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IMPROVEMENT OF TOMATO PERFORMANCE UNDER LOW TEMPERATURE STRESS USING SOME BIO-STIMULANTS COMPARED WITH LOW TUNNEL SYSTEM

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ABSTRACT: Chilling injury is one of climate change challenges which effect negatively on plant growth of warm season crops. Low temperatures can be overcome by utilization high cost protected cultivation systems such as low tunnels. Open field experiment was conducted in Private farm, located in Mansouria District, at North of Giza Governorate, Egypt during two winter seasons of 2019/ 2020 and 2020/2021 to study the response of tomato cv. Platinum under low temperature conditions for foliar spray with: 1) Melatonin (100 µM); 2) acetyl salicylic acid (178 mM); 3) potassium silicate (250 mg/L); 4) the mix between acetyl salicylic acid (178 mM) and potassium silicate (250 mg/L); 5) water (control) compared with low tunnel and their effects on agronomic, quality traits and productivity with using of Auxin application as common agricultural recommendation in winter season. Our results revealed that plants of control showed the highest significant injury index on leaves and percentage of injury. All treatments reduced of injury index and injury %, especially the tunnel and the mix treatment. The mix between acetyl salicylic acid and potassium silicate significantly enhanced the agronomic traits such as plant height, number of branches, leaf area, shoot fresh weight and number of leaves/plants. All cold mitigators significantly decreased total sugars, proline and total phenols, except acetyl salicylic acid in total sugars in first season, melatonin in proline in first season and potassium silicate in phenols. The highest lycopene and TSS were recorded in the tunnel and the mix treatment, while the highest Vit C were detected for potassium silicate and followed by the Mix treatment then the tunnel. Except melatonin application in first season only, all cold alleviating compounds clearly increased fruit set, and total yield. Tunnel in first season only and the mix treatment in both seasons produced the highest significant early yield, total yield and number of fruits/ plants which were higher in fruit set percentage than other treatments. We suggested using the Mix treatment as low-cost alternative for low tunnels for tomato production under low temperature condition.

Key words: Tomato, chilling injury, low temperature, climate change and fruit quality.

INTRODUCTION

Climate change is one of the most dangerous phenomena facing the world in recent years, especially the agricultural sector. Crops production is affected by climate variations in several regions around the world especially in the tropical, sub-tropical regions and developing countries which are suffering harshly from negative impacts (**Yadav *et al.*, 2019**). Temperature both low and high, is by far the most serious environmental are limiting crop production (**Meena *et al.*, 2017**). Low temperature is one of the most important environmental factors which are limiting geographical distribution of plants species (**Barrero-Gil *et al.*, 2016**). Low temperature effects on plant water relationships by loss of stomatal control and reducing hydraulic conductance (**Aroca *et al.*, 2003**). The capacity and efficiency of photosynthesis were decreased through change in pigment composition, decline

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in chlorophyll fluorescence and impaired chloroplast development under Low temperature conditions (**Farooq *et al.*, 2009**). Tomato considers a sensitive crop to chilling temperature (0-15°C). Necrotic lesions may happen on leaves, delaying leaf development, inducing wilting, and increase susceptibility to diseases under Chilling stress conditions (**Korkmaz and Dufault, 2001; Rymen *et al.*, 2007**).

Tomato (*Solanum lycopersicum* L.) is one of the most popular cultivated solanaceous species and extensively consumed crop in the world (**Afsana *et al.*, 2021**). FAO statistics in 2023 considered Egypt one of the major tomato producer's countries around the world. Egypt is ranked as the fifth largest tomato producing country which produced 6731220 tons. According to Egyptian ministry of agriculture Egypt ′s production of tomato in all seasons 2019/2020 was 6493724 tons, cultivated area was 380011 feddans, and average production was 17.08 tons/ feddan. Feddan = 4200 m2 = 0.42 hectares.

Adverse climate conditions such as low and high temperatures for horticulture production can be overcome by utilization of different protected cultivation systems (greenhouses and low tunnels), but some of disadvantageous of these systems are high cost, short life, lack of cladding materials and prevent the natural pollination by insects in cross-pollinated crops that obligate us to use manual pollination or development of parthenocarpic varieties (**Reddy, 2016**). Bio-stimulants are presented to increase plant abiotic tolerance. They are one of agricultural inputs that play an important role in sustainable agricultural practices. Chemical and natural bio-stimulant is a product or material used for several purposes in plant production depending on the aim of use. Bio-stimulant effects depends on nutrient content and its component. Bio-stimulant can improve plant growth by increasing efficiency of nutrient used and plant tolerance to abiotic stress and consequently, increasing in fruit set, yield and quality properties. Moreover, using some of natural bio-stimulants as eco-friendly inputs in agriculture industry is a new trend in organic farming instead of chemical material (**Poberezny *et al.*, 2020**).

Acetyl salicylic acid is a phenolic compound able to enhance cold tolerance of plants as exogenous application (**Horváth *et al.*, 2002**). Using of phenolic substances helps plants to overcome stress tolerance. Moreover, little is known about the suitable concentration of phenolic compounds to relieve low-temperature stress in tomatoes (**Meena *et al.*, 2017**). **Zhang *et al.* (2013)** reported that using acetyl salicylic acid as foliar spray application increased fruit yield, proline concentrations, and total anti-oxidant capacity. Application of acetyl salicylic acid reduced lipid peroxidation, increased superoxide dismutase and peroxidase activities, and inhibited superoxide free radical accumulation in tomato plants which exposed to low night-time temperatures. Application of acetyl salicylic acid enhanced growth, yield, and total soluble solids in tomato plants under low temperature stress conditions (**Meena *et al.*, 2017**).

Melatonin considers as one of tryptophan-derived compound. Two independent research groups, for the first time, identified the existence of melatonin in higher plants in 1995 (**Dubbels *et al.*, 1995; Hattori *et al.*, 1995**). Melatonin plays an integral role in regulating including plant growth, seed germination, flowering, senescence (**Ibrahim *et al.*, 2020; Nawaz *et al.*, 2021; Sun *et al.*, 2021**). Moreover, many previous studies have confirmed that exogenous applied melatonin can alleviate the harmful effects of different stresses in many plant species (**Zahedi *et al.*, 2020; Nawaz *et al.*, 2021; Sun *et al.*, 2021; Li *et al.*, 2022**), because it is responsible for stimulating physiochemical responses against environmental conditions melatonin enhances photosynthesis, growth, carbon fixation. It also modulates gene expression related to plant hormones and regulates stress-specific genes (**Nawaz *et al.*, 2021).**

Useful applications for potassium silicate in several domains such as plant Bio-stimulant and biocontrol agent. Potassium silicate improved productivity and fruit quality traits in tomato, like total sugars content and ascorbic acid content (**Soundharya *et al.*, 2019**). Potassium silicate increased the vigor of the tomato plants whish observed in higher vegetative growth parameters, fruit yield, and chemical composition (**Alkharpotly and Abdelrasheed, 2021**), also potassium silicate used in biocontrol for powdery mildew on tomato plants (**Yanar *et al.*, 2011**). This study aimed to compared between some bio-stimulants such as Melatonin, Acetyl salicylic acid and Potassium silicate and compared with high-cost low tunnel system on tomato productivity, fruit quality and nutritional value under low temperature stress.

MATERIALS AND METHODS

Experimental Site and Growing Conditions

Open field experiment was conducted for two successive seasons in Private Farm, located in Mansouria District, at North of Giza Governorate (30˚ 12′ E; 31˚ 08′ N), Egypt during two winter seasons of 2019/2020 and 2020/ 2021. Description of weather conditions (Monthly average of minimum, maximum air temperatures and Relative humidity) for the experiment period according to NASA POWER database are shown in Table 1.

Randomized complete block design (RCBD) was used with three replications. Each plot consisted of two rows each one was seven meters length and one meter width (14 m^2 contained 28 plants per plot). This experiment included 6 treatments.

Plant Material and Treatments

Seeds of commercial tomato (*Solanum lycopersicum* L.) hybrid called Platinum (Nunhems Seed company, Netherlands) were sown in plastic greenhouse nursery using speedlings trays (209 eyes) which filled with mixture of cocopeat and vermiculite (1:1). Transplants were planted in open field at 30 days after sowing date in second week of December 2019 and 2020. Spaces between rows were 1 m and 50 cm between plants. Foliar spray application for treatments were carried out three times at 30, 45 and 60 days after transplanting date. Treatments were foliar spray with: 1) Melatonin (100 µM); 2) acetyl salicylic acid (178 mM); 3) potassium silicate (250 mg/L); 4) the mix between acetyl salicylic acid (178 mM) and potassium silicate (250 mg/L); 5) water (control) compared with low plastic tunnels. Auxin treatment (with 4-chlorophenoxy acetic acid) as common agricultural treatment in winter season in Egypt was applied. Recommendations were followed according to the Egyptian Ministry of Agriculture. Surface irrigation system was used. The source of melatonin ($C_{13}H_{16}N_2O_2$) was Puritan's Pride company, the source of acetyl salicylic acid ($C_9H_8O_4$) was the Arab Drug Company and the source of potassium silicate (K_2OSi_3) was Peptech Biosciences Ltd Company.

Data Measurements

Agronomic characters

Chilling injury index was measured after 60 days of transplanting date which was described as the following points: 0) for non-low temperature injury; 1) for 0-20%; 2) for 21-40%; 3) for 41-60%; 4) for 61-80%; and 5) for 81-100% of leaf area damage according to **Vu *et al.* (2017)**. Growth parameters were estimated at 90 days after transplanting in at least five plants. The following characters were measured: Plant height, determined from soil surface to the apical meristem. Number of branches measured by counting all branches per the plant. Stem diameter, estimated by Calipers. Number of leaves/plants were determined by counting the leaves on the plant. Leaf area was measured in the fifth leaf from the top using program called ImageJ2 for multidimensional image processing and analysis version 0.33.0. Shoot fresh weight, was measured using digital balance for leaves and stem of plant. Fruit set percentage, calculated in the fifth cluster as the ratio between flowers number and fruits number. Early yield was determined as the weight of the first picking (Ton/fed). At the end of the crop cycle, the total yield was calculated by weighing the harvested fruits in each plot then converted ton per feddan.

Chemical analysis

Chlorophyll a, b and carotenoids content were spectrophotometrically measured in leaves according to **Mitic *et al.* (2013)**. P-dimethyl amino benzaldehyde was used to measure total indoles in leaves as described by **Larsen (1962)**. Total free amino acids and total phenols in leaves, were determined according to **Yemm and Cocking (1955)**. Total sugar in leaves was measured according to **Kawamura (1967)**. Bates's method was used to determine proline content as described by **Bates *et al.* (1973)**. Lycopene content in fruits was determined according to **Alda *et al.* (2009)**. Total soluble

Table 1. Description of weather conditions for the period of experiment.

Season	Weather parameters	December	January	February	March	April	May
2019/2020	**Maximum temperature (°C)**	24.25	23.1	26.71	29.66	33.92	42.01
	Minimum temperature (°C)	4.49	3.41	5	4.72	8.9	11.83
	Relative humidity %	66.31	69.19	66.44	59.81	57.25	50.69
2020/2021	**Maximum temperatures(°C)**	27.14	27.25	27.72	32.19	40.48	41.67
	Minimum temperature(°C)	8.37	4.1	3.72	4.66	6.09	14.9
	Relative humidity %	60.75	58.88	61.69	62.31	50.06	36.69

solids % in fruit juice was measured by hand refractometer (Atago digital, Japan). Total acidity (%) was determined in fruit juice as mentioned in **AOAC (1990)**, by titration with sodium hydroxide solution (0.1 N). Vitamin C was determined as described in **AOAC (1990)** by a titrimetric method using 2,6-dichlorophenol indophenol.

Statistical Analysis

Data statistical analysis was carried out using R Statistical Software (v4.1.2; R Core Team 2022). Means comparisons were performed by Duncan's multiple range test at the 0.05 level of probability (**Maxwell and Delaney, 1989**).

RUSTLES AND DISCUSSIONS

Temperature has an important influence on plant growing, development, productivity, and quality traits. Each plant species has an appropriate range of temperatures for ideal growth (**Hatfield and Prueger, 2015**). Tropical and subtropical origin crops such as tomato, are classified as a chilling-sensitive crops (**Lyons, 1973**). Temperatures below 12°C and above 32°C can cause harmful effects for tomato plants (**Meena *et al.*, 2018**). Low temperature injury is one of climate change challenges which reduce plant growth of warm season crops such as tomato. Low temperature affects plants at all stages of development, from germination until fruit maturity (**Chinnusamy *et al.*, 2007**). In our study we used Auxins (4-chlorophenoxy acetic acid) treatment as common agricultural treatment in winter season in Egypt. Auxins have an influence on several physiological responses, division, elongation and differentiation of plant cells (**Jiang *et al.*, 2017**).4-chlorophenoxy acetic acid (4-CPA) often known as synthetic auxin, is a plant growth regulator that reduces stress and increases fruit set and size. Synthetic auxins are often used commercially for promotion of fruit set in tomatoes (**Gemici *et al.*, 2006; Serrani *et al.*, 2007**) especially in under low temperatures. 4-CPA increased number of fruits per plant and yield of tomato grown under high temperature conditions (**Sasaki *et al.*, 2005**). This effect was confirmed when application of 4-CPA which increased the number of tomato fruit set which helps in increasing in fruit yield **(Baliyan *et al.*, 2013)**. Also, **Karim *et al.* (2015)** observed that 4-CPA had a significant influence on yield of tomato. Nevertheless, some authors reported some conditions for success application of 4-CPA. In this regard, **Poliquit and Diputadu (2007)** demonstrated that application of 4- CPA is more effective during anthesis period than one week after anthesis. Furthermore, **Jagdish *et al.* (2002)** foliar spraying with PCPA (50 ppm) recorded improvement in the fruit set per cluster, but the higher concentration (100 and 150 ppm) had no significant effect.

Chilling Injury

Data obtained on severity of low temperature injury on tomato plant revealed that non-treated plants showed the highest significant injury index value on leaves and percentage of low temperature injury, including wilting, necrosis, and then desiccation of the majority of the leaves (Table 2). All treatments reduced the value of injury index in first season without significant differences between them. In second

Table 2. Effects of foliar application of some cold mitigators on low temperature injury percentage and index at 60 days of transplanting during winter seasons of 2019/2020 and 2020/2021

Treatments	Low Temperature injury index		Low Temperature injury %	
	2019/2020	2020/2021	2019/2020	2020/2021
Control	2.93 [a]	2.65 [a]	49.25 [a]	48.22 [a]
Melatonin	1.03 [b]	1.30 [b]	26.13 [a-c]	26.63 [b]
Acetyl salicylic acid	0.99 [b]	1.28 [b]	17.33 [bc]	21.22 [c]
Potassium silicate	1.23 [b]	1.18 [b]	32.01 [ab]	21.33 [c]
The mix	0.00 [b]	0.00 [c]	0.00 [c]	0.00 [d]
Low plastic tunnels	0.00 [b]	0.00 [c]	0.00 [c]	0.00 [d]

[z]Mean values followed by a letter in common were not significantly different according to Duncan's multiple range test ($p < 0.05$).

season the tunnel and the mix between Acetyl salicylic acid and potassium silicate showed the best performance to reduce chilling injury. In both seasons the tunnel and the mix showed the lowest significant low temperature injury %. Melatonin ranked as the second better treatment in this trait.

The synergetic effect of Acetyl salicylic acid and Potassium silicate may be attributed to different tolerance strategy to cold stress. Acetyl salicylic acid alleviated the adverse effects of chilling stress by increasing the activities of proline and the antioxidant enzymes (**Soliman *et al*., 2018**). Hormonal balances were restored by Silicon to level comparable with non-stressed plants through stimulating the production of hormones involved in low soil temperature stressed plants (**Moradtalab *et al*., 2018**). Low temperature injury % and low temperature index for the plants kept under low tunnels showed zero value in this respect. According to **Lodhi *et al*. (2015)** the use of low tunnels conserves warmth climate. These structures also protect the plants from the high winds, rain, frost and snow. **Singh *et al*. (2012)** found that the rhizosphere temperature in the polytunnel was higher by 2.64◦C compared to open field.

Plant Growth Traits

In our study we observed that chilling stress decreased plant growth traits and increased the harmful impacts as shown in Table 3. Similarly, **Xiaoa *et al.* (2018)** observed that low temperature stress caused obviously reduction in some growth parameters such as plant height, stem diameter, leaf area in tomato.

All cold mitigators significantly increased plant height, number of branches and leaf area. The highest values of plant height, number of branches, leaf area in both seasons were recorded in low plastic tunnels treatment, and followed by the mix between acetyl salicylic acid and potassium silicate without significant differences among them except in plant height trait, also same result in shoot fresh weight and number of leaves / plants in first season, while shoot fresh weight was the highest in the mix treatment, acetyl salicylic acid and potassium silicate in second season, in number of leaves / plants trait the mix treatment had the highest value. Plants of control recorded the highest value for stem diameter in both seasons, in addition to acetyl salicylic acid, potassium silicate and melatonin in first season. In our study, although using acetyl salicylic acid and potassium silicate, each alone, enhanced all morphological growth characters of tomato at harvest time, the mix treatment was better than each alone coming after tunnel. Melatonin also had positive effects on plant height, number of branches, leaf area. In former studies acetyl salicylic acid caused significant increment in growth parameters, namely, plant height, number of branches, number of leaves, shoot and root

Table 3. Effects of some cold mitigators on plant height, number of branches, leaf area, stem diameter, shoot fresh weight and number of leaves of tomato plants at 90 days of transplanting during winter seasons of 2019/2020 and 2020/2021

Treatments	Plant height (cm)	Number of branches	Leaf area (cm^2)	Stem diameter (cm)	Shoot fresh weight (kg/ plant)	Number of leaves / plants
	Winter season of 2019/2020					
Control	47.86 c	7.35 c	79.84 c	2.19 a	1.91 c	228.42 d
Melatonin	58.75 b	8.69 b	105.97 ab	1.97 ab	2.16 bc	259.67 cd
Acetyl salicylic acid	57.15 b	8.79 b	86.09 bc	1.99 ab	2.16 bc	252.25 cd
Potassium silicate	57.98 b	9.10 ab	94.92 a-c	1.93 ab	2.17 bc	282.83 bc
The mix	58.97 b	9.50 ab	109.59 ab	1.53 bc	2.67 ab	303.08 ab
Low plastic tunnels	69.00 a	9.95 a	119.46 a	1.22 c	2.78 a	327.50 a
	Winter season of 2020/2021					
Control	53.30 d	7.58 c	90.03 d	2.24 a	1.41 c	186.00 f
Melatonin	57.80 c	9.15 ab	104.84 c	2.08 b	2.36 b	269.00 e
Acetyl salicylic acid	58.10 c	8.67 b	104.92 c	1.93 c	2.57 ab	316.67 c
Potassium silicate	61.05 bc	9.27 ab	112.75 b	1.95 c	2.57 ab	323.83 b
The mix	63.73 b	9.31 ab	124.76 a	1.74 d	2.66 a	364.25 a
Low plastic tunnels	69.38 a	10.02 a	127.52 a	1.75 d	2.33 b	299.58 d

[z]Mean values followed by a letter in common were not significantly different according to Duncan's multiple range test ($p < 0.05$).

length, total dry biomass (**Meena *et al.*, 2017**) and leaf area index (**Meena *et al.*, 2018**) of tomato under low temperature stress. The previous studies recorded improvement in shoot fresh mass in maize plants which subjected under chilling conditions due to spraying the plants with 10 mM Si 10 days before chilling (**Habibi, 2016**), also an enhancement was observed in No. of leaves, stem diameter, leaf area and fresh weight in tomato seedling under low temperature after the application of silicate at 16 mM (**Vu *et al*., 2017**).

Biochemical Characteristics

Data shown in Table 4 illustrate the effect cold mitigators on antioxidant of non-enzymatic compounds (Osmolytes) of tomato plants. All cold mitigators significantly decreased the levels of free amino acids, except the mix treatment and melatonin that significantly increased the total free amino acids in second year only, but potassium silicate only showed significant decrease in this treat in first year. Concerning T. indoles, the mix treatment and low tunnels increased T. indoles, but without significant differences with plants of control.

All cold mitigators significantly decreased the levels of total phenols, except potassium silicate in both seasons, in addition to acetyl salicylic acid and tunnel in first year. All cold mitigators significantly decreased the levels of proline, except melatonin in first year. All cold mitigators significantly decreased the total sugars, except acetyl salicylic acid in first year. Our results are in agreement with the previous studies that revealed that foliar application for strawberry with potassium silicate increased the total phenolic content (**Hajiboland *et al*., 2018**) and in squash fruits

Table 4. Effects of some cold mitigators on antioxidant of non-enzymatic compounds (total free amino acid, total indoles, total phenols, total sugars and proline) of tomato plants at 90 days of transplanting during winter seasons of 2019/2020 and 2020/2021

Treatments	Total free amino acid (g./100g. DW)	Total indoles (mg/100g. DW)	Total phenols (% DW)	Proline (mg/100g. DW)	Total sugars (% DW)
	Winter season of 2019/2020				
Control	0.771 ab	10.68 ab	0.989 ab	24.99 a	19.44 a
Melatonin	0.835 ab	9.52 b	0.657 c	23.65 a	11.73 bc
Acetyl salicylic acid	0.651 bc	9.31 b	0.822 a-c	15.44 b	16.22 ab
Potassium silicate	0.527 c	9.46 b	1.055 a	12.91 b	11.93 bc
The mix	0.917 a	11.62 a	0.785 bc	12.05 b	7.79 c
Low plastic tunnels	0.662 bc	10.92 ab	0.949 ab	12.51 b	12.45 bc
	Winter season of 2020/2021				
Control	0.761 c	11.02 ab	0.992 b	26.66 a	19.77 a
Melatonin	0.842 b	9.85 cd	0.663 d	24.65 b	12.40 c
Acetyl salicylic acid	0.661 d	8.98 d	0.818 c	15.11 c	15.55 b
Potassium silicate	0.534 e	9.13 d	1.088 a	12.57 d	11.46 c
The mix	0.920 a	11.95 a	0.782 c	11.38 d	8.12 d
Low plastic tunnels	0.672 d	10.65 bc	0.955 b	12.18 d	12.78 c

[z]Mean values followed by a letter in common were not significantly different according to Duncan's multiple range test ($p < 0.05$).

under greenhouse (**Abd-Elkader *et al*., 2022**). Also, they are in accordance with **Soliman *et al.* (2018)** who that revealed that spraying the plants with acetyl salicylic acid increased the total sugars content. On the other hand, the present results are in agreement with those of **Ibrahim *et al.* (2020)** who examined the impact of foliar application of melatonin on tomato plants grown in open fields under optimal and deficit irrigation conditions. Results showed that melatonin significantly reduced soluble sugars. Likewise, **Hafez *et al*. (2021)** reported a decrease in total free amino acids and proline in leaves with the application of potassium silicate.

On the contrary, total sugars and proline were significantly decreased in all treatments but, in first season for melatonin had high value of proline and acetyl salicylic acid had high value of total sugars. The reduction of the total sugars and proline and the non-significant effect of the different treatments on non- enzymatic antioxidants, as we expected, can be interpreted by the fact that plant response for these alleviators depended on plant species, the nature of stress and application time. (**Zhu and Gong, 2014**) and concentrations tested (**Javanmardi and Akbari, 2017**).

An effectively chlorophyll fluorescence measurement has been used to interpret some of Plant responses to various abiotic stresses (**Kalaji *et al*., 2016**). According to **Kim *et al.* (2017)**, plants produce carotenoids as part of a complicated antioxidant system to preserve homeostasis and mitigate the effects of cold stress.

Data presented in Table 5 showed a significant increase in chlorophyll b concentration in melatonin and the mix treatment in both seasons, in addition to acetyl salicylic acid and the tunnel in first season for chlorophyll b, while melatonin, acetyl salicylic acid, the mix and tunnel showed the highest total carotenoids in second season, while first season was without significant differences among the control and these treatments. In first season melatonin displayed the lowest value in chlorophyll a, while there were no significant differences among the other treatments, but in second season plants of control, acetyl salicylic acid and the tunnel showed the highest significant content of chlorophyll a.

Our results were in agreement with results of **Ibrahim *et al*. (2020)** showed that melatonin significantly improved chlorophyll in tomato plants grown in open fields under deficit irrigation conditions. In a recent study, **Li *et al*. (2022)** observed that melatonin treatment effectively increased the carotenoid content and chlorophyll pigment molecules in the leaves of pepper plants under the stress of low temperature and low light. Application of melatonin in the current study may prevent damage caused by stress on chlorophyll, where it increased chlorophyll b content. On the contrary, potassium silicate caused a decrease in the chlorophyll a, b and total carotenoids in leaves. Interestingly, in contradiction with our results, many previous studies proved increases in chlorophyll content due to application of potassium silicate (**Vu *et al*., 2017; Salim *et al*., 2021**) under the conditions of salinity, and water deficiency stress.

Chemical Composition of Fruits

Data in Table 6 demonstrated that all cold mitigators increased all studied traits of fruit chemical traits, except acidity that were reduced by these treatments. Moreover, the highest values of lycopene and TSS were recorded in the tunnel and the mix treatment, while the highest values of Vit C were detected in the treatment of potassium silicate and followed by the mix treatment then the tunnel. Lycopene, ascorbic acids are antioxidants that are negatively affected by reduction of temperatures (**Meena *et al*., 2018**).

Our results are with agreement with the findings of some studies which showed improvement of Vit. C and lycopene in tomato fruits after the foliar applications of acetyl salicylic acid under chilling stress (**Meena *et al*., 2018**). Using of acetyl salicylic acid as foliar application improved TSS under chilling stress (**Meena *et al*., 2017**) and under salt stress (**Sajyan *et al*., 2019**) in tomato fruits. In this experiment the increment of lycopene due to application of potassium silicate is in harmony with former studies that showed increase in lycopene in tomato fruits which planted in hydroponics, also potassium silicate enhanced Vit. C concentration in tomato fruits (**Stamatakis *et al*., 2003**). **Alkharpotly and Abdelrasheed (2021)** found that spraying tomato plants with potassium silicate increased Vit. C and TSS content. **Liu *et al*. (2016)** reported that soaking seeds with melatonin before germination increased ascorbic acid and lycopene. Weekly melatonin supplemented nutrient solutions improve soluble solids, ascorbic acid and lycopene content. Furthermore, **Ibrahim *et al*. (2020)** examined the impact of foliar application of melatonin on tomato plants grown in open fields under optimal and deficit irrigation conditions. Results showed that melatonin significantly improved quality attributes like total soluble solids, ascorbic acid, and lycopene.

Titratable acidity decreased with temperature reduction (**Fleisher *et al*., 2006**). The foliar application with acetyl salicylic acid reduced the titratable acidity (**Meena *et al*., 2017**), also potassium silicate reduced titratable acidity under chilling conditions (**Alkharpotly and Abdelrasheed, 2021**). **Dou *et al.* (2022)** reported that exogenous melatonin application clearly reduced the acidity content in tomato fruits.

Productivity Characters

Except melatonin application in first season only all cold alleviating compounds clearly increased total yield (Table 7). Considering yield, the tunnel (in first season only) and the mix treatment between acetyl salicylic acid and potassium silicate (in both seasons) produced the highest significant early yield, total yield, weight of fruits/ plant and number of fruits/ plants which were higher in fruit set percentage than other treatments. Plants in control in both

Table 5. Effects of some cold mitigators on chlorophyll a, chlorophyll b and total carotenoids of tomato plants at 90 days of transplanting during winter seasons of 2019/2020 and 2020/2021

Treatments	Chlorophyll a (mg^{-1} FW)	Chlorophyll b (mg^{-1} FW)	Total Carotenoids (mg^{-1} FW)
	Winter season of 2019/2020		
Control	0.383 a	0.159 b	0.243 ab
Melatonin	0.304 b	0.358 a	0.320 a
Acetyl salicylic acid	0.374 a	0.279 ab	0.323 a
Potassium silicate	0.317 ab	0.168 b	0.223 b
The mix	0.340 ab	0.343 a	0.320 a
Low plastic tunnels	0.371 a	0.289 ab	0.315 a
	Winter season of 2020/2021		
Control	0.373 a	0.162 d	0.257 b
Melatonin	0.307b	0.361 a	0.313 a
Acetyl salicylic acid	0.376 a	0.272 c	0.340 a
Potassium silicate	0.317 b	0.155 d	0.243 b
The mix	0.326 b	0.342 a	0.333 a
Low plastic tunnels	0.367 a	0.296 b	0.317 a

[z]Mean values followed by a letter in common were not significantly different according to Duncan's multiple range test ($p < 0.05$).

Table 6. Effects of some cold mitigators on some chemical quality characters in tomato fruits at harvest during winter seasons of 2019/2020 and 2020/2021

Treatments	Lycopene (g./100g)	Total Soluble Solids (%)	Acidity (%)	Vit.C (mg/100g)
	Winter season of 2019/2020			
Control	0.337 c	3.83 b	0.304 a	8.81 c
Melatonin	0.433 bc	4.17 b	0.260 ab	9.97 c
Acetyl salicylic acid	0.469 bc	4.80 ab	0.251 a-c	10.89 c
Potassium silicate	0.515 ab	4.57 ab	0.223 b-d	15.59 a
The mix	0.670 a	5.77 a	0.187 cd	14.93 ab
Low plastic tunnels	0.681 a	5.67 a	0.157 d	13.26 b
	Winter season of 2020/2021			
Control	0.367 d	4.03 c	0.323 a	8.55 e
Melatonin	0.437 c	5.00 b	0.283 b	10.78 d
Acetyl salicylic acid	0.516 b	5.50 b	0.260 bc	11.57 c
Potassium silicate	0.556 b	5.00 b	0.238 c	15.50 a
The mix	0.753 a	6.40 a	0.182 d	15.42 a
Low plastic tunnels	0.767 a	6.23 a	0.179 d	14.48 b

[z]Mean values followed by a letter in common were not significantly different according to Duncan's multiple range test ($p < 0.05$).

Table 7. Effects of some cold mitigators on yield components during winter seasons of 2019/2020 and 2020/2021

Treatments	Winter season of 2019/2020					
	Days to 50% Flowering	Fruit set (%)	Number of fruits/ plants	Weight of fruits/ plant	Early yield (ton/fed.)	Total yield (ton/fed.)
Control	61.00 b	76.32 b	75.33 c	6.76 c	9.81 b	20.70 d
Melatonin	69.00 a	82.73 b	87.75 bc	9.48 bc	11.15 ab	23.22 cd
Acetyl salicylic acid	71.33 a	84.62 b	95.92 bc	10.53 ab	12.72 a	25.15 bc
Potassium silicate	61.00 b	81.33 b	93.33 bc	9.58 bc	12.17 ab	26.11 a-c
The mix	73.33 a	86.67 ab	113.58 ab	13.64 a	12.91 a	27.80 ab
Low plastic tunnels	73.67 a	97.10 a	138.67 a	10.59 ab	10.63 ab	29.84 a
	Winter season of 2020/2021					
Control	60.00 d	64.02 d	74.67 c	6.83 d	11.33 d	22.11 e
Melatonin	67.33 c	82.11 b	94.25 b	10.81 b	12.51 c	24.12 d
Acetyl salicylic acid	70.67 b	93.45 a	93.33 b	8.43 c	12.91 bc	24.95 c
Potassium silicate	70.33 b	80.96 b	115.25 a	11.87 a	13.54 ab	27.16 b
The mix	72.67 a	75.65 c	116.50 a	12.10 a	13.64 a	28.27 a
Low plastic tunnels	73.67 a	95.92 a	118.50 a	9.20 c	11.34 d	27.35 b

[z]Mean values followed by a letter in common were not significantly different according to Duncan's multiple range test ($p < 0.05$).

seasons and potassium silicate in first season were earlier in flowering than other treatments. Meanwhile, the mix treatment significantly overrides acetyl salicylic acid and potassium silicate each alone. These results might be due to the role of these substances in overcome chilling stress, by stimulation of plant defense through non-enzymatic activity such as total free amino acids and total indoles in Table 4, in addition to chlorophyll b and carotenoid content in Table 5 which enhanced the vegetative growth characters of tomato plants.

Our results about yield are in line with the previous studies about the beneficial effects of potassium silicate that improved yield in many crops such as tomato grown under drought conditions (**Vu *et al.*, 2017**), in strawberries (**Zahedi *et al.*, 2020**), and in squash (**Salim *et al.*, 2021**). Similarly, foliar application of acetyl salicylic acid enhanced tomato yield under low temperature stress (**Meena *et al.*, 2017; Meena *et al.*, 2018**). Acetyl salicylic acid increased tomato yield under low temperatures stress during night hours (**Zhang *et al.*, 2013**).

Conclusion

There is a suggestion that the mix treatment between acetyl salicylic acid and potassium silicate worked in harmony. Together, they increased the tomato plants' ability for photosynthesis when exposed to chilling stress during winter season. The mix treatment between acetyl salicylic acid and potassium silicate increased total yield of tomato followed by low plastic tunnels during winter plantations.

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تحسين أداء الطماطم تحت إجهاد الحرارة المنخفضة باستخدام بعض المحفزات الحيوية مقارنة بنظام الأنفاق المنخفضة

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أضرار البرودة واحده من تحديات التغيرات المناخية والتي لها تأثير سلبي على محاصيل الموسم الدافئ. الحرارة المنخفضة ممكن مواجهتها باستغلال أنظمة الزراعة المحمية العالية التكلفة مثل الأنفاق المنخفضة. أجريت تجربة في الحقل المفتوح في مزرعة خاصة بمنطقة المنصورية بشمال محافظة الجيزة بمصر خلال موسم الشتاء عامي 2020/2019 و2021/2020 لدراسة استجابة صنف طماطم بلاتينيوم تحت ظروف الحرارة المنخفضة للرش بـ 1) الميلاتونين (100 μM) ، و 2) حامض الأسيتيل سلسيليك (178 mM) ، و 3) البوتاسيوم سيليكات (250 mg/L)، و4) الخليط بين حامض الأسيتيل سلسيليك (178 mM) والبوتاسيوم سيليكات (250 mg/L)، و 5) كنترول (ماء) وتم مقارنتها بنظام النفق المنخفض ودراسة تأثيرها على الصفات الخضرية وجودة الثمار والإنتاجية وذلك مع استخدام الأوكسينات كممارسة زراعية متبعة خلال فصل الشتاء. وأوضحت النتائج ان نباتات الكنترول كانت الأعلى في مؤشر الضرر على الأوراق ونسبة الضرر. كل المعاملات خفضت من مؤشر الضرر ونسبة الضرر خصوصا معاملة النفق والرش بالخليط. المعاملة بالخليط من حامض الأسيتيل سلسيليك وسيليكات البوتاسيوم حسنت جوهريا كل الصفات الخضرية مثل ارتفاع النبات وعدد الفروع ومساحة الورقة ووزن المجموع الخضري وعدد الأوراق/النبات. كل المحفزات قللت بشكل معنوي السكريات الكلية والبرولين والفينولات الكلية ماعدا حامض الاسيتيل سلسيليك بالنسبة للسكريات الكلية في الموسم الأول والميلاتونين بالنسبة للبرولين في الموسم الأول وسيليكات البوتاسيوم بالنسبة للفينولات. أعلى محتوى من الليكوبين والمواد الذائبة الكلية سجلت في معاملة النفق والرش بالخليط. بينما اعلى فيتامين ج كان في معاملة سيليكات البوتاسيوم يتبعها الخليط يتبعها النفق. كل المعاملات حسنت بشكل ملحوظ عقد الثمار والمحصول الكلي ماعدا الميلاتونين في الموسم الأول. معاملة النفق في الموسم الأول فقط ومعاملة الخليط في الموسمين أنتجت أعلى محصول مبكر وكلي واعلى عدد ثمار/ النبات والتي كانت أعلى في نسبة العقد عن باقي المعاملات. نقترح استخدام معاملة الخليط كبديل منخفض التكلفة للأنفاق المنخفضة لإنتاج الطماطم تحت ظروف الحرارة المنخفضة.

الكلمات الإسترشادية: الطماطم، أضرار البرودة، الحرارة المنخفضة، التغيرات المناخية، جودة الثمار.

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