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Modifying Low Tunnels to Mitigate Heat Stress on Cucumber Grown on Salt-Affected Soil under Late Summer Season Conditions

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INCREASING agricultural revenues and productivity is crucial to getting food and reducing poverty. At the same time, rising air temperatures because of climate changes considered real safety threatens agrarian production. Hence, to cope with these challenges, particularly in arid and semi-arid regions, it is vital to modify current agricultural practices. In this context, the current study was conducted to investigate the possibility of improving cucumber productivity under heat-stress conditions during the late summer seasons. The treatments included different protected cultivation techniques of cucumber, i.e., using soil mulch with a white plastic cover, an anti-stressor spray of aluminum silicate, shaded tunnel by net cover, misting under shaded tunnel by net cover, top white plastic sheet, misting without cover. The soils of all studied protected treatments were covered by white plastic mulch to decrease soil temperature and evaporation. All protected cultivation techniques were compared with the common open-field cultivation without any protection (control). The results revealed that all modifications of the low tunnels ameliorated heat stress and reflected better cucumber growth and fruit yield compared to open-field cultivation. The tunnel with mist under the net cover produced the highest plant growth, leaf area, and chlorophyll content. The favorable effect of the treatments on flowering was related to the increase in number of female flowers not the number of male ones. Rather than increasing fruit productivity, the modified tunnels also enhanced fruit quality (weight, size, firmness and TSS %).

Keywords: protected cultivation, misting, soil mulch, *Cucumis sativus*, growth, yield, quality.

1. Introduction

In the last few decades, food security has become a crucial global worry pushed by population increase projections and exacerbated by the impending stress of climate changes on the agricultural sector **(Molotoks et al., 2021)**. Recently, climate change has taken a lot of attention from the world due to the noticed risks to human life. Human activity via chopping down forests, burning fossil fuels, and farming livestock is one of the primary causes of gas emissions and worldwide warming, which is often known as the "greenhouse effect" **(Sharaf-Eldin et al., 2023 b)**. Global warming harms both human life and food security. Furthermore, it is well recognized that water scarcity has already impacted a large part of the world, and the problem is only worsening as the world's population and freshwater demands grow. In arid and semi-arid regions, agriculture has a substantial role in the total national income and is regarded as a livelihood for the majority of the population, such as in Egypt (**Farag et al., 2016**). Smallholder farmers are additionally more exposed to climate change because they lack adequate resources to address its negative effects **(Gentle et al., 2018)**. Thus, using sustainable methods to raise the standard of life for smallholder farmers can promote growth in the economy, decrease world

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poverty, and progress toward sustainable development targets **(Markelova et al., 2009)**. Furthermore, these strategies must be modified for improved climate change adaptation. Protected cultivation is recommended to play a vital role in achieving farm sustainability and coping with the adverse effects of climate change **(Yohannes, 2016; Liao et al., 2020).** Many types of protected growing facilities, including greenhouses, net houses, tunnels, and others, are produced based on the needs of the various plant species and climate conditions. Protected farming has many advantages, including decreased yield loss related to severe weather, pests, weeds, and disease control, improved utilization of resources, increased crop production and quality, and increased farmer income **(Sharaf-Eldin et al., 2023 b)**. Fully controlled greenhouses are ideal alternatives for adjusting the microclimate, but they have many difficulties. These involve high prices and advanced technologies in addition to energy-related issues that are not often applicable, especially for poor farmers and nations that are developing **(Hassanien et al., 2016; Liao et al., 2016)**. These reasons motivate farmers to set up various kinds of protected agriculture. Small-holder producers prefer low- and high-tunnels because they are less complicated and expensive alternatives to greenhouses **(Sharaf-Eldin et al., 2023 b)**.

Vegetable crops constitute a crucial ingredient in the human diet owing to their high nutritional value and bioactive content and could contribute to improving food availability and nutritional quality, especially when maintained under highly concentrated cropping systems in controlled environments **(Rouphael et al., 2018)**. Cucumber is one of the favored vegetables grown for domestic use and export in Egypt. They are grown in both open fields and under plastic or net houses. Cucumbers can suffer from heat stress even though they are a thermophilic vegetable crop (**Wei et al., 2019**). Several scientific investigations have demonstrated that heat stress has a variety of negative effects on plant development, growth, physiological traits, and productivity-both in terms of quantity and quality **(Sharaf-Eldin, 2015; Wang et al., 2016; Shalaby et al., 2021)**. Around the world, cucumbers are grown in a wide range of environmental conditions, which includes arid and semi-arid regions. The high ambient temperatures, particularly in the summer, are the key limiting factors for this expansion in these places **(Ding et al., 2016; Taha et al., 2020)**. Climate change is predicted to increase atmospheric temperatures, which negatively impact the growth and physiology of vegetable crops **(Khan et al., 2018).** These stresses of the heat are expected to be concentrated because of climate changes; under these conditions, the resulting imbalances in plant nutrition, physiological disorders, and hormones may also contribute to a rise in biotic stresses **(Tiwari et al., 2020**). Under heat stress conditions, plants are submissive to reduction in performance of plant cell functions including membrane fluidity, enzyme activity, chlorophyll synthesis, protein complexes formation, respiration, photosynthesis, and redox state (**Li et al., 2013**). Thus, many approaches are employed to mitigate the impacts of heat stress, such as shading to reduce light intensity which is one of the most simple, affordable, non-chemical, and environmentally friendly methods to modify the greenhouse/tunnel environment during hot seasons. Numerous studies have demonstrated the benefits of tunnel shading in mitigating the adverse effects of heat stress on plants, resulting in improved nutrition, growth, and production **(Kittas et al., 2012; Sulaiman and Sadiq, 2020).** The combination of shading nets and whitewash (i.e., the application of a solution of water mixed with calcium carbonate) is widely used in modifying the indoor climate for vegetables such as cucumber and tomato throughout months with high electromagnetic radiation, as it lets the intensity of light and, thus, the energy required for cooling to be reduced **(Ahmed et al., 2016; Nikolaou et al., 2018)**. Another successful strategy to alleviate heat stress on the crops is using evaporative cooling systems, based on the diversion of sensible heat into latent heat by evaporation of water provided directly into the greenhouse/tunnels atmosphere (fog or mist system) **(Baudoin et al., 2013; Sharaf-Eldin et al., 2023 b).** The misting method works through pressurized water into small aerosol particles that are distributed evenly throughout the tunnel. This procedure aids in hydrating and cooling plants.

Another strategy to cope with heat stress is using anti-stressors **(Shalaby et al., 2021)** or grafted cucumber **(Bayoumi et al., 2021).** Silicon application has been reported as anti-stressor for numerous abiotic stresses in plants (**Abd-Alkarim et al., 2017; Eissa, 2024**). It plays its role as an anti-stressor by improving water uptake, modifying osmotic pressure, controlling polyamine production, and stimulating the anti-oxidative defense mechanism **(Malhotra and Kapoor, 2019**).

To the best of our knowledge, no previous studies have applied low-cost tunnels with shading and cooling systems or mixing for both systems with soil mulch and drip irrigation to maximize the productivity of cucumber grown under late summer conditions. In this sense, there is an increasing need to improve crops production and optimize the use of water resources. Therefore, this study aimed to compare open field and low tunnel cultivation as they; (i) Aluminum silicate foliar spray (ii) Shaded tunnel by net cover (iii) Top white plastic cover, (iv) Misting without cover (iiv) Misting under net cover on cucumber productivity under Mediterranean conditions in northern Egypt during the late summer season.

2. Materials and methods

2.1 Experimental site

The current experiments were set up at the experimental farm of International Protected Cultivation Center, Horticulture Department, Faculty of Agriculture, Kafrelsheikh University, Egypt on cucumber plant (Prince F_1 hybrid, Seminis Co., USA) during the period from June to August in 2020 and 2021 seasons. Based on the climatic data, this period represents the highest temperature in Egypt during summer. The coordinates of this site are 31˚ 05′ 52″ N latitude and 30˚ 57′ 10″ E longitude which lies in the north River Nile Delta of Egypt. The elevation of this site is about 6 m over the mean sea level**.** The experimental site is shown in **Fig. 1**.

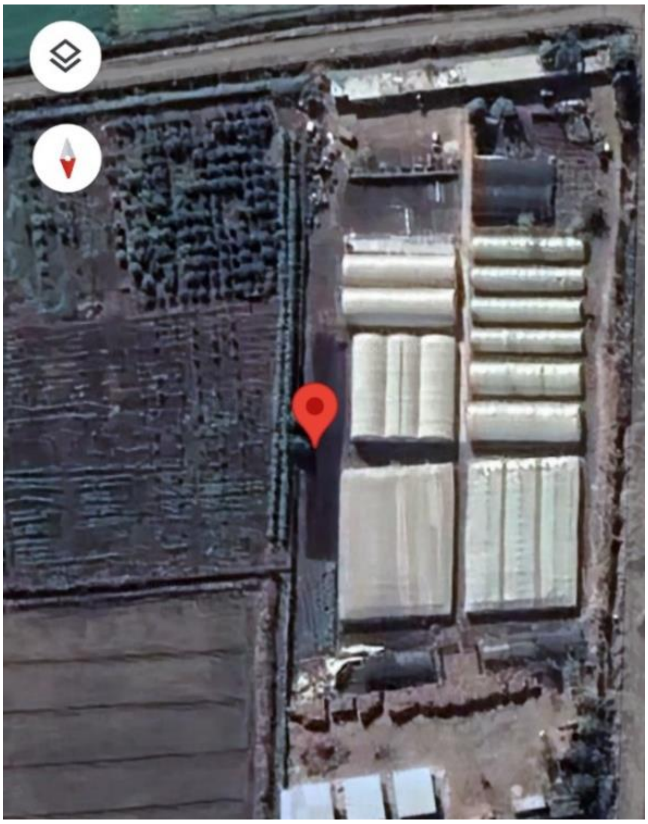


Fig. 1. The Experimental site (31.096911º N, 30.953825º E).

2.2 Climatic and soil conditions

The climate at the experimental site has arid summer with direct irradiation intensity ranges between 2000 to 3200 W/m^2. Mean air temperature, RH% and wind velocity during study period in both seasons are presented in Table 1. The soil of the experimental site was salt-affected clayey soil (EC 4.50 dS m^{-1}, 8.63 pH, 30 mmol L^{-1} Na^+ and 27 mmol L^{-1} Cl^-).

Table 1. Ambient air temperature, RH% and wind velocity during both seasons.

	Air Temp. (°C)		**RH (%)**		**Wind Velocity**
Month	**Max.**	**Min.**	**7:30**	**13:30**	**(Km/ hr)**
		2020			
June					
Mean 10^{st} days	32.5	24.7	77.1	45.0	١٠,٢
Mean 10^{nd} days	32.7	25.6	74.4	50.3	٩,٣
Mean 10^{rd} days	32.6	25.5	75.6	48.7	١٠,٠
July					
Mean 10^{st} days	33.9	25.7	82.1	51.2	٩,٨
Mean 10^{nd} days	34.2	25.1	83.3	50.4	٩,٤
Mean 10^{rd} days	34.5	25.4	82.4	51.4	7.7
August					
Mean 10^{st} days	34.3	25.5	84.1	51.4	7.5
Mean 10^{nd} days	33.9	25.2	81.5	50.8	7.8
Mean 10^{rd} days	33.5	25.0	81.7	51.9	7.6
		2021			
June					
Mean 10^{st} days	32.2	27.3	80.6	48.3	11.7
Mean 10^{nd} days	33.0	28.2	80.9	49.1	9.4
Mean 10^{rd} days	33.4	28.6	83.1	52.5	9.8
July					
Mean 10^{st} days	33.7	28.5	85.2	54.0	8.8
Mean 10^{nd} days	33.2	28.8	83.2	55.4	8.8
Mean 10^{rd} days	33.6	27.8	87.3	53.7	7.5
August					
Mean 10^{st} days	33.6	28.6	87.4	57.2	8.7
Mean 10^{nd} days	34.6	29.0	84.4	55.5	5.7
Mean 10^{rd} days	34.4	29.2	85.2	54.2	6.2

2.3 Experimental design and treatments

Experimental design was completely randomized block design with four replicates at both growing seasons (Fig. 2). The treatments were: common open field cultivation (control) (T1), aluminum silicate foliar spray (T2), shaded tunnel by net cover (with 35% shading level) (T3), top white plastic sheet (T4), misting without cover (T5) and misting under net cover with 35% shading level (T6), as shown in Fig 3. Natural Kaolin with 90% aluminum silicate (T2) was purchased from Al-Ahram Company. The plants were sprayed (2 gm/L) three times starting from two weeks after sowing with 10 days intervals. The soils of all treatments were mulched by white plastic cover; however, the control soil was left without cover.

Cucumber seeds (*Cucumis sativus,* L.) were sown on 15th June in the first season and on 20th June in the second one. The experiments were repeated in two seasons of 2020 and 2021 for confirming the getting results. The experiments were finished on 26th August and 6th September for the first and second season, respectively. Cucumber seeds were sown in raised beds with 1.0 m width and 10 m length. Every bed had one line of plants, with 0.50 m plant spacing. One empty bed was left between the treatments to avoid the interactions. One water tube (16 mm inner diameter) with misting nozzles every two meters was placed 25 cm below the tunnel roof.

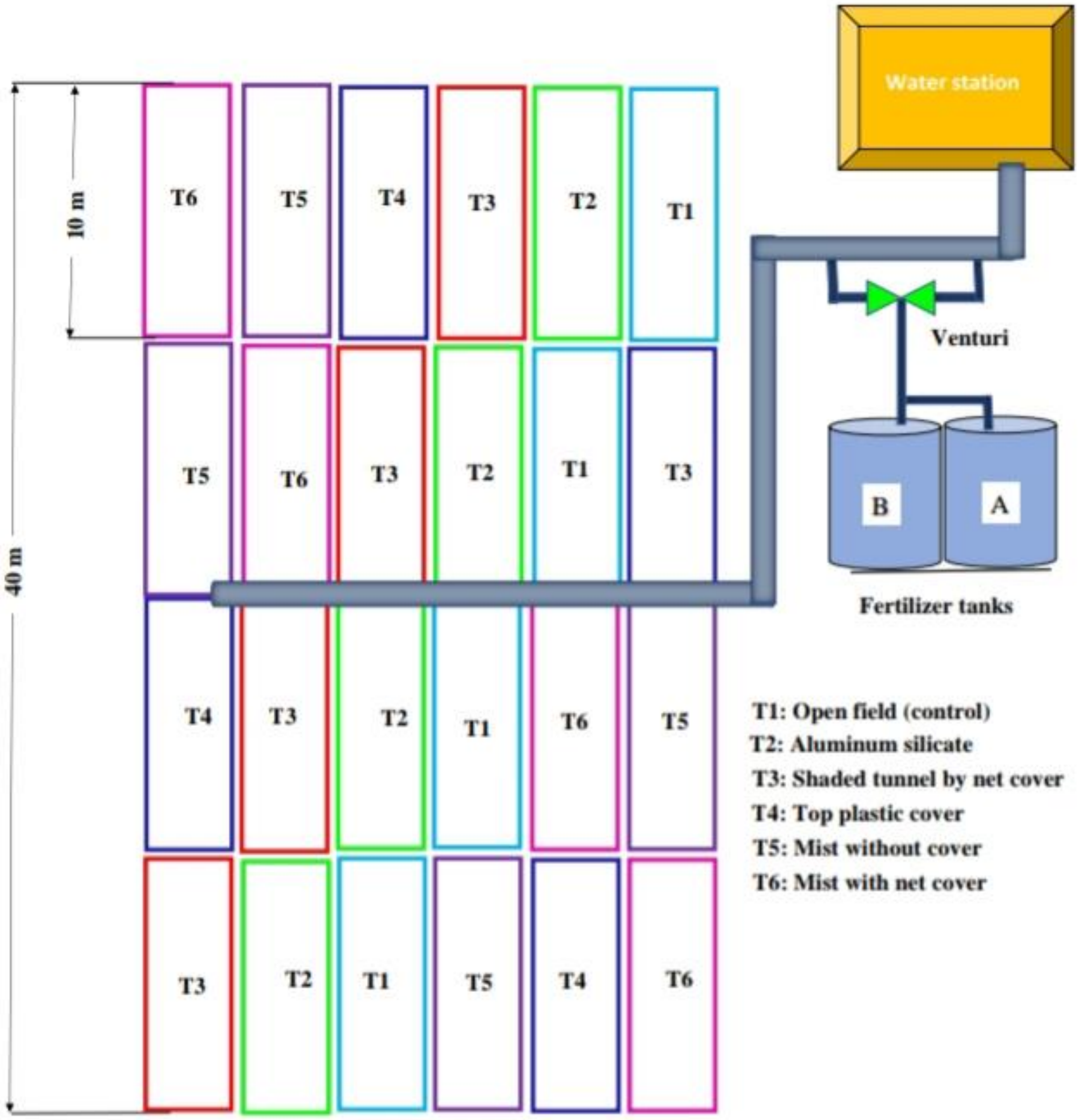


Fig. 2. A schematic diagram of the treatments showing dimensions and the experimental design.

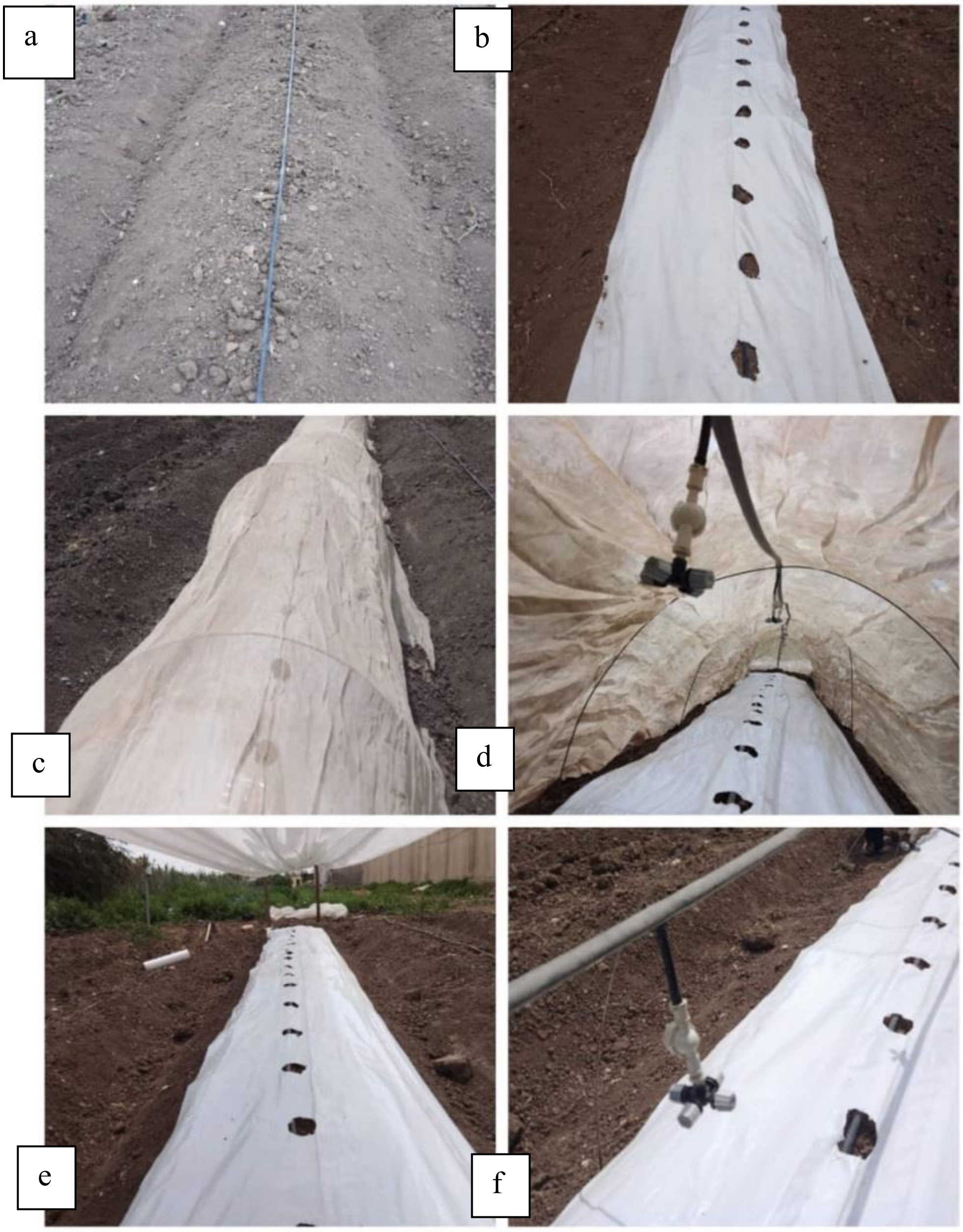


Fig. 3. Cultivation techniques, (a) common practice in open field (control), (b) soil mulch with white plastic, (c) shading by net cover, (d) mist under net cover, (e) top white plastic sheet, and (f) mist without cover.

2.4 Irrigation and fertigation systems

The irrigation system consisted of a single drip lateral of 16 mm diameter with GR emitters spaced at 50 cm were used in the center of each bed to irrigate one line of cucumber plants. Before planting, all plots were irrigated to ensure salt leaching and proper moisture in the field for seed germination. From the first week of the growing season until the last, the plants were given water daily and fertilized with the necessary nutrient concentration levels via a drip irrigation system equipped with a venture injector. Irrigation, fertigation, and other horticultural procedures were implemented in accordance to the guidelines of the Egyptian Ministry of

Agriculture and Land Reclamation. The application doses of N, P_2O_5 and K_2O were 100, 100, 200 kg/ha, respectively. Commercial fertilizers of ALSAFWA FERT (20-20-20), ALSAFWA SAIF (0-0-45, as potassium citrate), ALSAFWA phosphoric acid 85%, and calcium super phosphate (45% P_2O_5) were applied as sources for N, P, K and Ca. In addition, the fertilization program was supported by water soluble calcium nitrate and magnesium nitrate were used as sources for calcium, nitrogen and magnesium, respectively. The other micronutrients were obtained from a mixture of micronutrients (ALSAFWA MULTI-ELEMENTS) and foliar sprayed every two weeks. Two third of the recommended phosphorous dose was applied as calcium super phosphate during soil preparation before sowing and the remaining portion was obtained from phosphoric acid during growing season. The other water-soluble nutrients were applied via drip irrigation system twice a week.

2.5 Data recorded

2.5.1 Vegetative growth

Vegetative traits such as plant height (cm) and leaf area per plant (dm^2) were measured on three randomly selected plants from each experimental unit at 35, 45, and 55 days after sowing (DAS). The leaf area meter (modelLI-3000A, Lincoln, NE, USA) was used to measure the area of plant leaves.

2.5.2 Chlorophyll content

A SPAD 501 leaf chlorophyll meter (Minolta, Co., Ltd., Japan) was used to measure the chlorophyll content (total green color). At random, the fifth leaf through the growing top was selected from each experimental unit at 35, 45, and 55 DAS from five plants according to the method described by **Coste et al. (2010).**

2.5.3 Plant nutrient content

To determine the mineral composition, the samples of leaves were collected and dried at 70 ºC until the constant weight. The nitrogen, phosphorus, and potassium contents were measured in digested leaves using sulphoric acid and hydrogen peroxide method. Nitrogen was measured by the micro-Kjeldahle method (UDK 159, Velp Scientifica, Usmate, Italy). Phosphorus was measured at 650 µm using a spectrophotometer (Libra S80PC, Biochrom, Cambridge, UK). Potassium was determined by a flame photometer using an inductively coupled plasma-optical emission spectrometry (ICP- OES) apparatus (Prodigy 7, Leeman Labs., Hudson, NH, USA). N, P, and K were determined according to the described methods by **Sparks et al. (1996)** in dry leaf tissues after digesting with sulfuric acid and hydrogen peroxide. N was determined by micro-Kjeldahl method, P by a spectrophotometer and K by flame photometer PFP7 (Jenway). The measurements were carried out at the Central Laboratory of Environmental Studies (Accredited according to ISO/17025), Kafrelsheikh University, Egypt.

2.5.4 Fruit yield and quality

All plots were harvested starting from the 24^{th} of July in 2020 season and 3^{rd} of August in 2021 season. Ten fruits were picked from every plot during the peak of the yield and used to determine fruit quality including average fruit weight (g), fruit length (cm), fruit diameter (cm), fruit firmness, and total soluble solids (TSS %). Fruit firmness (g/cm^2) was measured by a hand penetrometer (2 mm) on the opposite cheeks at the center of each fruit. However, fruits TSS % was measured in fruit juice using a hand refractometer. Early, marketable, unmarketable, and total fruit yields for every plot were estimated for all harvested fruits. The early yield was determined as a sum of the first 10 pickings. The total yield is expressed as the weight of all obtained fruits. until the end of the season. Unmarketable yield comprised of malformed, diseased, and pest-infected fruits.

2.6 Statistical analyses

All the obtained data of the investigated study from both growing seasons were statistically analyzed using the "M-STAT" computer software package (version 5.4) and the means were compared by Duncan's multiple range test**.**

3. Results

3.1 Vegetative growth

The obtained results for plant length, number of leaves per plant, and leaves area of cucumber gradually increased by increasing plant age until 55 days after sowing (Tables 2 and 3). These growth characters were significantly higher when the plants were grown under covered tunnel by shading net with mist application (T6) compared to the control (without protection, T1) and the other protection methods (aluminum silicate foliar spray (T2), shaded tunnel by net cover (T3), top white plastic cover (T4) and misting without cover (T5). However, open-field cultivation (T1) had the lowest values and the other protection methods had intermediate values. These results were true at all sampling dates (35, 45, and 55 DAS) of both growing seasons. It was noticed that T6 significantly increased plant length from 104.75 - 81.83 cm with the open to field 125.25 -133.33 cm in the first and second seasons, respectively at 55 DAS. Moreover, it increased leaves number from 66.57 - 68.25 to 97.00 - 100.42. Furthermore, the increase in plant leaf area was from 104.75 with the control (T1) to 133.33 cm^2 at 55 DAS in 2020 season and from 66.57 to 100.42 cm^2 in 2021 season. In the case of number of branches per plant, T6 also had the highest significant values (Table 4). However, the other studied protection techniques did not significantly differ among themselves and had lower values.

Table 2. Effect of some protection techniques from heat stress on plant length and number of leaves of cucumber grown during the late summer seasons of 2020 and 2021 seasons.

Treatments	Plant length (cm)			Number of leaves / plants		
	Days after sowing					
	35	45	55	35	45	55
				2020		
T1	35.91 c	76.25 ab	104.75 b	14.08 c	36.25 b	66.57 b
T2	40.74 bc	75.00 ab	115.00 ab	17.33 b	43.50 b	76.25 ab
T3	47.58 b	69.25 b	103.92 b	18.30 b	42.50 b	80.75 ab
T4	42.64 bc	73.75 ab	105.50 b	14.33 c	40.00 b	78.67 ab
T5	40.33 c	85.00 a	103.75 b	17.08 b	40.00 b	73.75 b
T6	57.58 a	86.25 a	125.25 a	22.67 a	62.50 a	97.00 a
F- test	**	*	*	**	**	**
				2021		
T1	36.58 c	68.33 c	81.83 b	13.42 b	31.50 b	68.25 b
T2	40.34 bc	67.75 c	92.92 b	13.33 b	31.58 b	70.00 b
T3	47.67 b	96.08 b	119.58 a	14.58 b	32.67 b	67.17 b
T4	42.67 bc	78.00 c	98.00 b	12.42 b	32.58 b	71.00 b
T5	38.92 c	77.75 c	93.09 b	13.76 b	31.67 b	70.58 b
T6	59.00 a	114.17 a	133.33 a	18.50 a	52.42 a	100.42 a
F- test	**	**	**	*	**	*

(T1) open field (control), (T2) aluminum silicate foliar spray, (T3) shaded tunnel by net cover, (T4) top white plastic cover, (T5) misting without cover, and (T6) misting under net cover. As determined by Duncan's test, different letters in the same column represent significant variations between each treatment group. * and** indicate significant at p values ≤ 0.05, ≤ 0.01; respectively.

Table 3. Effect of some protection techniques from heat stress on plant leaf area of cucumber grown during the late summer seasons of 2020 and 2021 seasons.

Treatments	Leaves area (cm^2)					
	2020			**2021**		
	Days after sowing					
	35	**45**	**55**	**35**	**45**	**55**
T1	64.77 ab	166.92 d	307.9 c	127.60 c	305.02 c	653.11 c
T2	78.07 bc	198.01 d	343.46 c	213.98 c	324.76 c	691.45 c
T3	98.57 a	232.68 ab	436.94 a	147.57 a	297.56 b	660.99 ab
T4	69.14 b	193.11 bc	378.41ab	134.66 bc	306.81 b	667.06 b
T5	76.19 b	176.51 cd	329.36 bc	145.42 bc	318.30 bc	730.88 bc
T6	129.6 a	355.93 a	556.73 a	213.98 a	324.60 a	1119.46 a
F- test	**	**	**	**	**	**

(T1) open field (control), (T2) aluminum silicate foliar spray, (T3) shaded tunnel by net cover, (T4) top white plastic cover, (T5) misting without cover, and (T6) misting under net cover. Different letters in the exact same column represent significant variations between each treatment group, as determined by Duncan's test. ** indicate significant at p values ≤ 0.01.

3.2 Chlorophyll content

It was noticed that the plant leaves under the shaded tunnel with mist application were darker than those in the other treatments indicating that their SPAD values were higher (Table 4). These differences were significant in both growing however, the other protection systems did not significantly differ from the unprotected control and in-between. In the case of the number of plant branches, the use of soil and covering the tunnel by net cover with mist application had the highest significant values (Table 4). Whereas there was no substantial distinction between the unprotected control treatment and the various protected methods.

Table 4. Effect of some protection techniques from heat stress on the number of branches and leaf chlorophyll content of cucumber plants grown during the late summer seasons of 2020 and 2021.

Treatments	Number of branches/plant			Chlorophyll content (SPAD)		
	Days after sowing					
	35	45	55	35	45	55
				2020		
T1	3.58 b	4.33 b	6.00 b	28.72 b	32.75 b	30.40 b
T2	3.67 b	5.50 b	7.83 b	31.43 ab	30.48 b	31.75 b
T3	3.59 b	4.58 b	7.00 b	32.50 ab	30.78 b	28.65 b
T4	3.33 b	4.75 b	7.28 b	33.25 ab	33.23 b	29.33 b
T5	3.33 b	5.08 b	5.92 b	29.60 b	30.28 b	31.43 b
T6	5.83 a	7.25 a	10.8 a	38.78 a	40.90 a	36.60 a
F- test	**	**	**	**	*	*
				2021		
T1	2.08 b	3.25 c	5.42 b	32.60 b	31.67 c	31.24 b
T2	2.50 b	4.00 bc	6.50 b	38.63 ab	35.87 ab	31.63 b
T3	2.58 b	4.17 b	5.75 b	32.69 b	34.21 b	32.24 b
T4	2.17 b	3.67 bc	5.80 b	39.41ab	34.93 b	31.34 b
T5	2.42 b	4.42 b	7.00 b	37.75 ab	34.71 b	30.16 b
T6	3.42 a	6.00 a	8.92 a	44.08 a	37.88 a	39.44 a
F- test	*	**	**	*	*	**

(T1) open field (control), (T2) aluminum silicate foliar spray, (T3) shaded tunnel by net cover, (T4) top white plastic cover, (T5) misting without cover, and (T6) misting under net cover. Different letters in the exact same column represent significant variations between each treatment group, as determined by Duncan's test. * and ** indicate significant at p values ≤ 0.05, ≤ 0.01; respectively.

3.3 *Plant nutrient content*

All studied protection techniques significantly affected the leaf content of N, P, and K (Table 5). The mist under the net-cover tunnel (T6) achieved the highest values compared to the control (T1) and the other protection techniques. The leaves of unprotected plants (control) had the lowest contents of N, P, and K. However, the control did not significantly differ from the application of aluminum silicate as foliar spray (T2), shaded tunnel by net cover (T3), top white plastic cover (T4), misting without cover (T5) in the case of N and K contents. Whereas in the case of P content, the mist under net-cover tunnel (T6) had the highest values compared to the lowest ones in the control (T1) and the other protected techniques had intermediate values.

Table 5. Effect of some protection techniques from heat stress on N, P, and K contents of cucumber leaf during the late summer seasons of 2020 and 2021.

Treatments	Macro elements (% dry weight.)					
	2020 season			**2021 season**		
	N	**P**	**K**	**N**	**P**	**K**
T1	3.34 b	0.35 c	3.38 b	3.68 b	0.42 bc	3.30 b
T2	3.30 b	0.53 b	3.78 b	3.62 b	0.45 bc	3.45 b
T3	3.70 ab	0.55 b	3.72 b	3.74 b	0.48 ab	3.41 b
T4	3.45 b	0.57 b	3.56 b	3.71 b	0.53 a	3.38 b
T5	3.55 b	0.59 ab	3.79 b	3.59 b	0.39 c	3.28 b
T6	3.97 a	0.71 a	4.84 a	4.35 a	0.55 a	4.17 a
F- test	*	**	**	*	**	*

(T1) open field (control), (T2) aluminum silicate foliar spray, (T3) shaded tunnel by net cover, (T4) top white plastic cover, (T5) misting without cover, and (T6) misting under net cover. As determined by Duncan's test, different letters in the same column represent significant variations between each treatment group. * and ** indicate significant at p values ≤ 0.05, ≤ 0.01; respectively.

3.4 flowering

As a sensitive indicator for heat stress, the numbers of male and female flowers were considered as shown in Table 6. The highest mean number of female flowers (38.75-48.50, 32.75-48.25 and 33.25-44.75 per plant in 2020 and 2021, respectively) were recorded inside the net tunnel with cooling by mist treatment and white plastic soil mulch after 35, 45, and 55 days of sowing followed by white plastic cover with white plastic soil mulch (19.50-25.5, 21.50-24.5 and 24.50-23.5 female flower/ per plant). The lowest numbers of female flowers (10.25-23.75, 12.75-10.25, and 10.00-12.00 per plant) were produced from the grown plants in the open field without any protection from the high temperature (control) as shown in Table 6.

For the number of male flowers, there were no statistically significant differences among the treatments under investigation (Table 6).

Table 6. Effect of some protection techniques from heat stress on numbers of female and male flowers of cucumber plant during the late summer seasons of 2020 and 2021.

Treatments	Number of female flowers			Number of male flowers		
	Days after sowing					
	35	**45**	**55**	**35**	**45**	**55**
			2020			
T1	10.25 c	12.75 b	10.00 b	19.00	22.50	25.00
T2	17.75 bc	21.75 b	22.75 ab	16.50	18.75	29.25
T3	18.00 bc	18.25 b	17.75 ab	18.75	29.50	33.50
T4	19.50 b	21.50 b	24.50 ab	16.25	19.25	21.00
T5	15.00 bc	21.25 b	20.50 ab	14.75	13.75	18.75
T6	38.75 a	32.75 a	33.25 a	20.50	17.75	18.25
F- test	**	*	*	N.S.	N.S.	N.S.
			2021			
T1	12.75 c	10.25 c	12.00 d	21.50	15.50	29.50 ab
T2	20.75 bc	23.50 bc	31.25 b	16.25	20.50	22.75 ab
T3	22.75 bc	30.50 ab	20.00 c	15.50	26.25	33.00 a
T4	25.50 b	24.50 bc	23.50 bc	15.50	18.00	24.75 ab
T5	19.25 bc	35.00 ab	29.75 b	15.75	14.25	14.50 c
T6	48.50 a	48.25 a	4475 a	15.25	17.25	19.00 bc
F- test	**	**	**	N.S.	N.S.	N.S.

(T1) open field (control), (T2) aluminum silicate foliar spray, (T3) shaded tunnel by net cover, (T4) top white plastic cover, (T5) misting without cover and (T6) misting under net cover. As determined by Duncan's test, different letters in the same column represent significant variations between each treatment group. NS, * and **, indicate non-significant, or significant at p values ≤ 0.05, ≤ 0.01; respectively.

3.5 Fruit yield and quality

The studied protection techniques significantly affected fruit quality parameters (average fruit weight, average fruit length, average Fruit diameter fruit firmness and total soluble solids) as shown in Table 7. It was noticed that average fruit weight had the same trend as average fruit length. In this concern, the tunnel with shaded cover and misting system (T6) followed by misting system only without cover (T5) increased fruit weight, length, and firmness over the control (T1) and all other techniques. The unprotected cultivation (T1) did not significantly differ from foliar spray with aluminum silicate (T2) producing the lowest values. Whereas the different protection techniques had intermediate values (Table 7). Regarding average fruit diameter, all protection techniques (without significant differences in between) were higher than the open field cultivation without protection (Table 7). The fruit content of total soluble solids was significantly higher with aluminum silicate foliar spray (T2), misting system without cover (T5), and tunnel with shaded net and misting system inside, without any significant differences in-between. However, the top plastic white cover did not significantly differ from the open field cultivation producing the lowest values. These results are true for both growing seasons (Table 7).

Table 7. Effect of some protected cultivation techniques on fruit quality of cucumber plant during the late summer seasons of 2020 and 2021.

Treatments	**Average fruit weight (g)**	**Fruit length (cm)**	**Fruit diameter (cm)**	**Fruit firmness (g/cm^2)**	**Total soluble solids (TSS %)**
			2020		
T1	65.35 c	11.04 d	2.30 b	3.35 c	3.20 b
T2	66.58 c	12.36 cd	2.63 a	3.43 c	4.50 a
T3	75.15 bc	13.45 bc	2.75 a	3.48 bc	3.77 ab
T4	66.75 c	12.85 c	2.62 a	3.53 bc	3.40 b
T5	77.01 bc	14.50 ab	2.82 a	3.90 ab	3.75 ab
T6	87.73 a	14.95 a	2.94 a	4.08 a	4.25 a
F- test	**	**	**	*	*
			2021		
T1	67.34 c	11.54 d	2.55 b	3.55 c	3.21c
T2	68.69 c	12.86 cd	2.88 a	3.63 c	4.61a
T3	77.26 bc	13.95 bc	3.01 a	3.68 bc	3.80 bc
T4	68.86 c	13.35 c	2.89 a	3.73 bc	3.62 c
T5	79.11 bc	15.00 ab	3.07 a	4.10 ab	3.98 ab
T6	89.84 a	15.45 a	3.19 a	4.28 a	4.49 ab
F- test	**	**	**	*	**

(T1) open field (control), (T2) aluminum silicate foliar spray, (T3) shaded tunnel by net cover, (T4) top white plastic cover, (T5) misting without cover and (T6) misting under net cover. As determined by Duncan's test, different letters in the same column represent significant variations between each treatment group. * and ** indicate significant at p values ≤ 0.05, ≤ 0.01; respectively.

As shown in Fig. 4, the total and marketable fruits number per plant and square meter are significantly affected by the studied protection techniques. Misting under net cover treatment (T6) increase had the highest numbers of total and marketable fruits per plant and m^{-2}. T6 increased the marketable number of fruits from 4.35 fruits per plant with the control (T1) to 5.49 fruits and from 14.49 to 18.28 fruits per m^{-2} in 2020. Moreover, T6 increased the total fruits number from 25.07 to 29.41 fruits per m^{-2}.

Regarding total fruit weight, Fig. 5 illustrates that the highest significant values (3.153 and 1.880 kg m^{-2}) were achieved from the grown plant under the shaded tunnel with misting system with 2.27 and 1.61 kg of marketable fruits compared to the grown plants under the open field conditions without any protection from heat stress which recorded 1.901 and 1.120 kg m^{-2} as total yield and 1.180 and 0.761 kg m^{-2} as marketable yield in the first and second season, respectively. However, the other protection techniques had intermediate values. The data illustrate total and marketable fruit yields that were significantly increased by 60.29% and 51.98%, respectively in 2020 and with 59.57% and 47.20 % in 2021 compared to unprotected plants.

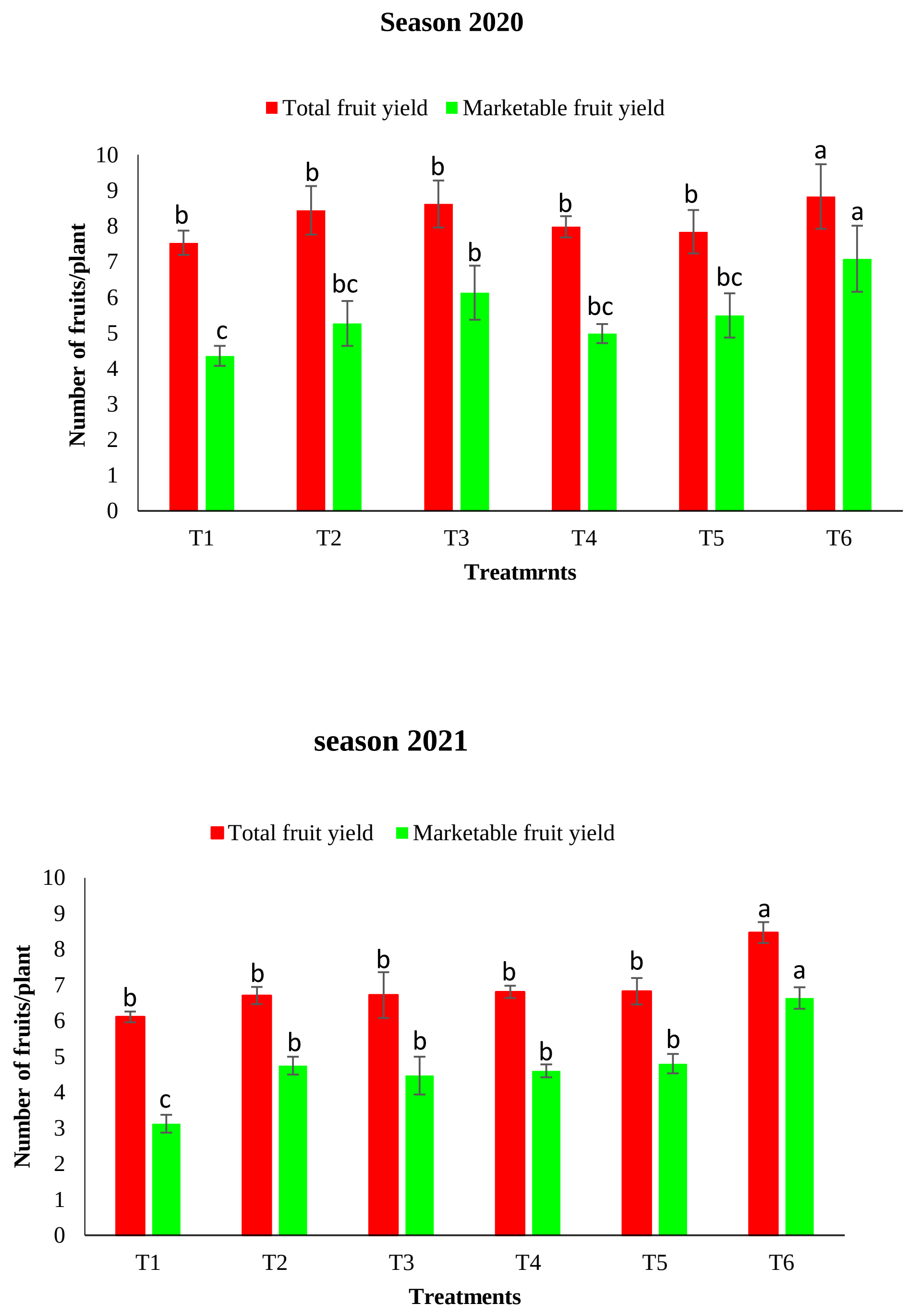
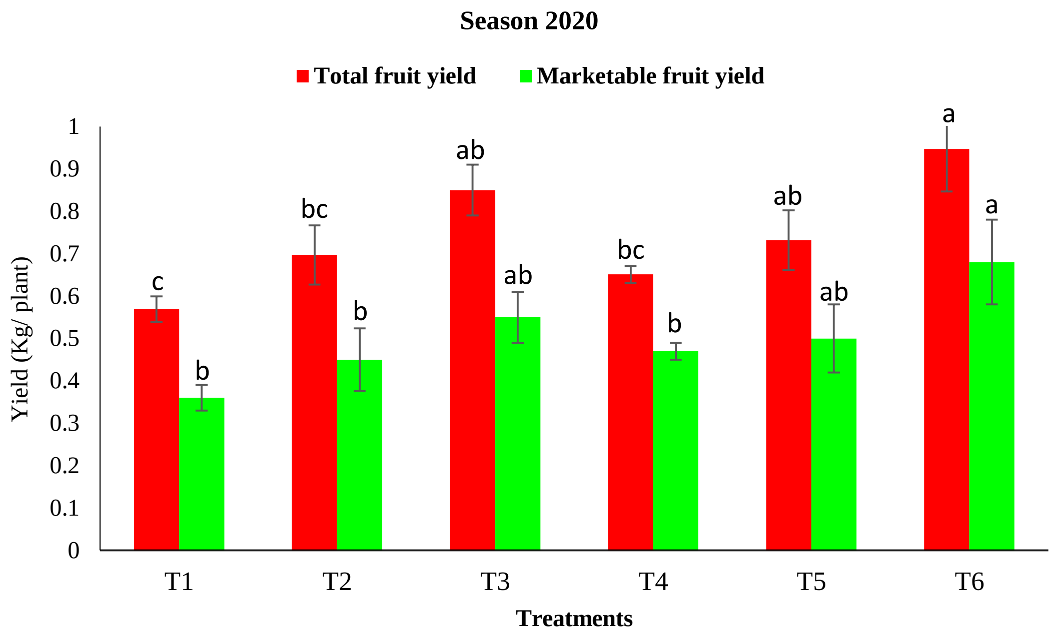
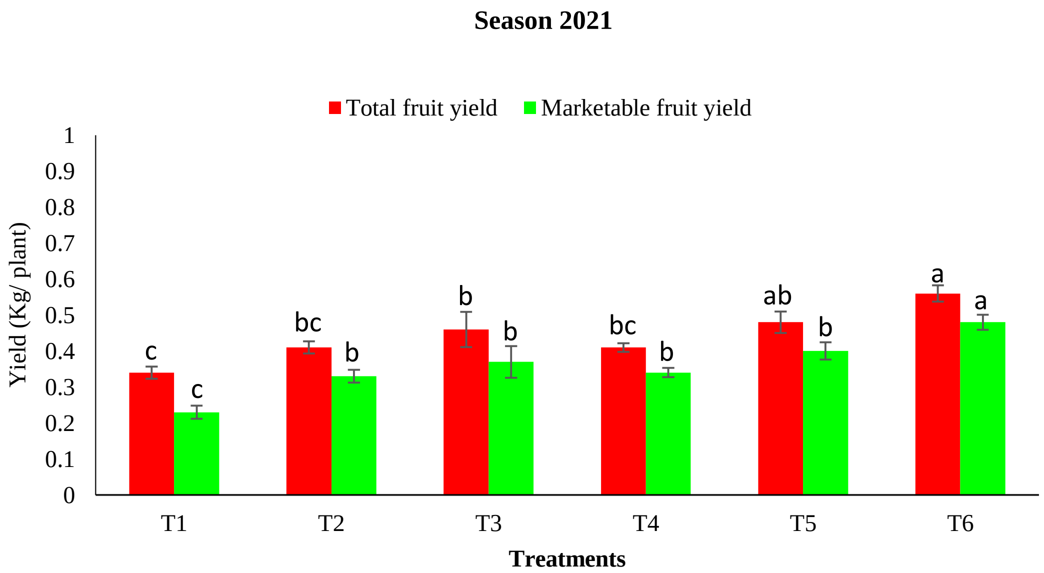
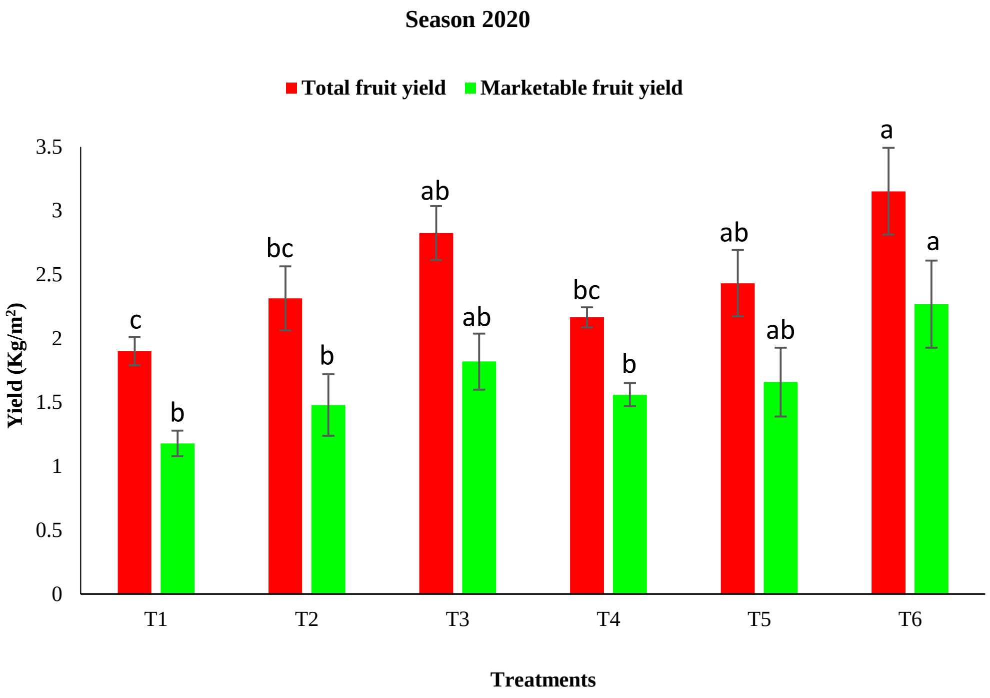


Fig. 4. Effect of some protected cultivation techniques on number of total and marketable fruits per cucumber plant grown during the late summer seasons of 2020 and 2021.

(T1) open field (control), (T2) aluminum silicate foliar spray, (T3) shaded tunnel by net cover, (T4) top white plastic cover, (T5) misting without cover and (T6) misting under net cover. Different letters in the same column indicate significant differences among each group of treatments according to Duncan's test at $p \leq 0.05$.


Season 2020
Total fruit yield
Marketable fruit yield
Yield (Kg/ plant)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
c
b
bc
b
ab
ab
bc
b
ab
ab
a
a
T1
T2
T3
T4
T5
T6
Treatments


Season 2021
Total fruit yield
Marketable fruit yield
Yield (Kg/ plant)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
c
c
bc
b
b
b
bc
b
ab
b
a
a
T1
T2
T3
T4
T5
T6
Treatments



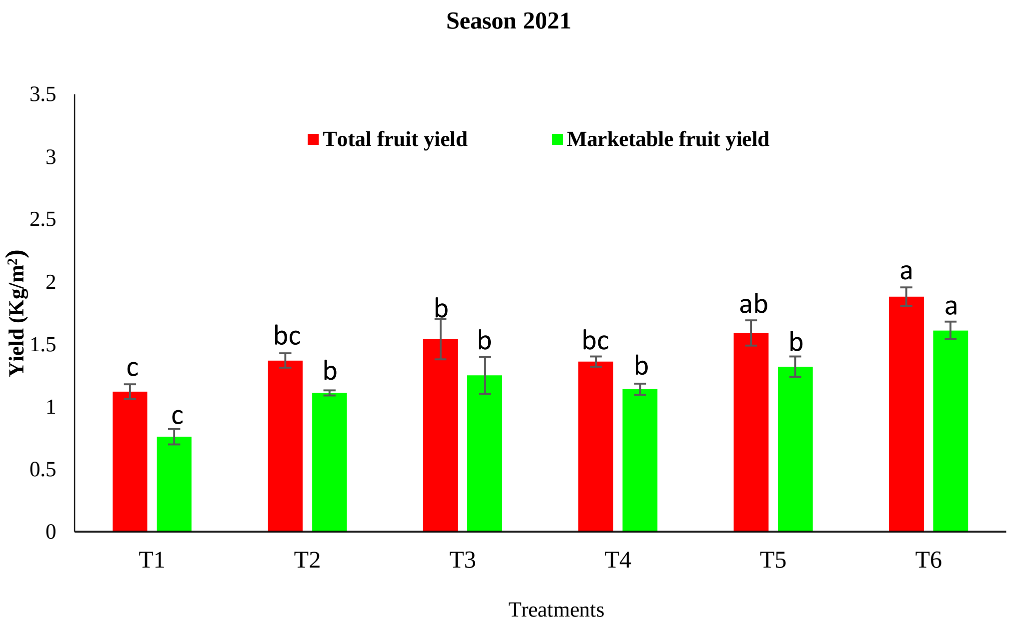
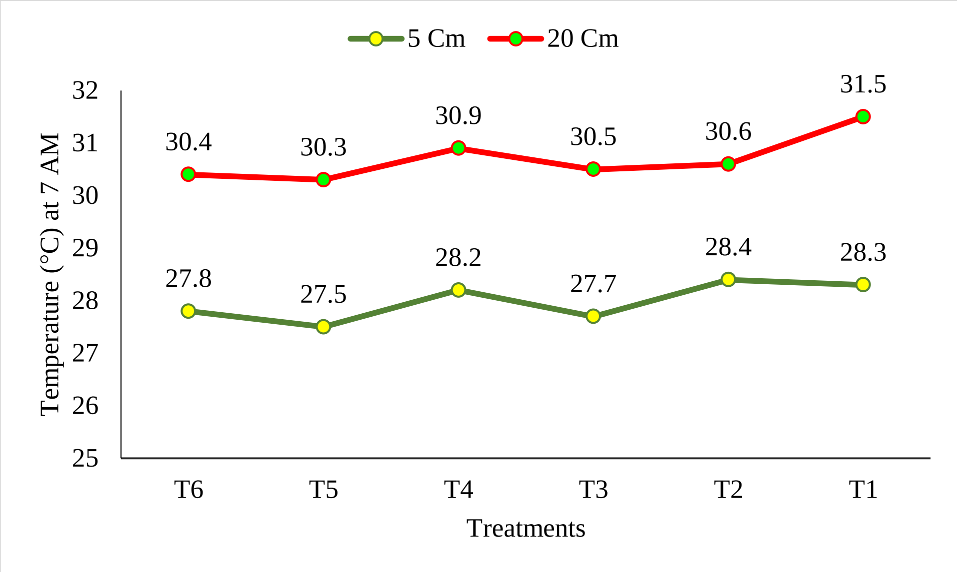


Fig. 5. Effect of some protected cultivation techniques on total and marketable fruits yields of cucumber plant grown during the late summer seasons of 2020 and 2021.

(T1) untreated open field (control), (T2) aluminum silicate, (T3) shaded tunnel by net cover, (T4) top white plastic cover, (T5) mist without cover, and (T6) mist under net cover. Different letters in the same column indicate significant differences among each group of treatments according to Duncan's test at $p \leq 0.05$.

3.6. Soil temperature

To study the effect of the investigated treatments in modifying the microclimate around the roots, the soil temperature was recorded at two depths of 5 and 20 cm and at different times 7 AM and 2 PM during the peak blooming and fruit set stage of the season on 24 July. As shown (Fig. 6), the investigated treatments modified the microclimate around the roots compared to the open field cultivation. It was observed that misting without cover or misting under net cover modified the temperature in both studied levels of the soil at 5 and 20 cm and during both recorded times at 7 AM and 2 PM (Fig. 6).



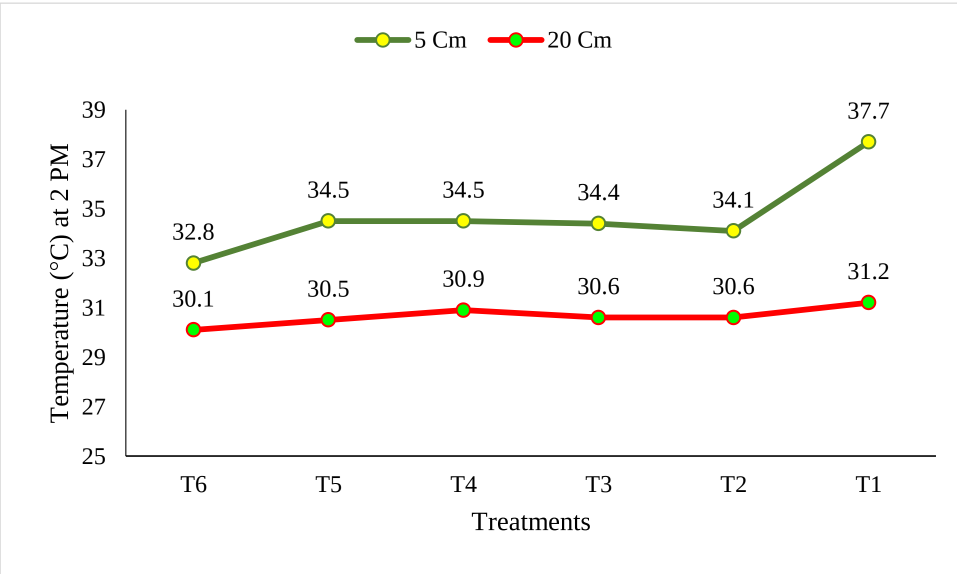


Fig. 6. Soil temperature changes at 7 AM (upper figure) and 2 PM (lower figure) at 5 and 20 cm from the soil surface on 24 July 2021 registered in (T1) open field (control), (T2) foliar spray with aluminum silicate, (T3) shaded tunnel by net cover, (T4) top white plastic cover, (T5) mist without cover, and (T6) mist under net cover.

4. Discussion

In the current study, we attempted to offer several remedies for the decline in cucumber growth, productivity, and quality that occur in the late summer growing season due to biotic and abiotic stresses, especially as a result of climate change. It is anticipated that global warming will have an impact on agricultural output in the next years **(Khan et al., 2018)**. Heat stress could be the direct reason for increasing water loss for the plant and the soil causing a bad salinity effect for the plant. In addition to the problems of water loss and salinity, disturbed absorption, photosynthetic reduction, and oxidative stress, all contribute to lowering plant production and quality **(Khan et al., 2020; Taha et al., 2020; Sharaf-Eldin et al., 2022)**. These conditions, in which the plants are subject to multiple stresses, are typical in the summer in an arid or semi-arid area close to the seacoast. In addition to biotic stress caused by diseases and insects, abiotic stress from heat and salinity typically occurs in the experiment site **(Saffan et al., 2024)**. As for, combined stresses have more attention nowadays instead of individual stress investigation **(Awwad et al., 2022)**. The negative effects of heat stress on plants may be exacerbated by increased soil salt. In this concern, **Shalaby et al. (2021)** indicated that the combined stress of salinity and heat stress strongly affected cucumber plant which decreased plant growth, photosynthetic rate, the activity of enzymatic antioxidants, fruit yield and quality, and economic efficiency of growing under these conditions. Moreover, **dos Santos et al. (2022)** indicated that the plant's ability to absorb water and nutrients was disrupted, and its physiological and biochemical characteristics quickly deteriorated when it was grown on saline soil in conditions of extremely high temperatures. In the current experiment, it was proved that the combined stress of heat and soil salinity had significant effects on plant growth, leaf area, chlorophyll content, nutrients content, flowering and fruit production and quality.

Since protected agriculture is the most significant farming method for preventing pest attacks and unfavorable climate changes, it improves the productivity and quality of the products (**Sharaf-Eldin et al., 2023 a)**. Greenhouses provide the best way of dealing with these issues, but they are inappropriate for small farmers and developing nations due to their high technological and financial requirements. In comparison to greenhouses, low- and high-tunnels offer an inexpensive alternative without requiring sophisticated technologies; however, strategies for agricultural production need to be developed to consider the varying abilities of farmers and optimize the use of available resources (**Sharaf-Eldin et al., 2023 b)**.

The current findings of this study show that all studied protection strategies successfully reduced the soil temperature inside the investigated low tunnels compared to the open field without any protection method, particularly at 2 PM when daytime heat peaks **(Fig. 6)**. As expected, the low tunnel with shaded or both shaded and misting applications had lower temperature than the non-shaded tunnel or control. Thus, the mean air and soil temperatures were greater in the non-shaded plots as reported by **Laur et al. (2021)**. Shading is a common practice to ameliorate plant microclimate in the late summer season by lessening both of temperature and transpiration rates of plant leaves, consequently mitigating the heat stress impacts **(Aberkani et al., 2008**). In this manner, **Masabni et al. (2016)** indicated that utilizing shade net (50% and 70%) for tomato and pepper production decreased air and soil temperatures compared to unshaded tunnels (control), resulting in increasing soil moisture levels and reduced evaporation rates. This is consistent with the results of the current investigation, which show that, as shown in Fig. 6, the shaded tunnel had noticeably greater soil moisture levels and noticeably lower soil temperatures. However, misting under net cover was the most succeeded treatment which it reduced soil temperature by about 5 °C, compared to the control. In addition, the soil temperature was slightly lower in the other treatments under investigation than in the control. These results are corroborated by the outcomes of **Montero (2006), Laur et al. (2021),** and **Sharaf-Eldin et al. (2023 b)**, who reported that the misting undercover was more effective than the only shading cover for modifying the microclimate around the plants under the hot summer regions. Misting increased the levels of both soil moisture and leaf wetness compared to without misting, after the misting, leaf moisture amounts kept higher which probably resulted in more soil moisture levels in the misting plots. In this concern, some researchers have found that misting under a shade net significantly decreased air and soil temperatures compared to shaded plots alone by net cover (**Willits and Peet, 1994**). As a result of the current work, the tunnel with mist under net cover (shading) produced the highest cucumber growth and yield. These increments may be due to the positive combined role of both shading and misting under the tunnel conditions. Likewise, **Abdel-Ghany et al. (2012)** indicated that while the shading technique lowers solar radiation, it also lowers the photosynthetic process, which is crucial for the growth of cucumber plants. It might be the cause of the shaded tunnel's solely slower growth and lower yield compared to the modified tunnel with cooling techniques by misting under the shading technique. In this manner, the positive findings of this study may be connected to the effective misting technique under the net-covered tunnel to raise air humidity surrounding the plant to the appropriate range. The favorable effects of the combined treatment (shading and misting) under tunnel conditions on vegetative growth traits and chlorophyll content of cucumbers as well as total yields may be due to their synergistic effects on mitigating the heat stress in the late summer season. It was reported that the fogging system is successfully used in plant production of arid regions

(Handarto et al., 2005). Furthermore, severe insect infestations are a critical factor facing the survival production during the late summer season in the arid zone which can cause direct plant damage or can transfer the virus to the plant. The use of an anti-virus net-proof cover was reported as a safe effective solution for plant protection during this season. In addition, it decreases heat stress for the plant through the partial shading effect **(Sharaf-Eldin (2015)**. The misting technique added benefit to the net-cover tunnel which can be a reason for the good outcomes. The mist under the net-cover tunnel (T6) achieved the highest values of macro elements (N, P, and K) compared to the control treatment (T1) and the other protection techniques in both seasons. Macro element levels in cucumber leaves were significantly higher with the combined application of shading and misting techniques (T6), suggesting nutrient uptakes were improved under the microclimate which resulted due to these combined techniques in the tunnels.

Thus, soil wetness levels were greater in plots subjected to T6 (mist with shade), plant nutrient uptake was increased. Misting application did interact with shade treatment affected nutrients level in cucumbers, so, there were obvious shading tendencies and misting acting a synergistically role in macro nutrients uptake by plants. In this line, **Laur et al. (2021)** stated that shading treatment increased the total uptakes of both phosphorus and potassium in lettuce, basil, and arugula plants under high tunnel productions. They also cleared that Shading increased nutrient level for most macro and micro elements in the three vegetable crops. The influence of shade and mist techniques on elements accumulation was due to the reduction in heat stress performed in the season. Others have reported that increment in foliar elements for crops grown under shade cloth as well (**Gent, 2017; Díaz-Pérez, 2013**). They reported that under shade cloth, the temperatures of the soil and air tend to be lower. It's been suggested that a rise in leaf chlorophyll may be the cause of the increase in N under shaded conditions. (**De Groot et al., 2002**). By decreasing air temperatures, shading may lessen heat stress in plants, tolerating for increased elements uptake (**Díaz-Pérez, 2013**). So, the superior effect of T6 application (shading and misting) may be due to their favorable impacts on mitigating heat stress challenge occurred in late summer season on cucumber plants. That superiority led to produce the largest leaf area (Table, 3), highest chlorophyll content (Table, 4), highest uptake of macro elements (Table, 5), and highest number of female flowers (Table, 6). All those appropriate impacts resulted from the mitigating high temperature challenge by most of protected cultivation techniques under low tunnels specially use of both shading and misting which significantly produced the highest cucumber productivity (Figs, 4 & 5).

5. Conclusions

In hot and sunny regions, the ambient temperature and solar radiation intensity are extremely high; this makes the cultivation in the open field is difficult in summer. In this study, we developed inexpensive low tunnels that can be used as alternative agriculture structures in arid and semi-arid regions worldwide. So, for double tress of heat and soil salinity, applied cooling by mist inside low tunnels covered with net treatment seems suitable for reducing heat stress and enhancing cucumber production and quality.

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