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EFFECT OF THE SOLAR EVAPORATIVE COOLING AND REDUCING THE COVER PERMEABILITY ON THE PRODUCTION AND QUALITY OF GREENHOUSE CUCUMBER

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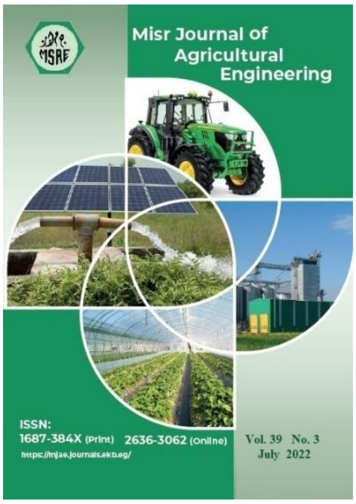

Keywords:
Solar Panel; Transmission coefficient; Evaporative cooling; Coating material; Cucumber; Productivity; Quality.

ABSTRACT

Climate change has become one of the most important factors affecting in agricultural production, the impact on our global food supply. We must expand our focus to avoid its effect on the crop's productivity. Environmental control inside greenhouse can be used to avoid the impact of different environmental changes. This work studies the effectiveness of greenhouse cooling by the solar energy -assisted evaporation concerted with painting its cover by influential coating material on the cucumber productivity and quality. To achieve this goal, the work was divided into two main experiments. The first one was the preliminary experiment; it was carried to choose the strong and effective parameters of treated coating materials which prevent the maximum value of solar radiation. The second one was the field experiment to validate the preliminary experiment integrated with solar-assisted evaporative cooling system for greenhouse cooling. The field experiment was done to assess both of the cucumber yield and quality under treated with control greenhouses. From the preliminary experiment, results showed that painting the cover using the selected material achieved the least transmission coefficient (0.59) and the lowest temperature (31.6 ^{o}C). Painting the greenhouse cover alongside evaporative cooling system which consumed 8.32 MJ day^{-1} attained from solar system (PV) decreased the temperature about 10 degrees. The yield increased by 11 %. The cucumber weight losses with control greenhouse increased by 21.6% compared with the treated greenhouse. This system can be applied to refrigerate most facilities with great efficiency to maximize the productivity and quality.

1. INTRODUCTION

Raised emissions generated from fuel combustion have given rise to excess in rate of carbon dioxide gas (CO_2) and another gas which resulted in increasing the earth's surface temperature since 1990 by ~ 1 °C. The average temperatures of earth's surface are predicted to rise by the end of the 21st century by 2.6–4.8 °C **Stocker et al. (2013).** Alterations in climate can challenge plant productivity in ways that impact the World capacity to sustain adequate food production for a growing and increasing population with shifting access to affordable and healthy food **Courtney et al. (2020**). An increase in intensity and/or period of drought in the late 21st century is predicted **Stocker et al. (2013)**. Changes in climate leads to increased incidence of extreme weather events and that poses a significant risk to future food production **Chen** et al. (**2015) and Tripathi et al. (2016).** The review literature abounds with results on the high importance of environmental control for vegetable production and quality **Youssef et al. (2018).** According to **Schonhof et al. (2007**), the integrated effect of controlled low radiation and inside air temperatures may have a useful impact on the yield quality. Although the high temperatures are useful on plant growth and production, temperatures higher than the optimum recommended thresholds have bad effects on plant growth, production and quality, which requires applying a cooling process **Youssef et al. (2018), Giri et al. (2017) and Liu et al. (2016).** More Studies were analyzed to comprehend the impacts of rising temperature on vegetable quantity and quality grade (the Flowering after exposure to temperatures higher than the recommended temperature for some days). The Study conclusion was that some vegetables may afford larger negative impacts on vegetable yield quality and production because of a hot climate **Bisbis et al. (2018).**

Moretti et al. (2010) reviewed the impact of changes in ambient temperature, (CO_2) and (O_3) on postharvest quality in vegetables, fruits and crops. Elevated temperatures can negatively affect several postharvest quality parameters. They affect flavor because of variations in sugar and acids ratio as well as oil content for the yield and fruit mechanical properties. Climate change would demand a great interest in focus in the applied systems (utilization of appropriate and advanced environmental controlled greenhouses) for the preservation from the effect of the bad climate. These efforts are made to increase the yield and enhance (or maintain) nutritional value **(Stocker et al. 2013).** A greenhouse is becoming an increasingly and a viable solution for modern methods of Vegetable production. Technological advances have avoided the effect of severe weather in warm climate conditions on the yield of greenhouse Vegetables. Greenhouse cooling is important to guarantee the appropriate range of humidity and temperatures **Marouen et al. (2019).** Greenhouse cultivation is necessary in a tropical climate to prevent plants from natural environmental damage, destruction from disease, and insects and pests. The agriculturist can also adjust environmental suitability for plants more easily **Mongkon et al. (2014)**. The reviews shows that the combination application of evaporative cooling, natural ventilation and shading has reduced greenhouse energy consumption and provided optimum indoor conditions required in warm climates to increase Vegetable yields in greenhouses. Hybrid cooling used systems must have an efficient control design to ensure the required humidity levels and temperature and distributions are kept in the greenhouse **Marouen et al. (2019).** Evaporative cooling system is one of the most efficient technologies in warm and dry regions for providing suitable greenhouse climatic conditions, which through evaporated water, the sensible heat converts to latent heat via evaporative cooling cellulose pads system **Kittas et al. (2013).** This technique raises the humidity inside greenhouse to the Suitable levels and decreases the indoor air temperature below the ambient air temperature. **Franco, Valera and Pe~na (2014))** investigated the water required for cooling greenhouses by evaporative cooling system. The study result showed that the consumption ranged between 1.8 and 2.6 $l\ h^{-1}\ m^{-2}\ ºC^{-1}$ of water at incoming airflow speeds between 1 and 1.5 $m\ s^{-1}$. The system utilized a centrifugal fan which caused the airflow. Several researchers have recommended that powering the fans using solar PV is an option to the requirements to minimize conventional energy consumption, although the capital cost can be high **Hartmann, et al. (2017).** The PV performance was assessed by **Lucas et al. (2017)**. An experimental study has been conducted using photovoltaic cells as an alternative for conventional energy and as an environmentally friendly source as well in order to produce energy and achieve heat dissipation in buildings. In warm regions, where the solar panel system is exposed to high temperatures around 40-70 ^{o}C, the maximum drop of energy generated can reach 22%. The electrical energy production efficiency from solar panels depends on solar irradiance and the ambient air temperature. So, cooling the solar panel increased the energy production efficiency about 12.62% for all the experiments performed, according to **Ruiz et al. (2020). Hassanien, Li, and Lin (2016)** reported that solar thermal and PV systems would be convenient options especially in desert areas for cooling greenhouses. The price reduction of PV module would make the PV power water pumping and PV greenhouse cooling systems more economical and efficient in the future. **Abu-Hamdeh and Almitani (2016)** designed a solar regenerated evaporative cooling system for greenhouses in Saudi Arabia. The inside air temperature was numerically simulated and experimentally validated. The study elucidated that the average daily temperatures lowered up to 6 ^{o}C using the desiccant evaporative cooling comparison of a normal evaporative cooling system. The reviews survey by **Ahmed et al. (2016)** showed that incorporating an evaporative cooling or normal ventilation with a shading method showed a significant impact on improving the microclimate inside greenhouse. This system subsequently decreases the water and energy consumptions and increases the yield quantity and its quality. In hot sunny regions, combining one of the cooling methods with a shading is able to conserve indoor air temperature lower than the outdoor temperature by 5–10 ◦C, increase the range of relative humidity about15–20% and decrease the solar radiation transmission by approximately 30–50% compared with a control greenhouse without treating. **Lee, Lee, Diop, and Na (2014**) studied the heat transfer coefficient of thermal screen with covering materials. The result showed that using two layers of covering material had 36% more isolation impact than a single layer covering. Greenhouse plastic covering with nets of different colors led to decreasing the sunstroke and vegetable cracking and had a significant impact on fruit quality, compared with control greenhouses and open field cultivation **Ilić and Fallik (2017).** In addition, fruit color, by higher content in lycopene and β-carotene had improved by colored nets, and also antioxidant compounds in vegetables **Díaz-Pérez (2014). Tinyane et al. (2013**) and **Ilić et al. (2015**), reported that using of pearl photo selective nets improved the shelf life and overall fruit quality of tomato cultivar 'AlfaV' compared with black nets. **Abdel-Ghany et al. (2016),** for arid and hot regions, used nets to cover roof greenhouses to improve microclimate condition. Comparing the transmittance pattern of the proposed designed net-house models with that of the conventional ones, the results presented that the proposed system produces conditions similar to that in the cooled greenhouse by evaporative system, while significantly decreasing the water and energy consumption and the construction cost. The energy consumption was reduced in net-house by 0.26 kWh $m^{-2}d^{-1}$ and decreased the water consumption about 13 kg m^{-2} d^{-1} in summer. In sunny region days, the CuSO4-water solution can offer an appropriate indoor air temperature in the house less than the outdoor air temperature by about 8–10 °C when used as a fluid radiation filter (LRF) method **Abdel-Ghany et al. (2016)**. Painting the greenhouse cover led to the minimum transmission radiation. Moreover, the highest water use efficiency and minimum water consumption was 10.23 kg m^{-3} and maximum yield production was 15.5 Mg/fed **Abo emera et al. (2018**). The main purpose is to select the most effective characteristic parameters of treated coating materials on the models of the greenhouse which prevent the maximum value of solar radiation. To study the effectiveness of greenhouse cooling by the solar energy -assisted evaporation concerted with painting its cover by selecting an influential coating material on the cucumber productivity.

2. MATERIALS AND METHODS

Empirical study

This work was done to study the effect of greenhouse cooling on some climate factors in an environmental controlled greenhouse to ameliorate the productivity, quality of cucumber yield. The greenhouse cooling process was operated using coating its cover by white plastic (most effective coating materials) combined with evaporative cooling system powered by solar energy (PV). The work was divided into two main parts. The greenhouse cooling in this work depends on two systems (painting the greenhouse cover and evaporative cooling system). The treated greenhouse covering by most effective coating materials reflects and prevents the most value of solar radiation transmission inside the greenhouse, to achieve the minimum coefficient value of radiation transmission. To stop heat increasing at the warmest periods and provide an extra cooling load, evaporative cooling is applied in greenhouses. The evaporative cooling system (fan and pads) converts the sensible heat to latent heat. As a result of the negative pressure created by the ventilation fan, the air permeates through the wet pads indoors during the warmest time. This implementation reduces the inlet outdoor air temperature by several degrees and, thus, decreases the inside air and soil temperature. Evaporative cooling is highly effective at minimum values of relative humidity of the outside air. Solar energy (pv) was powered using the evaporative system equipment.

The first part of the experiment was considered as the preliminary experiment; it was done to select the most effective characteristic parameters of treated coating materials on the models of the greenhouse which prevent the maximum amount of incoming solar radiation. The second part was the field experiment to validate the preliminary experiment and confirm the required energy from PV system design. The field experiment was carried out to validate the amelioration of important climate factors in the processed greenhouse which were coating its cover with white plastic material in addition to solar evaporative cooling. The solar panel system (PV) and the cooling system efficacy were validated. Improving the productivity and quality of cucumber yield were affected by treatments. The experiments of the work were conducted beginning June 2018 in the Faculty of Agriculture, Menoufia University farm, Egypt with a latitude angle of 30^o 54' north.

2.1. The Preliminary experiment

To select the most effective characteristic parameters of treated coating materials on the models of the greenhouse which prevent the maximum value of solar radiation, a preliminary experiment was conducted. The models of greenhouse were constructed as shown in **Figure 1.**

All greenhouse models were covered by a layer of single polyethylene cover with a thickness of 130-µm and coated with different levels of painting chemical materials and white emulsion paint. All treatments were painted at the same paint rate l/m^2 (0.013 cm) of greenhouse models cover.

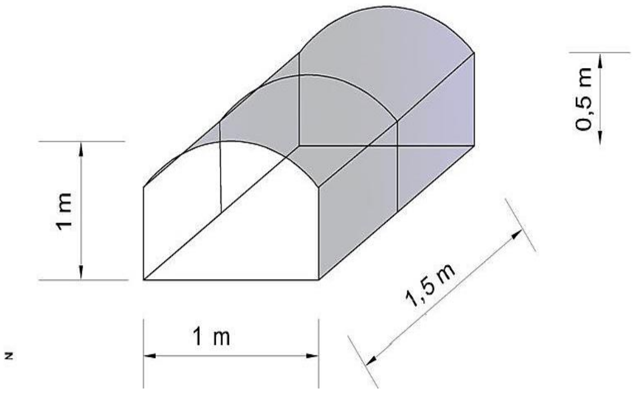

Fig. 1: Greenhouse model for preliminary experiment

The tested painting materials were six types of material resulting in twelve treatments, two levels of concentration were chosen to test for each tested coating material except white plastic. The tested painting materials were distributed to the treatments in a random method as shown in Table (1).

Table (1): The tested and concentration of painting materials of the preliminary experiment

Treatments	**Molecular symbols**	**Concentrtion**
Tr. 1	Na_2SO_4	Sodium Sulphate (70%)
Tr. 2		control plastic cover
Tr. 3	Fe_2O_3	Red oxide 1% = [(187.5g (lime) + 7.5g (oxide) + 0.75 (liter of water)]
Tr. 4	Fe_2O_3	Red oxide 1% = [(281.5g (lime) + 7.5g (oxide) + 0.75 (liter water)]
Tr. 5	CaO	Lime = [(150g (lime) + 0.75 (liter water)]
Tr. 6	Na_2SO_4	Sodium Sulphate (50%)
Tr. 7	$AlCl_3$	Ammonium chloride (50%)
Tr. 8	CaO	Lime= [(150g (lime) + 0.75 (liter water)]
Tr. 9		white plastic = [(200 ml (white plastic) + 1.100 (liter water)]
Tr. 10	$FeHO_2$	Yellow oxide 1% = [187.5g (lime) + 7.5g (oxide)+ 0.75 (liter water)]
Tr. 11	$AlCl_3$	Ammonium chloride (30%)
Tr. 12	$FeHO_2$	Yellow oxide 1% = [(281.5g (lime) + 7.5g (oxide)+ 0.75 (liter water)]

These models were tested for two times; the first one was done for all treatments to select the most effective characteristic parameters of treated coating materials on the models of the greenhouse which prevent the maximum value of solar radiation. The second was done in order to confirm the recommended treatment. The most effective characteristic parameter of the materials was selected after analyzing the obtained results from preliminary experiment. Then, the selected material was used in the mathematical model and field experiments.

2.2. Field experimental work

To achieve the purpose of the work, two greenhouses were used. The frame of the experimental greenhouses was fabricated from galvanized iron. The experimental greenhouses were covered by a layer of single polyethylene sheet with a thickness of 130-µm. The cover of the first experimental greenhouse was treated by white plastic (the most effective material which hindered the maximum value of solar radiation) as a painting material; in addition, the greenhouse was provided with the evaporative cooling method. The used evaporative cooling system was supplied by the renewable energy produced from the photovoltaic panel (PV) as a power source. The dimensions of the greenhouse were 8 × 12 m with a total area of 96 m^2. The schematic diagram of the control and treated greenhouse and drip irrigation system used in the experimental study was shown in Figure 2. The second experimental greenhouse was controlled and treated as a control treatment as shown in Figure 2. The experimental greenhouses were set with North-South direction to maximize the benefits of the ventilation during summer season.

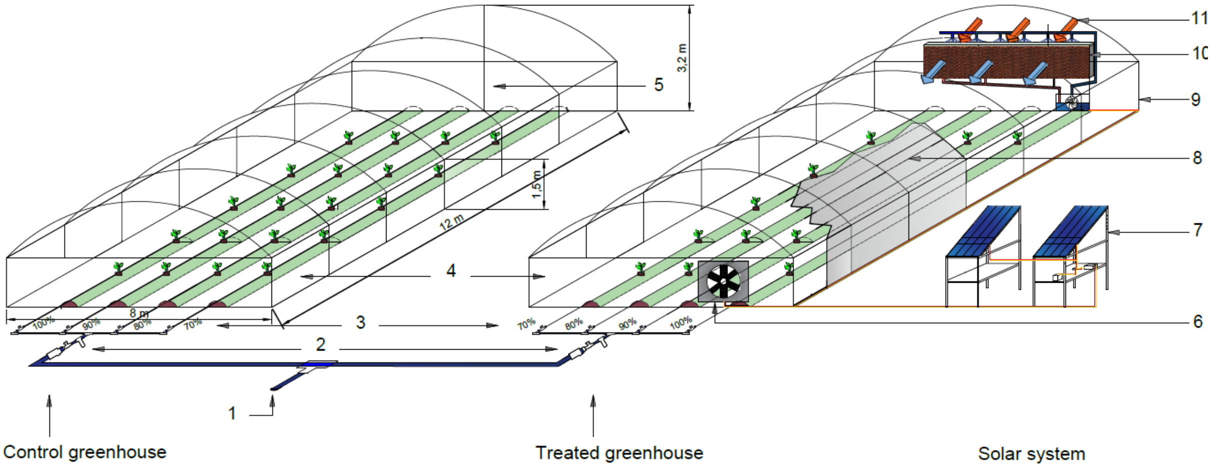

Fig. 2: Schematic diagram of the control and treated greenhouse, the experimental treatments setup and drip irrigation system used in the experimental study.

Table (2): The definition of items in greenhouse schematic diagram

Item	The definition	Item	The definition	Item	The definition
1	Water source	5	Greenhouses covere	9	Water pump
2	Water control valve	6	Ventilation fan	10	Blocks of cellulose material pads
3	Water control valve for each treatment	7	Solar system	11	Inlet air
4	The frame of the experimental greenhouses (galvanized iron)	8	Coating with white plastic		

2.3. Description of evaporative system

In the agricultural applications, to get rid of the increasing heat during the hot time, Evaporative cooling (ECP) was applied to prevent its harmful effect. The method of this operation is carried out by ventilation fan and water pump and blocks of cellulose material pads were used. The ventilation fan has been installed on the southern side of the greenhouse, which works to draw air from the inside, leading to a reduction in the internal pressure and forcing the outside air to pass from outside through the pads. Cooling pads are installed in the northern direction of the greenhouse as an advantage of the wind direction in this area. The cooled air permeates through the cooled pads to get inside the greenhouse (as shown in Figure 2).

The water required and used through pads in evaporative system depends on the internal temperatures required to be achieved, outside climate conditions and the pad thickness utilized, and generally, increasing water supply increases the evaporated water and cooling efficiency. In literature, a value of water flow rate about 12.3 l h^{-1} m^{-2} of pad is predetermined **Andrea et al. (2018).** In this study, water flow rate from the water pump is 65 l h^{-1} which is distributed on a horizontal tube through apertures to the upper of the ECP (Evaporative pad) and the used water was collected. The experimental work applied an air speed of 1.85 ms^{-1} and pad thickness is 15 cm according to **Abdollah et al. (2011).** The work of the ECP system started from 8 am to 7 pm.

2.3.1 Evaporative cooling energy

The cooling energy can be determined based on **Andrea et al. (2018**) through the following equations:

$$Q_c = V_{tv} C_{air} (T_{out} - T_{inlet}) \cdot \frac{\rho_{air}}{3600} \quad (1)$$

where Q_C is the cooling energy kW, V_{tv} is the value of the ventilation rate according to fan m^3h^{-1} , T_{out} is the outlet temperature of a cellulose evaporative pad, T_{inlet} is the inlet air temperature , C_{air} is the specific heat of air, 1.047, $kJkg^{-1}K^{-1}$, ρ_{air} is the air density, kgm^{-3}.

Ali Sohani and Hoseyn Sayyaadi (2017) used the following equation to determine the outlet temperature of a cellulose evaporative pad.

$$T_{out} = 2.5433 + 0.84056 T_{inlet} + 0.15121 HR_{in} + 0.84643 V_{in} - 26.952 \delta_p - 0.016312 A_p \quad (2)$$

where , HR_{in} is the inlet air humidity %, ,δp is the thickness of pad m, V_{in} is the inlet air velocity $m.s^{-1}$, A_p is the pad area, m^2.

$$A_P = \frac{V_{tv}}{V_{max}} \quad (3)$$

where, V_{max} is the maximum inlet air velocity through the pad (with a thickness of 15 cm), 2 ms^{-1}.

2.3.2 Estimation of PV panel energy to power the evaporative system

The consumed electrical power in the equipment of the cooling system (pcs) per W was calculated to evaluate PV panel power required. The energy consumption comprises the pump power and fan. The consumed power of ECP was obtained as Eq. (4) according to **Ali and Hoseyn (2017**).

$$pcs = pcs_{fan} + pcs_{pump} \quad (4)$$

where, pcs_{fan} per watt, is the consumed power of the fan which is calculated by Eq. (5).

$$pcs_{fan} = W_a \eta_{fan} C \quad (5)$$

$$W_a = Q_{air} Pt \quad (6)$$

$$Q_{air} = Z_n V_{green} \quad (7)$$

where, W_a is the air power, W, η_{fan}, is the efficiency of fan, %, Q_{air} is the volumetric flow rate, m^3s^{-1}, Z_n is the numbers of air change that would be removed from the greenhouse, that was taken 0.75 time per min, V_{green} is the volume of greenhouse, m^3 and Pt is the total pressure of the fan, Nm^{-2}

$$Pt = Ps + Pv \tag{8}$$

$$Pv = \frac{1}{2}\rho v_{air}^2 \tag{9}$$

where Ps, is the static pressure, Pv is the kinetic pressure, v_{air} is the air velocity, ms^{-1}, ρ is the air density, C is the Safety factor 1.25 dimensionless and pcs_{pump}, is the used pump power which was 10W.

2.3.3 Solar PV Characteristics.

The Electrical energy is generated from solar radiation by the photovoltaic panel and stored in a solar battery. The photovoltaic panel system is composed of solar cells, batteries, a charge controller and an inverter for the modification of the properties of the output electric current (as shown in figure 3). For the present study, a photovoltaic module panel (mono-crystalline PV type) with 400 W, and 2 m^2 area with 18% catalog efficiency is used to produce electrical energy which is related to operating the pump and fan. It was installed to south direction, and in a fixed position to achieve the most amount of the solar radiation by making the rays fall perpendicular to the solar panel.

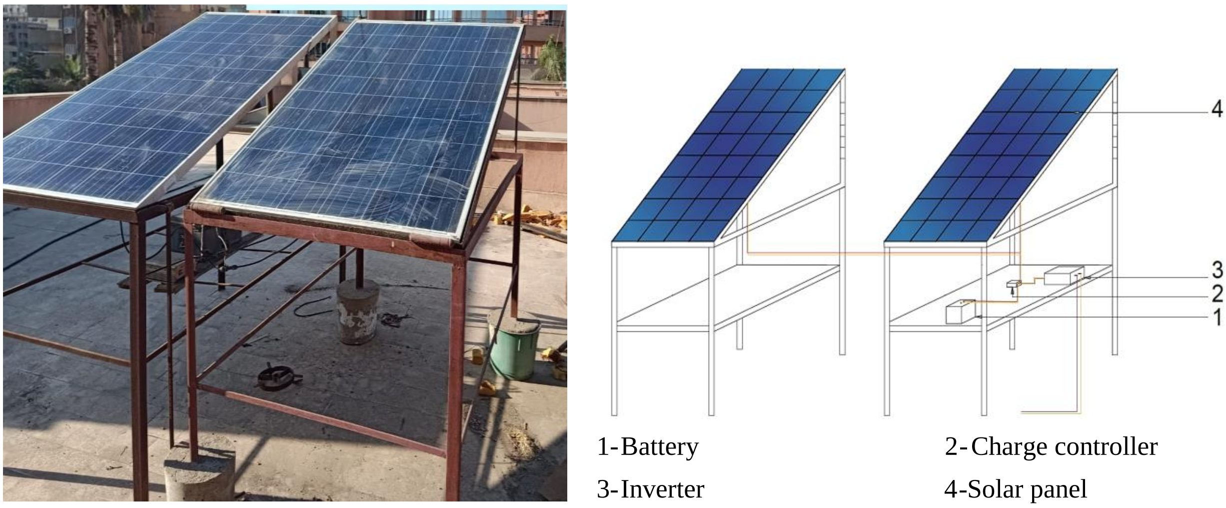

Fig. 3: photo and isometric view of solar panel system applied in the empirical study

In summer season, the better inclination angle (15^o) is equal to the location latitude angle (-15). The solar system contains an inverter with a capacity of 600 W and solar batteries to store the generated electricity and supply the required energy needed for the operation of the water pump and the air fan included in the system. The surplus electricity of the consumed amount is stocked in the solar batteries when the energy output is greater than the required. Decreasing the electricity production from solar PV panel was significant when the temperature of the ambient air is raised. The ambient air temperature (T_a) and the temperature coefficient (C_v) affect the actual electrical energy produced from the solar panel.

The temperature coefficient (C_v) is not a constant and it may change a little from 0.35%: 0.5% **Kumar et al. (2018**) for different cell manufacturers and the ambient air temperature is the present atmospheric temperature at the panel. Eq. (10) **Kumar et al. (2018**) gives the relation between the solar panel output and the ambient air temperature.

$$\text{Actual voltage} = V_{mp} + [C_v \times (T_a - 25)] \qquad (10)$$

where V_{mp} is the voltage at maximum power point, C_v is the temperature coefficient which was taken −0.35 %/°C in the theoretical calculations of the actual voltage.

2.4. Measurements and measuring tools

2.4.1 Solar radiation

The solar radiation was estimated inside and outside the greenhouse using a TES 1333 SOLAR POWER METER that was fixed on a top stand at an inclination angle of 30 º 54' . The data were recorded every hour (w/m^2).

2.4.2 Radiation transmission coefficient

The coefficient of radiation transmission (τ) was estimated from the ratio between internal and external solar irradiance ($\tau = R_{s,i} / R_{s,o}$).

2.4.3 Relative humidity

Spirated psychrometers were used to measure the inlet and the outlet humidity. The instrument has two thermometers. The thermometer measures the wet-bulb and dry-bulb temperature and then calculates RH.

2.4.4 Temperatures

With each painting material, the internal and external air temperatures in the two greenhouse models were estimated. The external test greenhouse air temperature, internal air temperature and soil temperature were measured. IC (LM35) sensors were utilized to estimate all the temperatures (surrounding air, internal air). The data collecting and frequency recording were registered every one minute and one hour average of each estimation by using a LabJacks data logger

2.4.5 Electricity energy productivity

Voltage and current measurements: Panel's voltage (Voc, VL) and current (Isc, IL) are sensed by using a current sensor ACS714 module and voltage divider which are coupled with a controller for maximum Power Point Tracking (MPPT)

2.4.6 Total Cucumber yield

The total cucumber crop yield per Hectare (Mg/ Hectare) was calculated by harvesting the fruits three times a week.

2.4.7 Quality properties of cucumber

Physical and mechanical characteristics of cucumber fruit samples were determined at the Agricultural Engineering Department Laboratory within 2 h of harvest. A random sample of cucumber of the growing season was collected to determine some physical and mechanical characteristics of the fruit. The cucumber was selected by colour uniformity, size, appearance and absence of damage; pyriform format includes a length of 146 mm, a diameter of 29.5 mm and an average weight of 99.73 g. The cucumber was stored at 5 ^{0}C and a relative humidity

90±5 % in cold room. Weight loss, colour and firmness were the most common physicochemical parameters used to evaluate fruit quality. Weight loss, firmness and colour of cucumber were measured at two different positions. Quality properties of cucumber were measured every three days during storage period for the same samples.

2.4.8 Firmness

Fruit firmness was measured by an FHT-1122 hardness tester related with a quill diameter of 3.5 mm that was pressed into cucumber fruits until penetration and then the device reading was taken. This test estimated cucumber firmness based on the resistance of the cucumber to deformation by the plate **Kader (2002**).

2.4.9 Colour determination:

Colour determination: Cucumber colour was determined with a WR-10 Colorimeter. Chroma values were the techniques for three definitions, for each cucumber along the equatorial axis. The L value refers to lightness of the colour of the cucumber sample and ranges from black = 0 to white = 100. A negative value of a indicates a green color where a positive value demonstrates a red-purple color. A positive value of b indicates a yellow color and a negative value demonstrates a blue color.

3. RESULTS AND DISCUSSION

3.1 Preliminary experiment results

Figure 4 and figure 5 show the average indoor air temperature as a result of painting the cover of the models of greenhouse within the duration of 24 hours (in the period from the 15th to the 25th of May 2018) to decide which the most effective characteristic parameters of the greenhouse models coating materials are. The determined results showed that the lowest average indoor air temperatures were 32.23, 29.59, 30.75, and 33.35 ℃ for Tr.8, Tr.9, Tr.10, and Tr.12 respectively. Therefore, these experimental treatments were tested again to select the most effective material of treated materials that reduce solar radiation. The concluded results confirmed that the most effective treated material was the white plastic material.

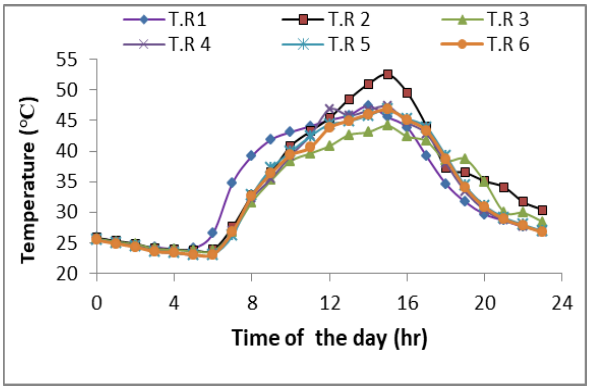

Fig. 4: Diurnal air temperature inside the greenhouse for the tested treatments.

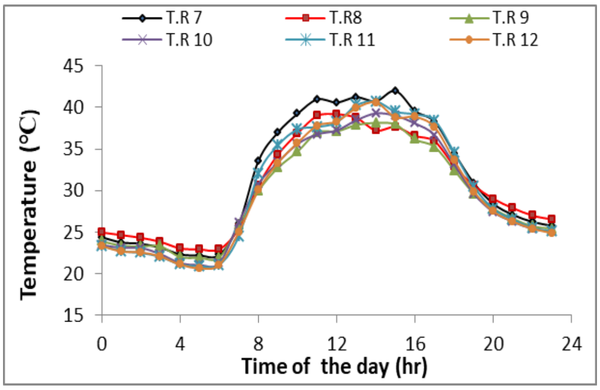

Fig. 5: Diurnal air temperature inside the greenhouse for the tested treatments.

3.2 Effect of greenhouse cover painting on its transmission

The average amount of solar radiation by W m^{-2} outside the greenhouse and the diurnal solar variation of τ for the selected four experimental painting materials are shown in **table (3)** which illustrates the most effective characteristic parameters of the selected painting materials. The average values of radiative fluxes over the period 9-16 hours by W m^{-2} are shown in **Table (3**), which presented the average value of outside solar radiation as 756.88 W m^{-2}. The minimum average amount of solar radiation inside the greenhouse was 334.63 W m^{-2} and this value was found with the white plastic painting material in treatment number 9 (Tr.9). The average transmission coefficient without painting of greenhouse was 0.75, with a very remarkable variation around this figure. The maximum value of greenhouse transmission coefficient was 0.86 and this value was observed around the noon. Painting with the selected painting materials indicated that the most effective characteristic parameters were yellow oxide (281.5, Tr.12), Lime (150gm, Tr.8) Yellow oxide (187.5, Tr.10) and White plastic (Tr.9) and their average values were 0.63, 0.60, 0.53 and 0.44 respectively with smooth variations around these values. Using the white plastic as a painting material for the greenhouse reduced the solar and net irradiance by about 46% and this reduction was a very relatively strong reduction. Finally, the most effective characteristic parameter of treated coating materials was the white plastic; therefore, it was used in the field experiment.

Table (3): Greenhouse transmission of the period 9-16 h local time.

Treatment		$R_{s,out}$ (W/m2)	$R_{s,I}$ (W/m^2)	τ
Control (control)	(Tr.2)	756.88	567.66	0.75
Yellow oxide (281.5)	(Tr.12)	756.88	476.83	0.63
Lime (150gm)	(Tr.8)	756.88	454.13	0.60
Yellow oxide (187.5)	(Tr.10)	756.88	401.15	0.53
White plastic	(Tr.9)	756.88	334.63	0.44

3.3 Actual measured efficiency of solar PV production.

Before conducting the experiment, a statistical model was made for the energy consumption that we will derive from solar cells. On the basis of the nominal efficiency of the solar cells used in the study, which amounted to 18%, according to their specifications, the values of the electric energy produced through the solar photovoltaic power, directed on the solar cells at the study site, were calculated. In order to estimate the real efficiency of the solar cells productivity under the weather conditions of the study site, their productivity of electrical energy was measured and the results were compared with the calculated values, on which energy consumption was designed. These data are represented in Figure 6. As noted in Figure 6, there is a good agreement between the calculated and measured values of this treatment and its relative error is 22.23%.

The measured and calculated results for the energy produced by the cells are represented in Figure 6. The figure shows that the measured values of energy yield from solar PV cells started at 6:30 AM and continued until 7 PM. The productivity of the experimental PV cells ranged from 40 watts in the morning to 308 watts in the zenith period for cells used in the study. The maximum value measured for the productivity of the system used during the study was 299 watts at 1 PM. As shown in the figure, there are small differences between the measured and calculated values of electric energy generated by the used system. This result is consistent with **Omar et al. (2021).**

As described in **kumar et al. (2018),** the actual efficiency was highly affected by both the ambient air temperature and the intensity of the direct solar radiation in the study site. The obtained results showed that the actual efficiency values ranged between 11% and 15% throughout the day (during the period of the incidence of the radiation), and the average value of the actual efficiency during the study days was 13.44%. The basic causes of the variation between the calculated and measured values of the generated electric energy can be explained as follows.

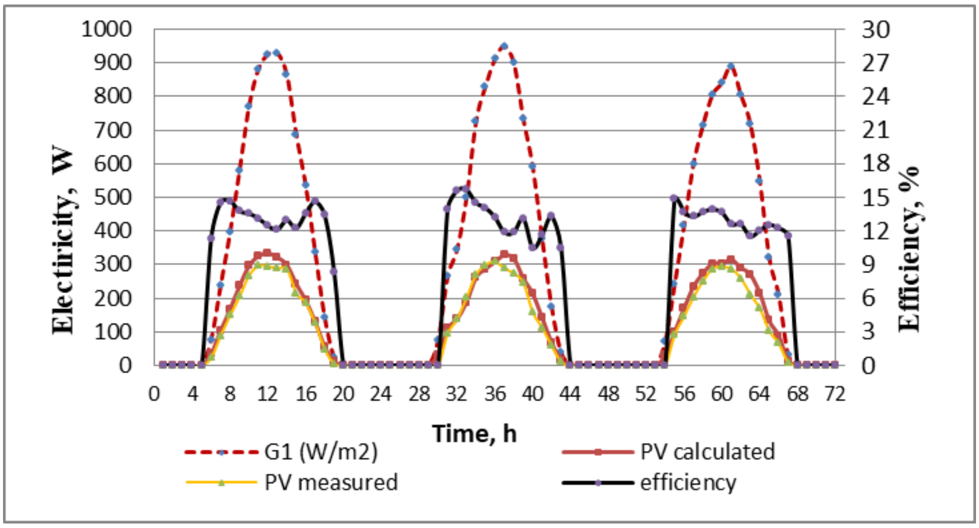

Fig. 6: Calculated and actual measured of electrical power production from PV and actual efficiency

The statistical model was made assuming that the coefficient of the temperature effect on both the current and voltage was constant. But it might somehow change, thus leading to the difference between the calculated and measured values. In addition, during the experiment, there are slight fluctuations between the intensity of the measured direct solar radiation and the one calculated in advance through its model, on which the calculations were based. There were also changes in the actual ambient air temperature in the solar cell unit. As some previous studies showed the effect of temperature on the productivity of cells, when the temperature of the solar cells rises as a result of being affected by the rise in the ambient air temperature by 1°C, the electric efficiency of the solar unit decreases by 0.35: 0.5%. The higher efficiency of converting light rays into electric energy is at 25°C and the solar irradiance is 1000 watt / m^2. Any change in these values affects the efficiency of the solar cell productivity. The wind speed also has an effect, and it is supposed to be 1 m s^{-1}. So, its change would have a major role in causing the differences. These issues have a direct impact on the values of the simulation results and this debate is consistent with **kumar et al. (2018), and Ruiz et al. (2020), and Omar et al. (2021).**

3.4 Effect of paint by effective coating material on transmission through the cover

As stated earlier, to adopt some methods to prevent the high intensity of solar irradiance, one of these methods was to treat the greenhouse covering with a paint that reflects the radiation. To study the effect of this process, the results of the incident solar irradiance values on the area were monitored, as well as the solar irradiance values that would permeate the treated and untreated coverings. Figure 7 shows the average solar irradiance incident on the greenhouse (W m^{-2}), the amount of solar irradiance that was reflected (prevented from permeating the covering), the amount of radiation that permeated the covering into the two painted and unpainted greenhouses and the change in covering permeability (τ) affected by the paint treatment process as well as the untreated. Figure 7 shows the average of the aforementioned values for 10 consecutive days, which is the highest in the values of solar radiation intensity and temperature. The paint had an effect on the permeability, as it led to an increase in the reflected solar irradiance and a decrease in the solar irradiance permeating the covering. The decrease in the permeability in the greenhouse with the painted covering has a remarkable effect on reducing the solar irradiance permeability inside it, and consequently this decrease leads to reduce in the inside greenhouse air temperature.

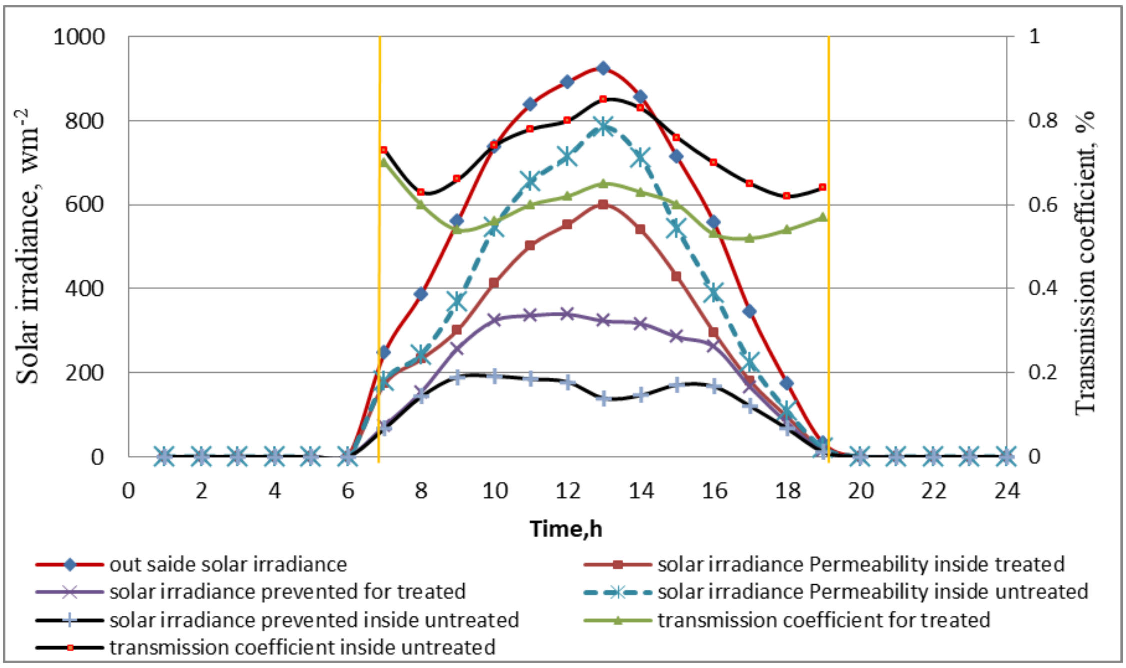

Fig. 7: The average hourly irradiance, solar energy, transmission coefficient and solar irradiance prevent

Figure 7 also shows the average values of solar irradiance intensity (W m^{-2}) during the day, which shows that the solar radiation is incident during the period from 7 AM to 7 PM. The data indicate that the average coefficient of permeability in the greenhouse with the unpainted covering was 0.75, with intangible fluctuations around this value. The maximum value was observed at noon and reached 0.86 for this greenhouse. Painting the covering (with white plastic) had a relatively strong effect on its permeability, thereby reducing the permeability to about 59% of the incident solar irradiance. The percentage of reflected solar irradiance (which was prevented from permeating) from the two coverings was 41% and 25.3% for the paint-treated and the untreated coverings, respectively. This means that there is about a 16 % decrease in the percentage of solar irradiance permeability into the greenhouse due to treating the covering with white plastic paint. This constitutes a significant value, which in turn would have a great impact on the internal temperatures and consequently the efficiency of water consumption and the quality of the produced crop. The results showed the effect of painting the covering, as the total value of the solar irradiance intensity inside the treated and untreated greenhouses was 446.5 and 567.66 W m^{-2}, respectively, with a reduction rate of about 21.4 % during that period as a result of the use of white plastic in painting the covering.

3.5 Confirm the required energy for ECP supply from PV system

The energy required to operate the Evaporative Cooling System was calculated for this study, and consequently the solar cell system was designed and identified as a new and renewable source of energy (and as an application for the use of solar energy in agriculture) and necessary to provide that energy, in terms of the capacity of the solar cells used and the capacity of the inverter, as well as batteries. And to verify the extent of the potential of energy supply required from the solar cell system, the energy consumed by the cooling system and the energy generated from the solar cell system were measured and the results were represented as shown in Figure 8.

It is clear from the data that the solar energy incident on one square meter (1 m^2) of the experiment site is used as a source of energy during the study. The table also shows the electric energy generated hourly from the solar cells, the average total energy obtained during the day, the energy consumed in the Evaporative Cooling System and the total energy consumption for the specified empirical day. The data indicate that the solar irradiance ranged from the lowest value to its maximum value, which is from 30 to 920 W m^{-2}. The total solar irradiance during the day was 7262 W m^{-2} day^{-1}, with a total energy output estimated at 26.14 MJ. The electric energy yield from the solar cells varied throughout the day, ranging from the lowest value of .03 during the hour of sunrise and sunset to its maximum value of 1.08 MJ at midday, and the average total electric energy generated during the day was 8.77 MJ day^{-1}. This result is consistent with **Ruiz et al. (2020).**

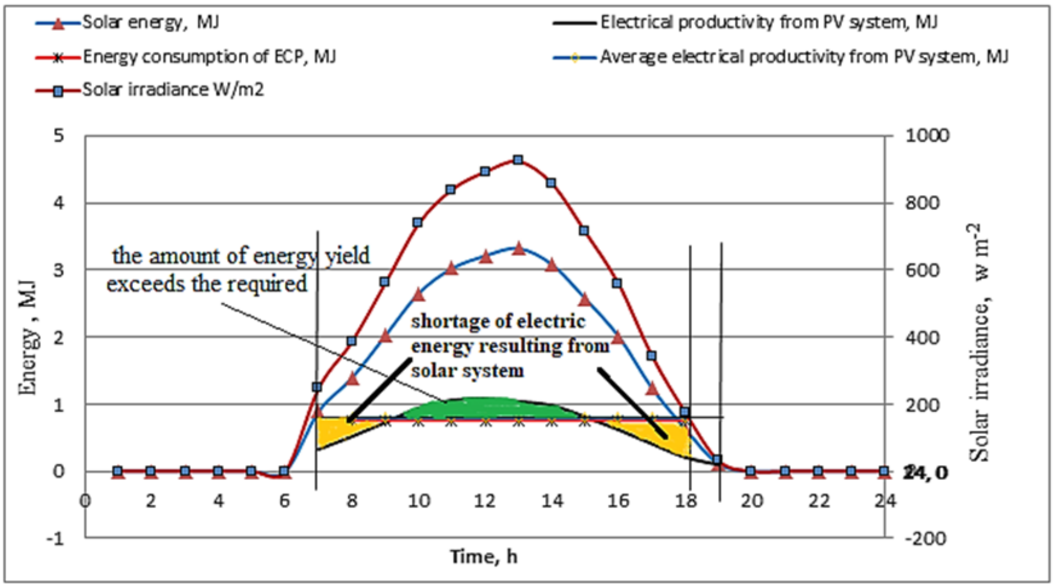

Fig. 8: The solar Energy, electrical productivity from PV and required energy for

As shown in the **Fig. 8**, the energy consumption in the ECP system, which includes the air fan and the water pump, was 8.32 MJ per day and it was obtained from the electric energy yield from the used solar cells. As is clear from the Figure, there is a shortage of electric energy resulting from the used solar system, which is to be used for the energy required to operate the cooling system during the period from the beginning of the sunrise until 10 AM. After that, the amount of energy yield exceeds the required energy until 4 PM and then the energy produced decreases again. Therefore, the generated electric energy that exceeds the amount used would be stored in the battery for recovery at the time of poor yield from PV. From the foregoing, it is clear that it is possible to save the energy by using solar cells in the design adopted during this study for the Evaporative Cooling System used. And in turn, there would be an excess of 0.45 MJ per day.

3.6 Evaluate microclimate inside the greenhouse affected by coating its cover integrated with evaporative cooling

The effect of painting the greenhouse plastic covering and the use of Evaporative Cooling on the environmental factors of air temperature, soil and relative humidity inside the greenhouse is shown in Figures (9 and 10) in the growth phase during a period of 24 hours from 16 to 18 August.

3.6.3 Indoor air temperature

The ambient temperature inside the greenhouse was compared. It was noted that it ranged between 25°C to 31.6°C for the paint-treated greenhouses with the Evaporative Cooling System, at the meanwhile, it ranged between 26°C to 41°C all the day (24 hours) in the controlled greenhouse (without treatments), and the outside air temperature varied between 25°C to 41°C. The results indicate that the largest variation in the highest and lowest temperatures in the cooled greenhouse was 7 degrees Celsius over the course of the day (24 hours) as shown in the Fig. 9. And it is lower than that in the controlled greenhouse, which was 16 degrees Celsius, thus resulting in reducing the heat shocks that the plants were exposed to. Accordingly, there was an improvement in the weather conditions suitable for growth, flowering and clustering, in addition to the quality aspects of the harvest.

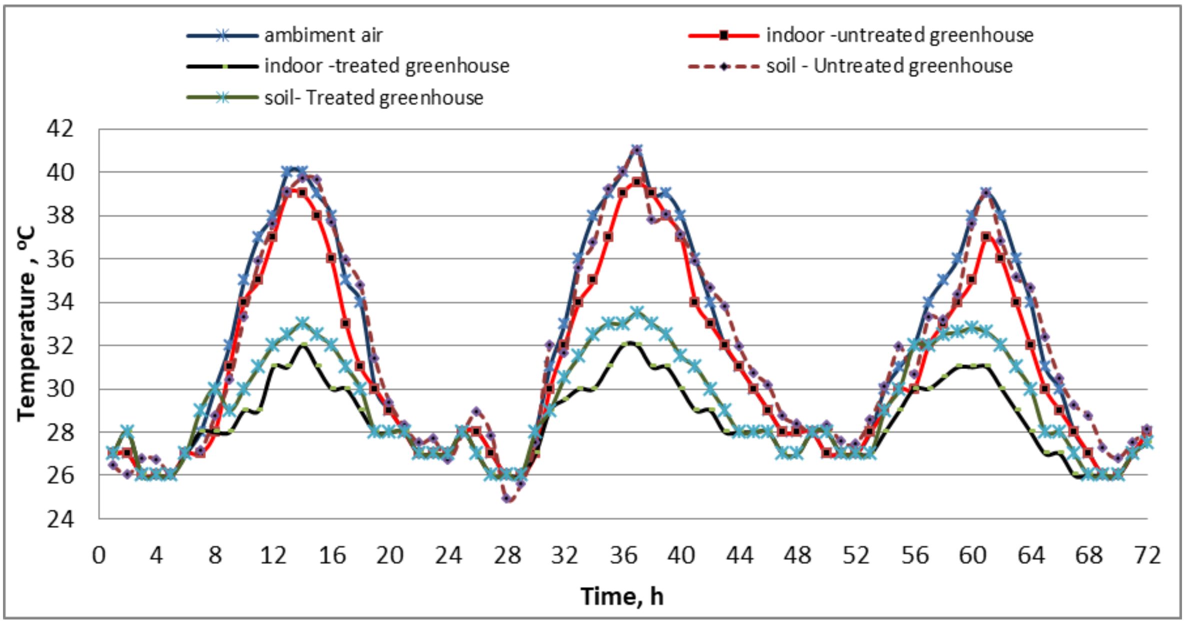

Fig. 9: Measured ambient and inside air and soil temperature of the treated and control greenhouse

As describe**d in Pervin et al. (2019**), the difference between the indoor air temperatures for both treated and controlled greenhouses reached its peak at noon. The maximum value of the difference between them was 9 degrees Celsius and decreased in the late afternoon and early morning until it was equal in both greenhouses. The resulting difference in the internal temperatures of the two greenhouses was due to the painting of the outer plastic covering with a substance that helped reflecting a large portion of the solar irradiance, thus decreasing the solar radiation permeating inside. Furthermore, it is attributed to the Evaporative Cooling System (ECP), which lowered the temperature of the air entering the treated greenhouse by using a part of its energy to evaporate the water that passes through the cooling pads, thus converting the sensible heat into latent heat, resulting in a decrease in the indoor air temperature. Painting the greenhouse plastic covering during the study had a significant positive effect on reducing the permeability of the solar irradiance into the painted greenhouse to 59%, while it was 75 % in the unpainted greenhouses. The cooling of the greenhouse by using the Evaporative Cooling System (ECP) in addition to painting its covering with white plastic material improved the weather conditions inside the treated greenhouse, which led to an increase in flowering and, consequently, its production. Accordingly, the total cucumber harvest increased in the painted greenhouse.

3.6.2 Root-zone temperature

During the period of sunshine, the soil absorbs heat from the part of the solar irradiance that permeates through the covering (which varies from the painted covering to the unpainted one), and then a reverse process occurs during the evening (where the upper thick layer of the soil surface acts as a heat exchanger), which reflects most of the heat absorbed during the day. Soil temperature plays a vital role for plants in many processes that occur in soil; such as root spreading and absorption of nutrients, water, salts, and fertilizers. Soil temperature relies on various factors: the incident solar irradiance intensity, soil type, soil heat absorption, moisture content, vegetation, and air temperature inside the greenhouse. The impact of greenhouse painting and ECP on the average soil temperature in the growth phase within a period of 24 hours (from 16 to 18 June 2018) is evident. The results of this impact are represented in Figure 9. Average outdoor air temperatures were mentioned during the previously specified days. As for the inside of the controlled greenhouse, the highest temperature of the soil surface was recorded during the middle of the day, where the temperature increased from 26°C to a maximum value of 41.5°C. As for the treated greenhouses, it increased from 25 degrees Celsius until it reached its maximum value of 31.5°C at noon.

The results reveal that the maximum difference among the root zone temperatures of the treated and controlled greenhouses was 10° degrees Celsius. This difference is due to painting the covering with white plastic, which led to an increase in the reflection of solar irradiance and a decrease in the amount of the solar irradiance permeating into the greenhouse from the part permeated through the unpainted covering, which led to a decrease in the heat absorbed from the soil, 440ogetherr with the Evaporative Cooling System (ECP). The painting of the greenhouse plastic covering showed a notable impact on soil temperature in the morning and afternoon. Soil temperature value inside the painted greenhouse was higher than that inside the unpainted greenhouse in the morning, then it decreased during the afternoon. This can be ascribed to the difference between the energy inside both the painted and unpainted greenhouses, and the wavelength change of the reflection of solar irradiance from the inside out through the plastic covering at night.

3.6.3 Relative humidity and its effect on cooling efficiency

Evaporation efficiency is clearly affected by many factors; such as the ambient air temperature, air relative humidity, and air velocity. It was concluded from studying the efficiency through the pads that the efficiency of the water evaporation process increases with the decrease in the relative humidity of the air that would pass through the pads into the greenhouse, thus increasing the efficiency of the cooling process.

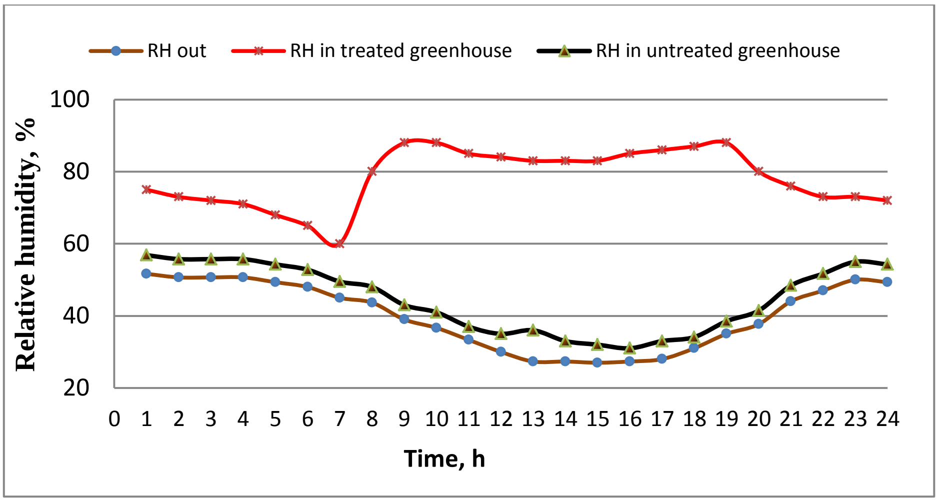

Fig 10: The outdoor, indoor treated greenhouse and control greenhouse relative humidity

Also, it is clear that there is an increase in the relative humidity inside the cooled greenhouse and it's affected by the evaporation. Figure 10 shows the percentage of humidity of the air outside the greenhouse, as well as the percentage of air for each of the treated and controlled greenhouses. It was observed that the humidity increased during the night and decreased relatively during the day compared with the night, as it decreased from 55% to 27%. When humidity is low during the day, relatively dry air can evaporate more of the water that passes through the cooling cells; which leads to an increase in the efficiency of the evaporation process. During the day, the outside relative humidity is low and the temperature is high. During the same period, it is high inside the cooled greenhouse due to the Evaporative Cooling, which causes an increase in the relative humidity from 30% to 90%. The figure shows a slight increase in the relative humidity inside the controlled greenhouse in comparison with the outside air throughout the day, and the stability of this simple percentage, due to the natural ventilation used inside this greenhouse. The increased efficiency of the evaporation process through the pads leads to the conclusion that there are increases in the cooling efficiency, internal relative humidity and the efficiency in the energy consumption of the cooling system. High humidity leads to a positive effect inside the treated greenhouse as it reduces water consumption and increases water use efficiency as well as product quality aspects. This is in agreement with the research of **Issam and Hind (2017), Omar et al. (2021).**

3.7 Total Cucumber Crop Productivity

The results of the total cucumber productivity under experimental treatments are presented. The reported results clarified that the highest amount of crop yield for the control greenhouse was 32.95 Mg per Hectare. Otherwise, in the treated experimental greenhouse, the biggest amount of crop production was 36.55 Mg per Hectare. The rate of increase in the yield from treated greenhouse was 11%. The increasing was a result of an improvement in the weather conditions suitable for growth, flowering and clustering, in addition to the quality aspects of the harvest.

3.8 Quality Characteristics of cucumber affected by treated greenhouse

Covering plastic greenhouses with nets of different colors led to decreasing the sunstroke and vegetables cracking and had a significant impact on fruit quality, compared with control greenhouses and open field grown **Ilić and Fallik (2017).** In addition, fruit color, by higher content in lycopene and β-carotene had improved by colored nets, and also antioxidant compounds in vegetables **Díaz-Pérez (2014). Tinyane et al. (2013)** and **Ilić et al. (2015),** reported that, the improving the shelf life and overall fruit quality of tomato cultivar 'AlfaV' using of pearl photoselective nets compared to black nets. Some quality parameters were measured to evaluate the improvement in the quality of the cucumber yield affected by cooling the greenhouse and painting its plastic cover. Weight losses, color and firmness are the important factors in estimating the deterioration of quality. The effect of treated and control greenhouse on appearance and outer color of cucumber shelf life, during 15 days of storage at 5°C, is presented in Figure 11. Throughout the storage period the decay level increased progressively and was higher for control greenhouse fruit.

Figure 11: Appearance and outer color of cucumber shelf life after for treated and Control greenhouse.

3.8.1 Weight loss

The weight losses (%) of cucumber after 15 days was extrapolated based on the weight losses rate every 3 days until the end of storage period for treated and control greenhouse. The initial weight of cucumber was 99.73 g. The control greenhouse showed higher weight loss than the treated one during cold storage as shown figure 12. The average of weight loss after 15 days was 4.34 and 6.72 % for treated and control greenhouse, respectively. The overall average of weight losses of cucumber decreased from 0.14 to 0.09 % h^{-1} using treated greenhouse. Loss of weight in fresh fruits and vegetables is essentially attributed to the losses of water caused by transpiration and respiration processes **Zhu et al. (2008).** In the present study, fresh weight loss may be related to the water flow in the cucumber. However, after harvesting, water supply to the plant is stopped and transpiration becomes responsible for promoting water loss.

3.8.2 Firmness

The vegetable firmness which is an attribute that indicates the shelf life and quality properties of cucumber for treated and control greenhouse is presented in figure 13. The reduction was observed in firmness of cucumber planted in control greenhouse after 15 days of cold storage. The cucumber firmness reduces with increasing cold storage period. The mean values of cucumber firmness decreased from 19.97 N to 13.93 N, and from 19.97 N to 10.44 N after 15 days of cool storage for treated and control greenhouse products respectively. It can be observed from the results that the decreasing percentage of firmness was 47.8 % for control greenhouse and 30.78 % for treated greenhouse products after 15 days of cold storage. Cucumber softening is attributed to wilting in the cell structure, the cell wall structure and the intracellular materials **Shiekh et al. (2013).** It is a biochemical process relating the hydrolysis of pectin and starch by enzymes such as wall hydrolases. The result of the current study agrees with the work of **Rab et al. (2013), Makwana et al. (2014)**

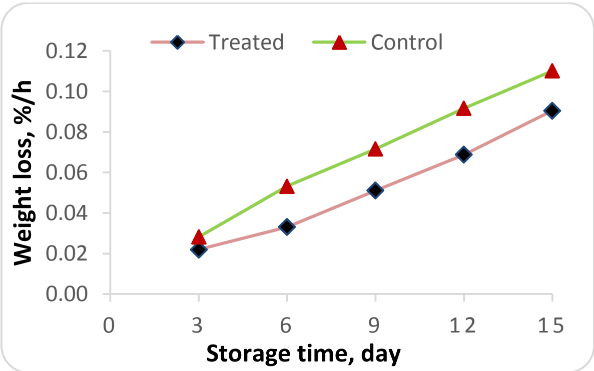

Fig. 12: Weight loss of cucumber at 5 °C: for treated and Control greenhouse

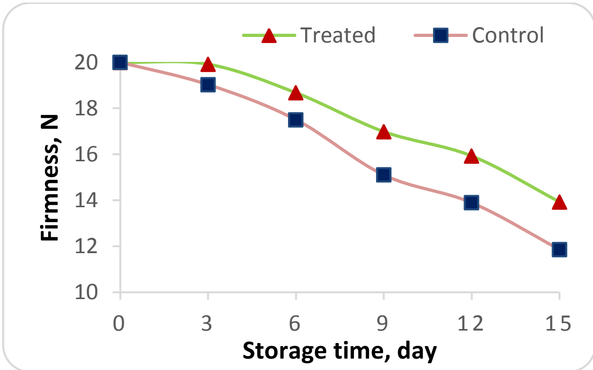

Fig. 13. Firmness of cucumber at 5 °C: for treated and Control greenhouse

3.8.3 Color

The color was changed in cucumber influenced by storage time for treated and control greenhouse as shown in figure 14. The evaluation considered the appearance color, the lightness (L value), green/red components (a value) and blue/yellow components (b value). The L values for cucumber decreased with increasing storage time. The initial L value was 67.89. The maximum decreasing of L value was 55.27 occurring after 15 days for control greenhouse products while the minimum decreasing value for L was 60.61 for treated greenhouse. The values of color parameters (a-value) increased with increasing storage time. The a-value of cucumber increased from -6 to -3.98 for control greenhouse while it increased from -6 to -3.14 for treated greenhouse. The larger percentage increasing of a-value was 4.7 % occurring after 15 days of cold storage for control greenhouse.

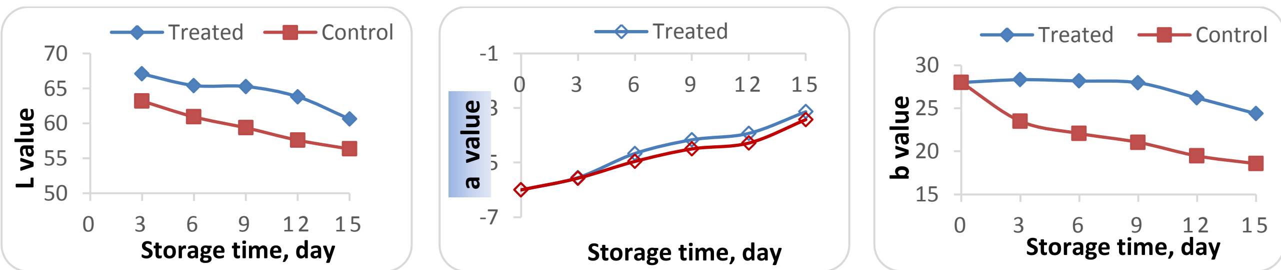

Fig. 14: Color Change of L value, a and b value of cucumber at 5 °C: for treated and control greenhouse

Figure 14 shows the effect of storage period on b-value of cucumber for treated and control greenhouse. From this figure, it can be obtained that the b-value gradually decreases by increasing time of cold storage. The initial b-value was 27.94 and the higher decreasing of b-value was 18.57 after 15 days of cold storage of cucumber for control greenhouse. On the other hand, the decreasing of b-value was 24.37 after 15 days of cold storage of cucumber for treated greenhouse. Finally, painting plastic cover of the greenhouse improved quality criteria of cucumber fruits.

4. CONCLUSIONS

- The minimum transmission coefficient was (0.59). It was achieved using the strong and effective coating material (white plastic), which hindered the maximum amount of solar radiation and achieved the lowest temperature (to 31.6 ^{o}C).
- The total productivity of the electricity from solar panel was 8.76 MJ day^{-1}. The energy required for the ECP system was 8.33MJ day^{-1} attained from the energy produced from solar cells.
- The prevented value of solar irradiance through the cover was 41 % for the painted and 26 % for the unpainted cover, which indicates approximately 15% decrease in the ratio of solar radiation transmission through the painted cover by the selected material (White plastic).
- The maximum temperature inside paint-treated greenhouses is 32°C. Meanwhile, it was 41°C all day (24 hours) in the controlled greenhouse (without treatments), which means a decrease of 9.4 degrees as a result of transactions.
- The weight loss of cucumber decreased from 0.14 to 0.09% h^{-1} after 15 days of cold storage when using treated instead of control greenhouse. This means that the cucumber weight with control greenhouse decreased by 21.6% compared with treated greenhouse.

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تأثير التبريد التبخيرى بالطاقة الشمسية وتقليل نفاذية الغطاء على انتاج وجودة خيار الصوب

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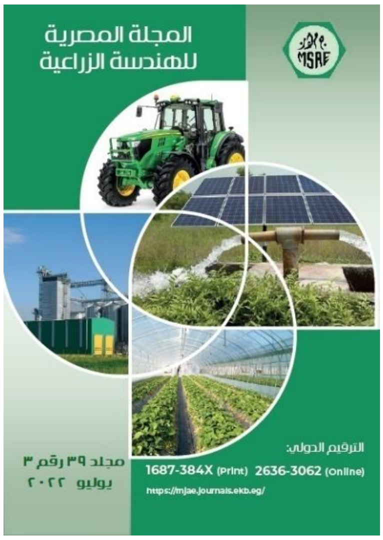

الملخص العربي

أصبح تغير المناخ أحد أكبر العوامل التي تؤثر على الإنتاج الزراعي وعلى إمداداتنا الغذائية. لذلك يجب أن يوسع الاهتمام لتجنب تأثيره على جودة المحاصيل وإنتاجيتها. يمكن استخدام التحكم البيئي داخل الصوب لتجنب تأثير التغيرات البيئية المختلفة. أجرى البحث بهدف دراسة فعالية تبريد الصوب الزراعية عن طريق التبخر بمساعدة الطاقة الشمسية مع طلاء غلافها بمواد طلاء فعالة لتقليل نفاذيته للإشعاع الشمسي من خلال الغطاء وتأثيرها على إنتاجية الخيار وجودته. لتحقيق هذا الهدف تم تقسيم العمل إلى تجربتين رئيسيتين. كانت التجربة الأولى هي التجربة الأولية لاختيار مادة طلاء قوية وفعالة والتي تمنع نفاذية الحد الأقصى من الإشعاع الشمسي. التجربة الثانية هي التجربة الحقلية للتحقق من صحة التجربة الأولية والمدمجة مع نظام التبريد التبخيري بمساعدة الطاقة الشمسية لتبريد الصوبة الزراعية. حيث أظهرت النتائج من التجربة الأولية أن طلاء الغطاء باستخدام مادة البلاستيك الابيض حقق أقل معامل انتقال للأشعة الشمسية (٠,٥٩) وأدنى درجة حرارة (٣١,٦ درجة مئوية). كذلك دهان غطاء الصوبة جنبًا إلى جنب مع نظام التبريد التبخيري الذي استهلك ٨,٣٢ ميجا جول/اليوم والناتجة من النظام الشمسي (PV) أدى إلى خفض درجة الحرارة بنحو ١٠ درجات. أيضا ارتفع المحصول الناتج بنسبة ١١٪ في الصوبة المعاملة. وزاد فقدان وزن الخيار الناتج من الصوبة الزراعية الغير معاملة بنسبة ٢١,٦٪ مقارنة بالصوب المعاملة اثناء التخزين. وبناءً على ذلك هناك بعض التوصيات التطبيقية التي يمكن اتباعها عند تصميم المزارع لتلافي تأثير درجات الحرارة المرتفعة والحفاظ على الطاقة في عملية الإنتاج وهي:

- دهان غطاء الصوب بالبلاستيك الأبيض لتحقيق أقل نفاذية للإشعاع وتقليل درجة الحرارة.
- في المناطق شديدة الحرارة، يوصى بتبريد الصوب باستخدام التبريد التبخيري إلى جانب طلاء غطائها.
- استخدام الخلايا الكهروضوئية لتوفير الطاقة المستهلكة في نظام التبريد التبخيري وأي استخدام آخر للطاقة بالمزرعة.
- يمكن تطبيق هذا النظام لتبريد معظم المنشآت بكفاءة عالية لزيادة الإنتاجية والجودة مع خفض تكلفة الطاقة.

الكلمات المفتاحية:

اللوح الشمسي؛ معامل نفاذية الضوء؛ التبريد التبخيري؛ مواد الطلاء؛ محصول الخيار؛ الإنتاجية؛ الجودة.