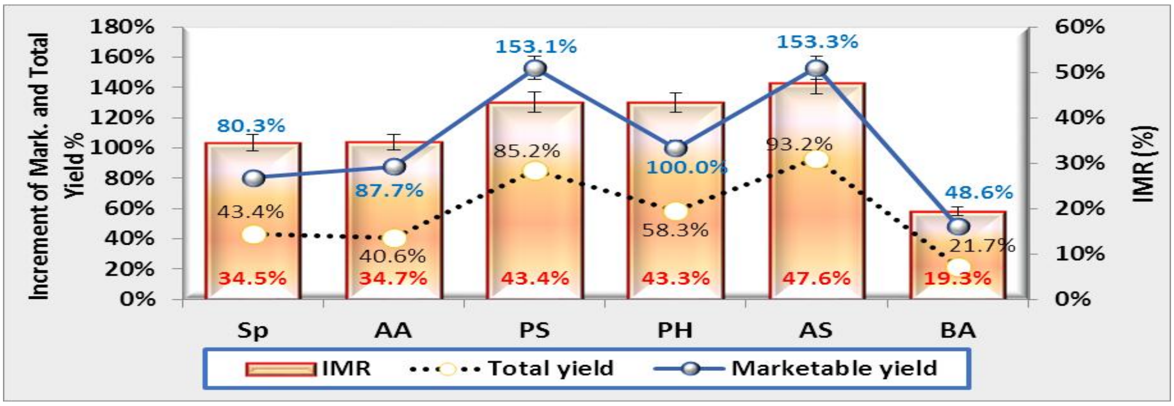


Fig. 6. Infestation means reduction (IMR) overall insects along with both total and marketable yield as affected by different anti-stressor treatments in average of both seasons.

(Treatments where, Sp: Spirulina algae, AA: Amino acids, Ps: Potassium silicate, PH: Potassium humate, As: Aluminum silicate, BA: Boric acid).

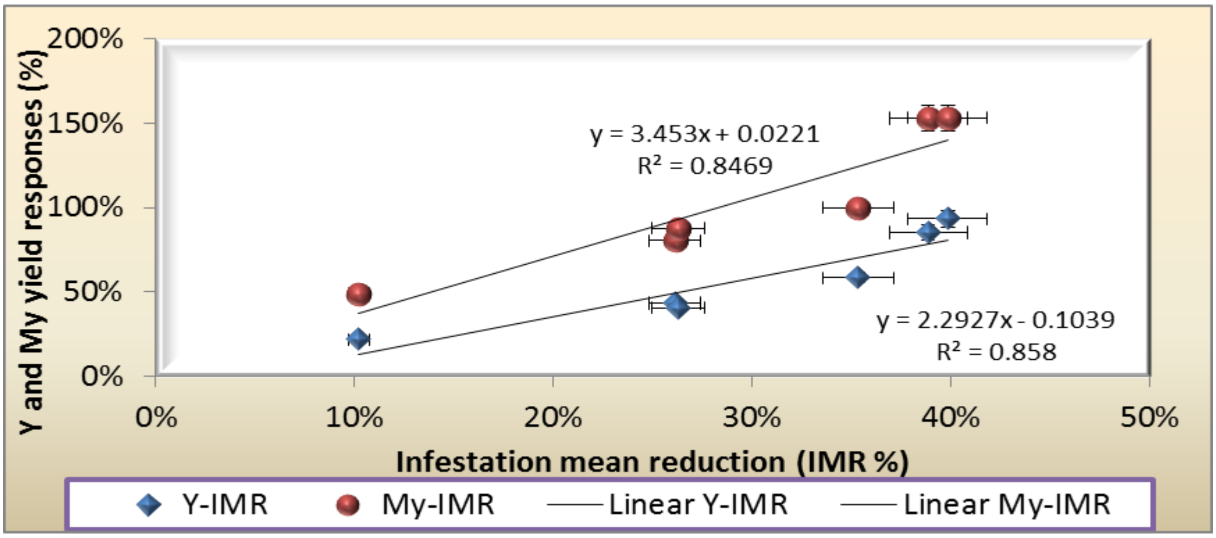


Fig.7. Linear regression results for reduction levels of infestation mean reduction (IMR) overall insects along with total (Y) and marketable (My) yield responses as affected by different antioxidants.

(Treatments where, Sp: Spirulina algae, AA: Amino acids, Ps: Potassium silicate, PH: Potassium humate, As: Aluminum silicate, BA: Boric acid).

systemic resistance **(Correa *et al*., 2005; Fauteux *et al*., 2005)**. Many researchers have adopted various mechanisms to explain the role of silicon treatment in enhancing plant resistance against insect infections. Silicon treatment enhances plant tissue hardness through the formation of solid compounds known as "phytoliths," making it more challenging for insects to damage leaves and weaken their mouthparts. It also reduces leaf digestibility by limiting nutrient availability during digestion. Silicon presence induces metabolic changes in plants that protect them from insect infestations. Additionally, silicon enhances plant defense mechanisms, altering insect behavior during exploration and feeding. It negatively impacts sap-sucking insects, decreasing their population and reproductive capacity. Silicon also influences trichrome structure and promotes lignin formation. Moreover, it contributes to the increased synthesis of phenolic compounds, chitinases, and peroxidases, among other defense mechanisms **(Hodson *and* Sangster, 1988; Salim and Saxena, 1992; Massey *et al*., 2006; Redmond and Potter, 2007; Hunt *et al*., 2008; Nazaralian *et al*., 2017; Verma *et al*., 2021; Al-Saidi and Al-Obaidy 2022)**.

According to a study conducted by **Malik *et al*. (2022)** on growth stimulants, it was found that the application of amino acids and algal extracts resulted in the highest levels of peroxidase enzyme, superoxide dismutase, and catalase, especially after 14 days. Conversely, phenols demonstrated the highest level during the 21-day period. On the other hand, enzymes such as polyphenol oxidase (PPO), phenylalanine ammonia-lyase (PAL), and peroxidase (POD) play a role in the production of these compounds. Indirect defenses are achieved through the release of volatile substances by the host plant or through herbivore-induced plant volatiles (HIPVs), which are triggered by insect feeding. Both direct and indirect responses to insect attacks contribute to plant resistance and can be either constitutive or inducible (**Howe and Jander, 2008)**. A study was conducted by **Abdelwines and Ahmed (2022)** to examine how the application of humic acid, as a resistance inducer, affects the biological characteristics and life table parameters of *T. urticae*, an insect pest. The findings revealed that the use of humic acid resulted in a significant reduction in the total fecundity of *T. urticae*. Specifically, on the Festival cultivar, the total number of eggs produced per female decreased from 74.25 eggs/female to 66.60 eggs/female in the treated plants. Similarly, on the Fortuna cultivar, the total fecundity decreased from 55.31 eggs/female (in the control group) to 34.28 eggs/female in the treated plants. **El-Shaboury and Abd Elrahman (2021)** demonstrated the synergistic effect of humate potassium and yeast combined treatment with 75% nanoparticles (NP) in improving plant quality. This combination also resulted in reduced insect infestation and decreased environmental pollution caused by repeated application of chemical fertilizers and pesticides. The population of *T. urticae* ranged from 9.5 to 8.5 individuals per 10 leaves compared to the control's population range of 9.17 to 9.11 individuals per 10 leaves.

Brief Comparison for Results (Effects of 6-Anti-Stressors Treatments under Stress Conditions)

Field experiments were carried out to study the effect of foliar spray with 6 anti-stressor compounds on the growth and productivity of pepper plants cultivated under abiotic stress, *i.e.*, heat stress as well as natural insect infestation. Accordingly, comparing the performance of the anti-stressors based on yield (ton/fed.) under heat stress (general control) with a reduction percentage of insect infestation and the highest desirable response for yield (% over corresponding control) under various treatments (combined stress) as well as the effects of the anti-stressors on other traits was done. The best anti-stressors, which are classified since these parameters, are shown in Table 8. Five out of the studied anti-stressors were classified as a good effect source in a desirable trend on yield and exhibited a significant increase or equal PPO enzyme activities in leaves. Three out of these 5 anti-stressors showed a significant increase in POD enzyme activities in leaves and fruits along with a high reduction in whitefly infestation. Two out of the three, namely AS (*Aluminum silicate*) and PS (*Potassium silicate*) exhibited significant positive effects for the reduction percentage of both Thrips and Spider mite infestations along with superiority for early and total fruit yield as well as fruit quality in both seasons, indicating the possibility of combining both high yield and good quality characters under various environmental conditions. Both compounds combined significant/highly significant desirable negative or positive (depending on the viewpoint) effects for three or more key studied characters, including vegetative growth, quality of pepper fruits in terms of total flavonoid, total soluble solid, pH, and vitamin C, as well as total soluble protein, *etc.* Additionally, AS had strong favorable results as compared to PS in all vegetative development traits, the majority of fruit attributes, and mean of combined infestation reduction (IMR). High yield affects from treatment did not, however, always result in high levels of other qualities, particularly qualitative traits, and *vice versa*. Our findings suggest that the anti-stress treatments may be crucial for maintaining good yields and/or some of the traditional agricultural practices' essential elements.

Conclusion

Crop management depends on environmental parameters once the cultivar is chosen and can be improved by a wide range of measures so that yields are maximized at an acceptable risk. Many efforts have been made and are still being made to overcome the problem of heat and/or insect effects on pepper plants which can be controlled largely through appropriate management practices in parallel with the addition of adequate fertilizers

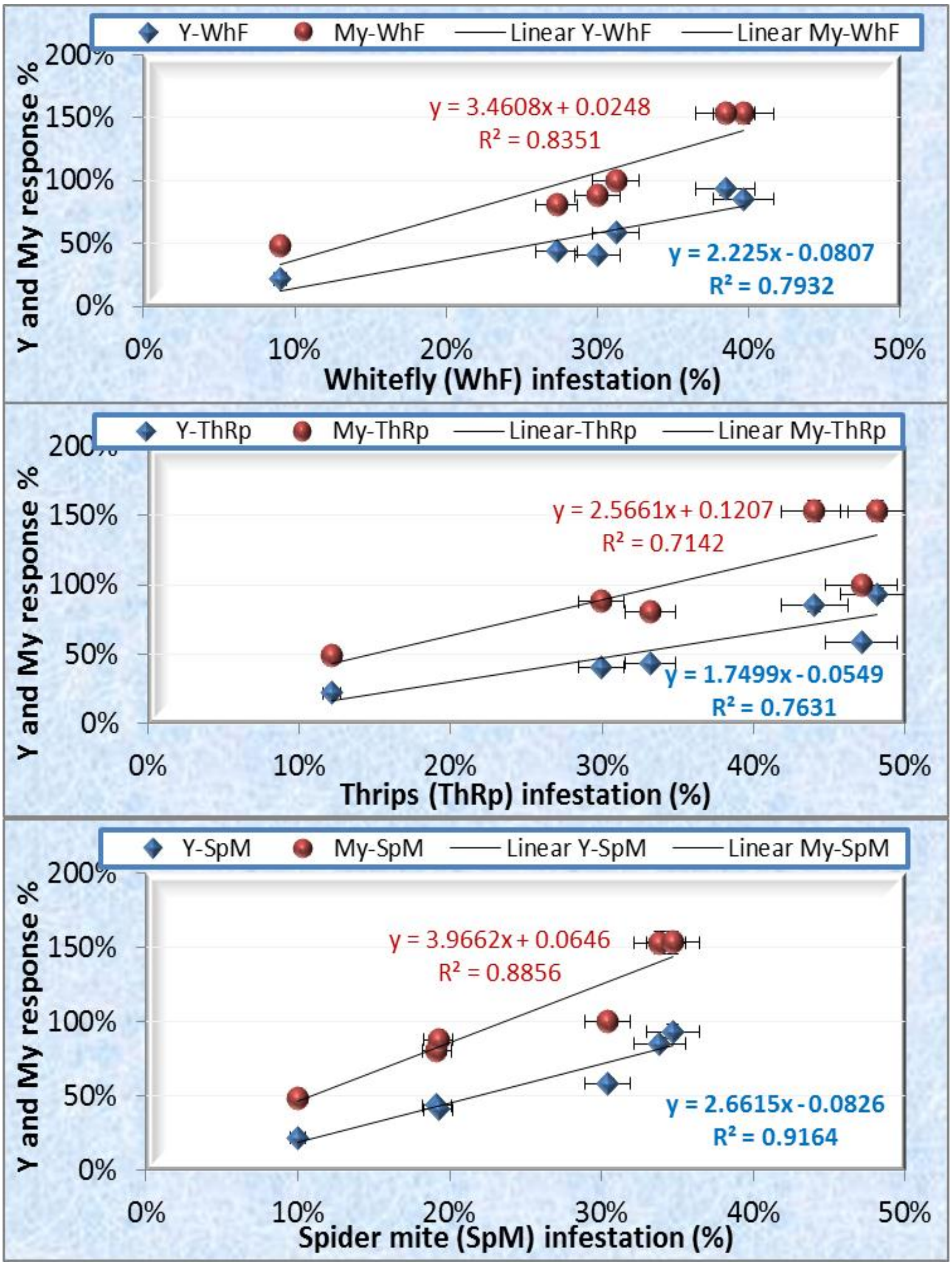


Fig. 8. Linear Regression results for reduction levels of whitefly (WhF), thrips (ThRp) and spider mite (SpM) insects' infestation (%) along with total (Y) and marketable (My) yield responses as affected by different antioxidants.

(Treatments where, Sp: Spirulina algae, AA: Amino acids, Ps: Potassium silicate, PH: Potassium humate, As: Aluminum silicate, BA: Boric acid).

Table 8. The best Anti-stressor chosen based on mean yield along with desirable significant effect for other fruit and enzymatic traits comparing with general control under different stress of heat and insect infestations conditions

Anti-stress treatments	**Changes of fruits yield and pest infestations (over control) under heat stress (average two seasons)**						**Desirable significant effect for other traits due to compare with the control of treatment under heat stress**					
	Value and percentage (%) of fruits yield (over control)		**General mean of reduction (%) of**				**increased traits**		**decreased traits**		**Equal traits**	
	Total yield (ton/fed)	**(%)**	**White fly**	**Thrips**	**Spider mites**	**IMR**	**1st season**	**2nd season**	**1st season**	**2nd season**	**1st season**	**2nd season**
Co.*	6.79	0	0	0	0	0	-	-	-	-	-	-
Sp	9.74	43.4%	40.5%	34.1%	28.9%	34.5%	a, d,e,g,i,k,	a, b, d,e,g,i,k	f,h,j	f, h	b, c,	c, j
AA	9.545	40.6%	43.4%	31.6%	29.1%	34.7%	a, d,e, f-k,	a, c-k	-	-	b, c,	b
PS	12.575	85.2%	43.0%	43.2%	44.1%	43.4%	a-e, h,j,k	a-e, g-k	f	f	g, i	-
PH	10.75	58.3%	44.7%	45.1%	40.1%	43.3%	a, c, d, e, i, k	a, c, d, e, g, i k	h,j	h	b, f, g	b, f, j
AS	13.12	93.2%	52.6%	46.0%	44.4%	47.6%	a-e, g-k	a-e-k	-	-	f	-
BA	8.265	21.7%	20.7%	17.5%	19.8%	19.3%	a, d, f-i, k	a, d-g, i, k	j	h	b, c, e	b, c, j

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

* General control under stress of heat and insect infestations

a,b, c: Fruit length, Fruit diameter and average fruit weight; d, e: Yield/Plant and early yield, respectively

f, g, h: Protein, PPO, POD enzymes in leaves, and i, j, k: Protein, PPO, POD enzymes in fruits.

(Treatments where, Co: Control, Sp: Spirulina algae, AA: Amino acids, Ps: Potassium silicate, PH: Potassium humate, As: Aluminum silicate, BA: Boric acid,)

(the rate, placement, timing and source). For instance, the planting of the crop in the summer season (and offseason growing cycles, especially the late agricultural seasons), is seriously affected by the risk of high daytime temperatures, In this case, adjustments are made based on field information, both before and during the growing season, *e.g.*, if the beginning of the growing season has been warmer than usual, as in the case of the late agricultural seasons, this is reflected on crops performance during the rest of the growing season, *e.g.* the amount and sources of anti-stressor and nutrients needed to support this (and major components accompanying the addition before planting) can be adjusted using the proposed program of foliar spray.

In this study, good agricultural practices are suggested to reduce the effects of heat risk as follows:

- It is recommended to foliar spraying the pepper crop with aluminum silicate (20 g/L) or potassium silicate (5 cm/L), four times, with the initial foliar spraying commencing 30 days after the seedlings were transplanted, at 15-day intervals throughout the sweet pepper plants' growing season.
- The recommended program for planting in the off-season growing cycles will give the highest yield due to the balanced fertilization and anti-stress/antioxidants as well as at the same time will take care of the fruit quality. Thus, the yield will gain the highest values of economic competition in local and international markets and contribute as a good source of hard currency for Egypt.

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المقاومة المحتملة لنباتات الفلفل الحلو للإجهاد الحراري والحشرى المتأثرة بمحفزات النمو وعلاقتها بالنشاط الأنزيمي والنمو والمحصول

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أجريت تجارب حقلية في مزرعة قها – معهد بحوث البساتين -مركز البحوث الزراعية، بمحافظة القليوبية -مصر، وذلك على مدار موسمين متتاليين 2022 و2023 لدراسة تأثير الرش الورقي بـ 6 مركبات مضادة للإجهاد على نمو وإنتاجية نباتات الفلفل الحلو المنزرع تحت الإجهاد الحراري والإصابة الحشرية الطبيعية. تم تصنيف خمسة من مضادات الإجهاد المدروسة كمصدر تأثير جيد في اتجاه مرغوب فيه على المحصول، وأظهرت زيادة معنوية أو مساوية لنشاط إنزيم البولي فينول أوكسيديز في الأوراق. أظهرت ثلاثة من مضادات الإجهاد الخمسة زيادة كبيرة في أنشطة إنزيم البيروكسيديز في الأوراق والثمار إلى جانب انخفاض كبير في الإصابة بالذبابة البيضاء. أظهر اثنان من الثلاثة، وهما (سلكيات الألومنيوم، سلكيات البوتاسيوم) تأثيرات معنوية كبيرة في تقليل نسبة الإصابة بكل من التربس والعنكبوت بالإضافة إلى التفوق في إنتاجية المحصول الثمري المبكر والإنتاج الكلى وكذلك جودة الثمار في كلا الموسمين. مما يشير إلى إمكانية الجمع بين كل من الصفات ذات الإنتاجية العالية والجودة الجيدة في ظل ظروف بيئية متباينة. جمع كلا المركبين تأثيرات معنوية/عالية الأهمية لثلاثة أو أكثر من الصفات الرئيسية المدروسة، بما في ذلك النمو الخضري، وجودة ثمار الفلفل من حيث محتوى عصير ثمار الفلفل من الفلافونويدز، المواد الصلبة الذائبة، ودرجة الحموضة، وفيتامينC ، بالإضافة إلى محتوى البروتين القابل للذوبان، وما إلى ذلك. بالإضافة إلى ذلك، كان لسلكيات الألومنيوم نتائج إيجابية قوية مقارنة بسلكيات البوتاسيوم في جميع صفات النمو الخضري، وغالبية صفات الثمار، ومتوسط الخفض من الإصابة الحشرية. تشير النتائج التي توصلنا إليها إلى أن المعاملات المضادة للإجهاد المذكورة أعلاه قد تكون ذات تأثير إيجابي للحفاظ على محصول جيد و/أو ويمكن ادخالها ضمن الممارسات الزراعية الجيدة لنباتات للفلفل.

الكلمات الاسترشادية : الفلفل، والمقاومة، الحشرات، الاصابة، والمحفزات، والإنزيمات.

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