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Water productivity and stomatal gas exchanges of greenhouse tomato in two hydroponic systems

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Abstract

The amount of water and fertilizers used in the production of vegetables, specifically tomatoes, is high. This experiment was carried out to investigative of effects of yield, nutrient solution efficiency,Vegetative growth, and stomatal gas exchanges of two greenhouse tomato cultivars (V4-22, Amira) in open and closed hydroponic systems, as split-plot design based on completely randomized block design with three 3 replications at Shahid Chamran University of Ahvaz. The results showed that the effect of the hydroponic system had a significant effect on the efficiency rate of nutrient solution usage, fruit length, fruit firmness, leaf area, plant height, stomatal conductance and leaf temperature (P≤%5). The highest fruit length, fruit firmness, leaf area, plant height, stomatal conductance, and leaf temperature were measured in the open hydroponic system. The water productivity per performance in closed hydroponic system was greater than (approximately 55%) open hydroponic system. The highest and lowest water productivity biomass were obtained in the closed system and open system (48.91 and 34.42 kg/m^3), respectively. The highest and lowest crop yields were measured in V4-22 and Amira cultivar (3874.29 and 3648.70 g per plant), respectively. Based on the results, the open hydroponic system has increased the characteristics such as plant height, leaf area, number of leaves and stomatal conductance, but the performance of the product in these two hydroponic systems is not different and also the closed hydroponic system reduces nutrient solution consumption up to 96% and fertilizer consumption up to 97%.

Introduction

Today's climate change and scarcity of good quality water are becoming increasingly severe worldwide. Particularly important are hydroponic systems that can maximize water savings and rational water use. Through the production of greenhouse crops, Water resources can be used more efficiently through the production of greenhouse crops because there is better control of environmental conditions for crop production (Costa et al., 2018). Including tomato as one of the most cultivated vegetables due to its profitability and its consumption (Krause et al., 2017; Atzori et al., 2019; De Wrachien and Goli., 2015). Hydroponic systems belong to the standard technology in modern high-tech greenhouses, while they are increasingly adapted also in greenhouses of a low or medium technological standard to cope with the soil-borne diseases and the diminishing soil fertility due to monoculture (Savvas ., 2021). The hydroponics system was introduced as one of the methods increasing crop production and water use efficiency in the greenhouse. Hydroponic systems, such as open hydroponic system and closed hydroponic system are essential tools in plant factories (Rosa-Rodriguez et al., 2020 and Son et al., 2020). The studies showed that the highest yield of tomatoes is produced per unit area in hydroponic cultivation; moreover, it reduces the amount of water and fertilizer consumed, thus significantly increasing the water usage productivity of the crop (Zhang et al., 2016). Rodriguez-Jurado et al. (2020) in a study examined several crops (tomatos, cucumbers, and lettuce) in three hydroponic systems (open, soil, and closed) reported open and closed hydroponic systems and found them to have no significant difference in yield performance. The most efficient water consumption system was the closed hydroponic system with water consumption savings of 55.69% as compared to the open system. Rosa-Rodriguez et al. (2020) in a study compared the nutrient solution efficiency in closed and open hydroponic systems in tomato production, and concluded that the efficiency of water and fertilizer consumption was higher in a closed system , in as such that such a system produces 13.5 kg more fruits per cubic meter of water than an open system. Rufi-Salis et al. (2020) in a study on nutrient recycling of closed hydroponic cultivation systems in green pea production concluded that closed hydroponic systems reduce water consumption by 40% ,and nutrient consumption by 35% to 54% daily. Mendez-Cifuentes (2020) in a study on open and closed hydroponic cultivation systems concluded that to produce 1 kg of tomatoes in an open system 53 liters of a nutrient solution, and in a closed system 22 liters of a nutrient solution are used and the open system had 9/5% higher yield and consumed 86% more water. Rodriguez-Ortega et al. (2019) in a study of three hydroponic cultivation systems (deep flow technique, perlite, nutrient film technique) concluded that water usage productivity was higher for tomato plants which are grown using a nutrient film technique, whereas the highest yield was obtained in the open system. De Souza et al. (2020) in a study on the efficiency of a nutrient solution in a nutrient film technique system and its effect on the growth and development of watercress, observed that by increasing the concentration of the nutrient solution the rate of photosynthesis, stomatal conductance, and transpiration rate would be reduced. In the production of lettuce in closed system consumed approximately 42% less water, 23% less KH_2PO_4, 57% less KNO_3, and 58% less $MgSO_4$ than open system (Christie., 2014). The purpose of the current study was to investigate the effect of open and closed hydroponic systems on yield, water usage productivity, fruit quality, vegetative traits and the gas exchange after the inagurating of two greenhouse tomato cultivars in the Shahid Chamran University of Ahvaz.

Materials and methods

This experiment was done as split-plot design based on completely randomized block design with three 3 replications at Shahid Chamran University of Ahvaz. The two hydroponic systems (open and closed) and two cultivars (V4-22 and Amira) were treatments. Type of hydroponic systems and cultivars were selected as main and subplot in this experiment, respectively. The parameters such as water productivity, water productivity per biomass, yield, leaf area, plant height , fruit diameter, fruit volume, fruit length, fruit firmness, fruit dry matter, nutrient solution efficiency, and stomatal gas exchange were measured during and end of the experiment. An experiment was conducted in Autumn ,2019 at latitude 31˚ 20’ N and longitude 48˚ 41’ E with an elevation of 22 (m). Tomato seeds were planted in the planting tray on September 23, 2019 and the seedlings were transferred to open and closed hydroponic systems on October 20, 2019. The Amira cultivar was bred in the Netherlands and procured from Sepahan Royesh Isfahan Company (representative of Rijk Zwaan Company in the Netherland). The V4-22 cultivar was bred in the Shahid Chamran University of Ahvaz. In the closed hydroponic system, the nutrient solution had a constant volume in the pots and flowed consistantly during the day and night. During the culture period, the nutrient solution was recycled and reused in the closed hydroponic system by adjusting the electrical conductivity (in the reported range). In the open hydroponic system, the nutrient solution was transferred to the plant by pipes and drippers using a digital timer. Irrigation started from the beginning of the project with 150 mL per day for each plant in the open hydroponic system and by the end, this amount reached 1800 mL per day for each plant. The dripper flow was adjusted to 100 mL/min in the open hydroponic system. In the open hydroponic system during the production stage, on average, 18-20 irrigations per day were applied. In each pot, one adjustable drip emitter (6 L h^{-1}) was installed. The culture medium in the open hydroponic system was (50% cocopeat+50% perlite). however, the closed hydroponic system was without any culture medium. In both hydroponic systems, the pots were placed in rows at 100 cm apart with a spacing of 25 cm between each pot in a row (Figure 1). A Resh nutrient solution was used to feed the plants (Resh, 2013) (Table 1). After preparing the nutrient solution, the EC and pH of the nutrient solution in both the closed and the open hydroponic system were measured using a manual digital conductivity meter and a pH meter. The EC of the nutrient solution was adjusted to 3.2 ($dS.m^{-1}$) in the open hydroponic system and ranged from 2.6 to 4.6 ($dS.m^{-1}$) in the closed hydroponic system. After resetting the EC of the nutrient solution in the closed hydroponic system, the pH of the nutrient solution was measured and adjusted using H_2SO_4 1 N or NaOH 1 N in the range of 5.5-6.5 as requ.

Measured variables

Yield

In the current study, by aggregating the weight of healthy and marketable fruits (above 70 g and without damage) packaged and sent to the consumer market, the yield of marketable fruits was determined.

Volume of applied solution

The amount of nutrient solution consumed in the closed hydroponic system from the first day after transplanting to the end of the growing season was calculated daily using a volumetric meter. AlsoMoreover, in the open hydroponic system, in order to determine the nutrient solution consumed, the volume of water drained from the pots was recorded daily and reported as a percentage value.

Water productivity

The water productivity per yield was calculated by dividing weight of fruit production (end of experiment) to cubic meters applied water (m^3). To calculate these values , the researchers used the formula below (Rosa-Rodriguez et al., 2020):

$$\text{Water productivity}= \frac{\text{Kilograms of fruits}}{\text{Cubic meters applied water}} \quad (1)$$

Water productivity per biomass in the open and the closed hydroponic system was obtained from the ratio of total crop yield (kg) and plant biomass (kg) to applied water (cubic meters) (Hooshmand et al., 2019):

$$\text{WPB}= \frac{\text{Y + B}}{\text{W}} \quad (2)$$

(Water productivity biomass (Kg/m^3), Y = crop yield (Kg), B = plant biomass (Kg), W = volume of product consumed (m^3)).

Drainage percentage

Drainage percentage was obtained in both hydroponic systems based on the ratio of the volumes of drained nutrient solution to applied nutrient solution, according to the following formula (Rosa-Rodriguez et al., 2020):

$$\text{Drainage percentage}= 100\times\frac{\text{NS drained}}{\text{NS applied}} \quad (3)$$

Fruit quality analysis

Fruit length (mm), fruit diameter (mm), and fruit volume (cm^3) were measured for 10 fruits per replicate per treatment in each graft combination. A digital compass which was sensitive to ±0.1 mm, was used to measure fruit length and diameter of tomatoes, and the mean values were calculated. For fruit volume, the fruit was put in a container that was measured and filled with water; the overflowing water was recorded.

Fig. 1- Closed hydroponic system (A), Open hydroponic system (B)

Table 1- Dr Howard Resh formulation (Resh, 2013)

High consumption fertilizers	Fertilizers Consumption (g/l)	Low Consumption fertilizers	Fertilizers Consumption (mg/l)
$(NH_4)2SO_4$	1.76	FeEDTA	769.25
$Ca(NO_3)^2$	28	$MnSO_4.H_2O$	38.5
KNO_3	5.55	$ZnSO_4.5H_2O$	7.5
$MgSO_4.7H_2O$	11.4	$CuSO_4.5H_2O$	9.75
KH_2PO_4	6.9	H_3BO_3	71.5
		Na_2MoO_4	3.25

The fruit firmness of tomato fruits was measured by pushing a plunger tip (8 mm and a speed of 20 meters per second) into their opposite pared surfaces along the equatorial region using a handheld penetrometer (Santam STM-1) and the values were expressed as newton (N). Fruit fresh weight was taken to calculate the total dry matter content of tomatoes. After weighing, the fruits were divided into four pieces and put in a 72 °C oven until the dry weight reached a constant weight. Fruit fresh and dry weight data were used to calculate the % dry matter content of 100 g of fresh tomato fruit.

Vegetative traits

At the end of the experiments, the plant height (cm) and the leaf number were recorded. Leaf area (m^2) was measured at the end of the experiment with a leaf area meter (Delta-T Divises LTD, UK).

Gas exchanges

Leaf gas exchanges (net photosynthesis rate, stomatal conductance, intercellular CO_2 concentration, and leaf temperature) were measured using an LCI-SD device made in England. All measurements were performed at 10-12 am at a light intensity of 950 $\mu mol/m^{-2}.s$ photons. Mature and middle leaves were used for sampling so that the first three leaflets of each leaf were used for measurement. 9 samples were taken in each treatment (Marques et al., 2020).

Statistical analysis

Statistical analyzes were performed using MSTAT-C 2.1 (analysis of variance) and SPSS (correlation between trait) software and graphs were drawn by Excel software.

Results and discussion

Greenhouse temperature and humidity

Greenhouse temperature and humidity were recorded using a digital thermometer from the time of seedling transfer (Figure 2).

Yield

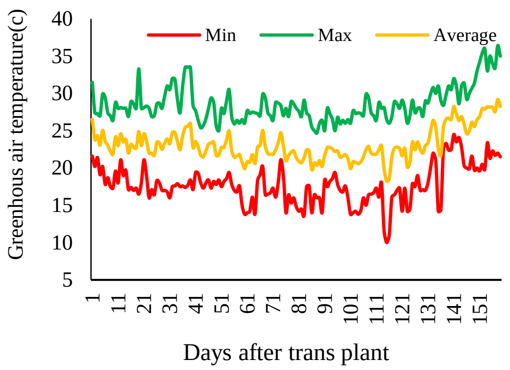
Based on the results of the analysis of variance (data are not shown), the effect of the cultivar on tomato plant yield showed a significant difference at a 5% level ; however, the treatment of the hydroponic system and their interaction was not significant. The highest fruit yield was related to the V4-22 cultivar (3874.29 g per plant) and the lowest fruit yield was obtained in the Amira cultivar (3648.70 g per plant) (Table 2). The findings are consistent with the results of Schmautz et al. (2016) and Rodriguez-Jurado et al. (2020). In hydroponic systems, there is a difference between the yields of different cultivars, and this difference may be due to the genetic characteristics of each cultivar. Cultivars commonly show high sensitivity to production conditions in hydroponic systems. Also been reported a wide range of differences in number of fruits, yield and quality per plant in tomato cultivars. Generally, association of characters indicated that fruit yield per plant, number of fruits per plant, number of fruit clusters per plant are the most important fruit yield components which contributes more to highest fruit yield and quality per hectare (Bozo et al.,2019). The crop yield had a positive and significant correlation at 5% level with stomatal conductance (0.61^{*}), fruit length (0.65*) and leaf area (0.65*). In addition, the yield had a strong and significant correlation at 1% level with plant height (0.87^{**}) (Table 4). There was no significant difference between the two hydroponic systems, but with increased stomatal conductance in the open hydroponic system, more water reached the fruit and the yield increased. The results clearly show that to improve crop yield and the tolerance of increasing nutrient solution concentration in tomatoes, should focus on controlling these traits (Tembe et al., 2017 and Zhang et al., 2016).

Water productivity (WP)

The effect of the hydroponic systems at the 5% level on water productivity were significantly different, while the effect of the cultivar and the interaction of the hydroponic system and cultivar did not cause any significant difference. The highest water productivity occurred in the closed hydroponic system with an average consumption of 33.70 kg/m^3 , whereas the lowest water productivity occurred in the open hydroponic system with an average of 21.84 kg/m^3 (Table 2). The water productivity had a strong and significant correlation at 1% level with water productivity biomass (0.93^{**}) and fruit dry matter (0.74^{**}) (Table 4). The closed hydroponic system showed an increased water productivity by 54.3% in this system. The findings in this study correspond with those of Rodriguez-Ortega et al. (2019), Valenzano et al. (2008) and Rodriguez-Ortega et al. (2017) in which it is stated that the water use efficiency in the closed hydroponic system is higher due to the rotation of the nutrient solution and its reuse, moreover for the production of each kilogram of the tomato crop in the closed hydroponic system 46 liters of nutrient solution is needed ;however, in this study to produce each kilogram of fresh fruit, 45.83 liters were used in the open system and 29.8 liters in the closed system.

Water productivity biomass (WPB)

The effect of the hydroponic system on water productivity biomass caused a significant difference at the level of 5% and the effect of the cultivar and the interaction between the cultivar and the hydroponic system had no effect on water productivity biomass. The highest and lowest water productivity biomass of the tomato plant were measured in a closed hydroponic system (48.91 kg/m^3) and an open hydroponic system (34.42 kg/m^3), respectively and a reduction of water was observed (Table 2).



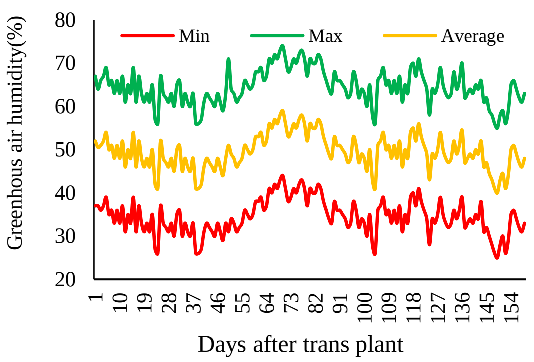


Fig. 2-The left figure: greenhouse temperature graph, the right figure: greenhouse humidity graph.

The water productivity biomass had a strong and significant correlation at 1% level with fruit dry matter (0.87^{**}) (Table 4). The reduction of water productivity biomass in the open hydroponic system was due to the increased nutrient solution consumed in this system, while in the closed hydroponic system, the nutrient solution consumption had a higher efficiency due to its reuse and rotation within the system, resulting into an increased water productivity biomass by 42%.

Leaf area

The effect of the hydroponic systems at the 5% level on leaf area were significantly different, while the effect of the cultivar and the interaction of the hydroponic system and cultivar on the leaf area of tomato plant did not cause any significant difference. The highest and lowest leaf area were measured in open hydroponic system (5.28 m^2) and closed hydroponic system (3.04 m^2), respectively (Table 2). The findings in this study correspond with those of Rodriguez-Ortega et al. (2019), Ahmad Khan et al. (2017) and Zhai et al, (2016), in which it is stated that the closed hydroponic system reduces the leaf area due to the higher concentration of nutrient solution than the open hydroponic system. Increasing the EC level of the nutrient solution significantly reduces the total leaf biomass in a closed hydroponic system. Increasing the leaf area in the open hydroponic system indicates more light absorption, increasing net photosynthetic rate and thus producing more dry matter (Shongwe et al., 2019). Plant growth and dry matter accumulation are related to nutrient uptake. This process is done only by the increases the plant size, leaf area and absorbs more light by the leaf (Fraile-Robayo et al., 2017).

Leaf number

The effect of the hydroponic system, the effect of the cultivar and the interaction of the hydroponic system and the cultivar on leaf number was not significant (Table 2).

Plant height

The effect of the hydroponic systems at the 5% level on plant height were significantly different, while the effect of the cultivar and the interaction of the hydroponic system and cultivar did not cause any significant difference. The highest and lowest plant height were measured in open hydroponic system (248.00 cm) and closed hydroponic system (206.33 cm), respectively (Table 2). Inverse Osmosis in the root environment due to the high concentration of salts in the closed hydroponic system, restricts the growth of shoots and leaves and thus affects on plant height (Ahmad et al., 2017; Dannehl et al., 2017; Shongwe et al., 2019).

Fruit diameter and volume

The effect of the hydroponic system, the effect of the cultivar and the interaction of the hydroponic system and the cultivar on fruit diameter and fruit volume was not significant (Table 3).

Fruit length

The effect of the hydroponic system on fruit length was significant at the 5% level. The effect of the cultivar and the interaction of the hydroponic system and the cultivar on fruit length did not cause significant differences. The maximum and minimum fruit length were measured in open hydroponic system (4.73 cm) and closed hydroponic system (4.54 cm), respectively (Table 3). The fruit length had a positive and significant correlation at 5% level with plant height (0.67^{*}) (Table 4). Tomato fruit length decreases in closed hydroponic systems due to increased nutrient concentration, osmotic conditions and decreased water uptake from roots to fruits, and approximately 93% of the tomato fruit texture is made up of water, therefore the salinity of the nutrient solution reduces the height of the fruits (Shongwe et al., 2019; Rodriguez-Ortega et al., 2017).

Fruit firmness

The effect of the hydroponic systems at the 5% level on fruit firmness were significantly different, while the effect of the cultivar and the interaction of the hydroponic system and cultivar on fruit firmness did not cause any significant difference. The highest and lowest fruit firmness were obtained in open system (45.99 N) and closed system (36.56 N), respectively (Table 3). Increasing the concentration of nutrient solution in a closed hydroponic system can affect fruit firmness by reducing calcium (Ca^{2+}) absorption, which can be due to reduced transpiration and decreased vascular activity and reduced calcium transfer in the plant (Saito et al., 2008 and Rodriguez-Ortega et al., 2017).

Fruit dry matter

The effect of the hydroponic system, the effect of the cultivar and the interaction of the hydroponic system and the cultivar on fruit dry matter was significantly different at the 5% level. The highest and lowest Fruit dry matter were obtained in Amira cultivar in closed hydroponic system (8.53%) and Amira cultivar in open hydroponic system (5.07%), respectively (Table 3). Increasing the concentration of nutrient solution in the closed hydroponic system reduced the transfer of assimilation substances to the vegetative organs, while increasing the percentage of dry matter of the fruit. Due to the increase in the concentration of nutrient solution in the closed hydroponic system, the amount of stomatal conductance and transpiration of plants decreased and reduced water absorption by the fruit and increased the dry matter of the fruit and improved the quality of the fruit (Saito et al., 2008 and Romero-Aranda et al., 2001).

Efficient quantity and consumption of nutrients and fertilizers

In this experiment, the total volume of the nutrient solution consumed in a culture period was measured as being 2310 liters for an open hydroponic system and 1181 liters for a closed hydroponic system. The consumption of the nutrient solution in the open hydroponic system was 192.50 liters per plant , and in the closed hydroponic system ,the consumption of the nutrient solution was equal to 98.43 liters per plant. The results show that the hydroponic system had reduced the consumption of the nutrient solution (depending on the amount) by 96%. The amount of fertilizers used during the cultivation period (6 months) was calculated to be 6.3 kg in the open hydroponic system and 3.2 kg in the closed hydroponic system, respectively, while it was observed that the closed hydroponic system reduced fertilizer application by 97%.

Percentage of Drainage

The amount of drainage in the open hydroponic system was calculated to be 23.5% on average ;moreover, 543 liters of the nutrient solution which was calculated as being between 20-25% was removed from the open system as drainage.

Electrical conductivity(EC) and pH of nutrient solution

Effect of closed hydroponic system on EC

The results of the current study show that the EC of the nutrient in the closed hydroponic system increased within the range of 1.6 to 4.6 ($dS.m^{-1}$) (with an average of 3.02).

Table 2- The effect of irrigation systems on the mean of studied traits of tomato cultivars

Treatment	Yield (g)	WP (Kg. cm^3)	WP_B (Kg. cm^3)	Leaf area (m^2)	Leaf numbr	Plant height (cm)
Irrigation system						
Open system	4205.08^a	21.84^b	34.42^b	5.28^a	34.75^a	248.00^a
Closed system	3317.91^a	33.70^a	48.91^a	3.04^b	34.16^a	206.33^b
Cultivar						
V4-22	3874.29^a	28.59^a	41.41^a	3.86^a	35.16^a	224.50^a
Amira	3648.70^b	26.96^a	41.91^a	4.46^a	33.75^a	229.33^a
System× Cultivar						
Open× V4-22	4337.25^a	22.53^a	34.39^a	4.86^a	36.33^a	249.00^a
Open× Amira	4072.91^a	21.16^a	34.45^a	5.69^a	31.16^a	256.00^a
Closed× V4-22	3411.33^a	34.65^a	48.44^a	2.86^a	34.00^a	203.00^a
Closed× Amira	3224.50^a	32.76^a	49.37^a	3.23^a	34.33^a	210.00^a

Mean followed by similar letters in each column, are not significantly different at the 5% level of probability .

Table 3- The effect of irrigation systems on the mean of studied traits of tomato cultivars.

Treatment	Fruit volume (cm^3)	Fruit diameter (cm)	Fruit length (cm)	Fruit firmness (N)	Dry matter (%)
Irrigation system					
Open system	132.70 ^{a}	5.81 ^{a}	4.73 ^{a}	45.99 ^{a}	5.12 ^{b}
Closed system	130.91 ^{a}	5.64 ^{a}	4.54 ^{b}	36.56 ^{b}	7.50 ^{a}
Cultivar					
V4-22	134.92 ^{a}	5.76 ^{a}	4.61 ^{a}	42.17 ^{a}	5.83 ^{b}
Amira	128.68 ^{a}	5.69 ^{a}	4.67 ^{a}	40.39 ^{a}	6.80 ^{a}
System×Cultivar					
Open× V4-22	128.60 ^{a}	5.79 ^{a}	4.66 ^{a}	47.72 ^{a}	5.18 ^{b}
Open× Amira	136.80 ^{a}	5.83 ^{a}	4.81 ^{a}	44.26 ^{a}	5.07 ^{b}
Closed× V4-22	141.23 ^{a}	5.74 ^{a}	4.56 ^{a}	36.61 ^{a}	6.47 ^{b}
Closed× Amira	120.57 ^{a}	5.55 ^{a}	4.53 ^{a}	36.51 ^{a}	8.53 ^{a}

Mean followed by similar letters in each column, are not significantly different at the 5% level of probability.

The observed increase in the solution concentration parallel the results of Rosa-Rodriguez et al. (2020) and Son et al. (2020).

Effect of open hydroponic system on EC

The EC of the nutrient solution in the open system was 3.2 ($dS.m^{-1}$). The nutrient solution increased to 4.8 ($dS.m^{-1}$) after passing through the culture medium in the open system. In the open system, the increase in EC occurs after the nutrient solution leaves the pots, and this increase is due to the evaporation of water from the nutrient solution, and the effect of the root of the nutrient solution during the hydroponic phase within the pots and after leaving the pots.

Effect of hydroponic systems on the pH of the nutrient solution

The pH level in the open hydroponic system was adjusted between 5.5 and 6.5 with an average of 6.2. The pH changes in the closed hydroponic system ranged from 5.5 to 7.5 with an average of 6.60. This variation was dependent on the ammonium/nitrate ratio (Rosa-Rodriguez et al., 2020).

Net photosynthesis rate (Pn)

The effect of the hydroponic system, the effect of the cultivar and the interaction of the hydroponic system and the cultivar on net photosynthesis rate was not significant (Table 5).

Table 4- Correlation coefficient* between studied characters.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1														
2	0.93**	1													
3	-0.77**	-0.84**	1												
4	-0.04	-0.02	0.03	1											
5	-0.35	-0.52	0.53	0.01	1										
6	-0.61*	-0.68*	0.65*	0.28	0.49	1									
7	0.58*	0.44	-0.61*	0.18	-0.39	-0.10	1								
8	0.74**	0.87**	-0.71**	-0.24	-0.56	-0.55	0.30	1							
9	-0.91**	-0.73**	0.65*	0.13	0.23	0.53	-0.62*	-0.57	1						
10	0.01	-0.08	0.42	-0.43	0.11	-0.09	-0.30	-0.02	-0.09	1					
11	-0.92**	-0.93**	0.87**	-0.01	0.44	0.67*	-0.54	-0.73**	0.75**	0.23	1				
12	0.35	0.23	-0.21	0.09	0.26	0.05	0.39	0.05	-0.28	0.05	-0.21	1			
13	-0.79**	-0.78**	0.61*	-0.11	0.16	0.49	-0.49	-0.60*	0.59*	0.04	0.80**	-0.49	1		
14	0.43	0.44	-0.33	0.19	-0.31	-0.21	0.19	0.44	-0.49	0.12	-0.21	0.02	-0.09	1	
15	-0.91**	-0.87**	0.75**	-0.13	0.38	0.71**	-0.52	-0.64*	0.82**	-0.03	0.84**	-0.42	0.79**	-0.50	1

**: Correlation is significant at the 0.01 level, *. Correlation is significant at the 0.05. N=12, 1- Water productivity yield ($kg.cm^3$), 2- Water productivity biomass ($kg.cm^3$), 3-Yield (g), 4- fruit volume(cm^3) , 5- Fruit diameter(cm), 6- Fruit length(cm), 7- Fruit firmness(N), 8- Fruit dry matter (%), 9- Leaf area (m^2), 10- Leaf number, 11- Plant height (cm), 12- Net photosynthetic rate (Pn, $\mu mol\ co_2.m^{-2}.s^{-1}$), 13- Stomatal conductance (gs, $mol\ H_20.m^{-2}.s^{-1}$), 14-Internal CO_2 concentration (Ci,vpm), 15- Leaf temperature (°C).

Table 5- Comparison of the mean of the gas exchange with Duncan test.

Treatment	P_n (µmol co_2. m^{-2}. s^{-1})	g_s (mol H_20.m^{-2}.s^{-1})	C_i (vpm)	L_t (°C)
Irrigation system				
Open system	8.24^a	0.44^a	402.27^a	28.18^a
Closed system	9.19^a	0.37^b	426.29^a	24.64^b
Cultivar				
V4-22	8.38^a	0.38^a	412.22^a	26.02^a
Amira	9.05^a	0.44^a	416.35^a	26.80^a
System× Cultivar				
Open× V4-22	7.14^a	0.39^a	401.44^a	27.80^a
Open× Amira	9.33^a	0.50^a	403.11^a	28.55^a
Closed× V4-22	9.61^a	0.37^a	423.00^a	24.24^a
Closed× Amira	8.76^a	0.38^a	429.59^a	25.04^a

Treatments with at least one common letter are not have a significant difference.

Stomatal conductance (Gs)

The effect of the hydroponic system on stomatal conductance was significant at the 5% level. The effect of the cultivar and the interaction of the hydroponic system and the cultivar on stomatal conduction did not cause significant differences. The maximum and minimum stomatal conductivity were measured for the open hydroponic system at an average of 0.49 mol/m^2.s ,and for the closed hydroponic system at an average of 0.37 mol/m^2.s respectively (Table 5). The findings are consistent with the results of De Souza et al. (2020) who stated that in the nutrient film technique, the pore conductance decreases with the increasing of the concentration of the nutrient solution. Due to the lower pore conductance in a closed system, the photosynthesis rate increases via aperture conduction (A/gas) , which in itself indicates better water productivity in the product production of such a system (Wang et al., 2019). Various factors such as light, humidity, CO_2, temperature and air flow, are influential in water productivity which also reduces the amount of CO_2 (Haworth et al., 2016). Ultimately CO_2 fixation by the enzyme Rubisco is less, which may lead to lower biomass production, which is consistent with the results obtained in the current study on biomass reduction in the closed hydroponic system (Leakey et al., 2009). It seems that increasing the concentration of the nutrient solution in the closed hydroponic system causes an accumulation of abscisic acid in the roots which is transfered to the shoot, and which subsequently leads to the closure of the stomata and reduces transpiration (Khan et al,. 1998).

Intercellular CO_2 concentration (Ci)

The effect of the hydroponic system, the cultivar and the interaction of the hydroponic system and the cultivar on intercellular CO_2 concentration was not significant (Table 5).

Leaf temperature (LT)

The hydroponic system had a significant difference at the level of 5% on leaf temperature, but the cultivar and the interaction between the hydroponic system and the cultivar were not significantly different. The highest and lowest leaf temperatures were measured in the open hydroponic system with an average of 28.18 °C and in the closed hydroponic system with an average of 24.64 °C, respectively (Table 5). High leaf temperature has a beneficial effect on plant gas exchange, photosynthesis and plant yield. In addition to affecting photosynthetic structures, high temperature increases light respiration ,and thus decreases photosynthetic efficiency (Sajadinia et al., 2009). The high leaf temperature in the open hydroponic system indicates the lower photosynthetic efficiency of this system due to the fact that photosynthesis is not significant in the treatment of the hydroponic system, but it is higher in the closed system.

Conclusions

According to the results of this experiment, the highest and lowest crop yields were measured in the V4-22 cultivar (3874.29 g per plant) and in the Amira cultivar (3648.70 g per plant), respectively. The main advantage of the modern hydroponic system is water-saving and increasing productivity per unit area. According to the results of this study, the closed hydroponic cultivation system has a water productivity up to 96% and nutrients up to 97% as compared to the open hydroponic system and the crop yield in the two systems was not significantly different. In terms of the ecophysiological characteristics of the plants, the two systems did not differ in terms of their photosynthesis, but the open system had better ecophysiological properties than the closed system due to its higher stomatal conductance. In the closed system, due to the reuse of the nutrient solution, drainage into the environment in addition to environmental pollution nutrient toxicity and the contamination of groundwater aquifers did not occur.

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