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Comparison of open and combined closed hydroponic system on water productivity, nutrient use efficiency yield and fruit quality of cucumber

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Abstract

One of the greatest challenges currently facing society is the production of high-yield and high-quality foods due to population growth and the need to increase food production. In this study, the effect of two hydroponic systems on water productivity, nutrient use efficiency yield and fruit quality of three greenhouse cucumber cultivars have been investigated. This experiment is in the form of split plots in a randomized complete block design, with the treatment of cucumber cultivars (Strong, Yalda, and RY) and type of hydroponic cultivation system (open and combined closed) in which 3 replicates were implemented at Shahid Chamran University of Ahvaz. The studied traits included water productivity, nutrient use efficiency, crop yield, fruit length and diameter, fruit volume, fruit firmness, fruit dry weight, fruit carotenoids, phenolic compounds, total soluble solids, titratable acidity were measured. The highest fruit length, fruit diameter, yield, water productivity and nutrient use efficiency were obtained in the combined closed system. The highest fruit firmness, total soluble solids, phenolic compounds were obtained in the open system. The combined closed system increased crop yield, water productivity and nutrient use efficiency by 22.63%, 80.81% and 81.92 % respectively, as compared to the open system. The highest phenolic compounds, fruit length, yield and water productivity were calculated in the RY cultivar. The RY cultivar increased phenolic compounds by 56.30% and 71.98% respectively, as compared to the Strong and Yalda cultivars. Based on the results, Fruit diameter had a significant correlation with fruit length (0.47^{*}) and crop yield (0.55^{*}). According to the results of this study, combined closed system and RY cultivar have the highest quality characteristics of fruit and yield, therefore they can be recommended for greenhouse production.

Introduction

Due to the high demand for water resources and the consequent supply of food, many new trends have evolved in innovative farming methods that involve a complex system of agricultural production. Greenhouses play an essential role in reducing water consumption, food supply, and the farmer's economy due to their ability to control environmental factors and enable the production of off-season crops (Miller et al, 2020). The hydroponics cultivation system is the production of a crop using the nutrient solution, which is divided into open and closed systems. In this system provide water and nutrients to the plant as a nutrient solution and in the open system (about 25%) is drained from the system as water, causing environmental pollution (Fayezizadeh et al, 2021; Maucieri et al, 2018; Savvas and Gruda, 2018). In the closed system, the nutrient solution is returned to the main tank after passing through the pot and is rotated uniformly and continuously in the system during the day and night (Maucieri et al, 2018). In the closed system nutrients are absorbed by the plant, to regenerate the nutrient solution nutrients and water are added to it with a certain percentage. The high efficiency of the nutrient solution in the closed system for the production of crops such as leafy vegetables, tomatoes, cucumbers, and peppers are among the advantages that can encourage greenhouse growers to grow products in this system (Fayezizadeh et al, 2021). Khafajeh et al. (2020), in a study of a closed hydroponics cultivation system (Aqua Crop) on the morphological characteristics and yield of greenhouse cucumber, concluded that the closed system produced the highest yield and biomass with the least evapotranspiration. In a study to determine the effect of wick systems (closed) and drip (open) on the yield and quality of tomato fruit, the results showed that the wick system increased of fruit firmness, ascorbic acid, soluble solids and yield, as compared to the drip system (Kaur et al, 2018). Abd-Elmoniem et al. (2006) in the study of closed and open systems in lettuce cultivation reported, the yield in the closed system was 5% higher than the open system in lettuce cultivation, and closed system reduced water and nutrient consumption. Fayezizadeh et al. (2023), in a study on the effect of open and closed hydroponics systems on the quality characteristics and yield of tomato reported, the highest fruit length and fruit firmness were obtained in the open irrigation system and the total soluble solids, lycopene, fruit carotenoids were obtained in the closed irrigation system (NFT) and also the irrigation systems were not significantly different in terms of crop yield. Rodriguez Ortega et al. (2019) in the study of the effect of three hydroponics systems (DFT, perlite, and NFT) on the quantitative and qualitative characteristics of tomatoes concluded that the NFT system increased total soluble solids and titratable acidity and fruit quality. Fayezizadeh et al. (2023), reported, water productivity in a closed system (about 55%) was higher than open system, and closed irrigation system decreased nutrient solution consumption by up to 96% and fertilizer consumption by up to 97% compared to the open system.

Cucumber (Cucumis sativus L.) is listed among the top four important vegetable crops after *Solanum* lycopersicum, *Brassica oleracea*, and Allium cepa (Ghani et al., 2022), in addition, its nutritional contribution and nutraceutical properties have positive impacts on health, especially in people with diabetes, hypertension, cardiovascular, and Alzheimer’s disease. Moreover, it is also a high source of fiber, carbohydrates, proteins, magnesium, iron, vitamin B and C, flavonoids, phenolic compounds, and antioxidants (Yuan et al, 2019; Uthpala et al, 2020).

The innovation of this research is the use of integration of several combined irrigation systems included drip irrigation system, aeroponics system, wick system, and deep water culture system. The combination of these systems in cucumber cultivation caused the water productivity in this system to be calculated at about 72 kg/m^3 while the open system was measured at 39 Kg/m^3. Also, no droppers were taken in this system. Environmental pollution is at a minimum. The energy required for irrigation was generated using the earth's gravity, and only small pumps carried water from the sewage collection containers to the main tank. Therefore, the purpose of the current study was comparison of open and combined closed hydroponic system on water productivity, nutrient use efficiency yield and fruit quality of cucumber at Shahid Chamran University of Ahvaz.

Materials and methods

This experiment was carried out in the autumn and winter of 2021 in the greenhouse and qualitative analysis laboratory of the Department of Horticultural Sciences, the Shahid Chamran University of Ahvaz in the form of split plots in a randomized complete block design with three replications. Experimental treatments include two types of open and closed hydroponics systems and 3 cucumber cultivars (Strong and Yalda from Rijk Zwaan Company in the Netherlands, and RY cultivar was bred at the Shahid Chamran University of Ahvaz). The temperature and humidity in the greenhouse were recorded daily by a digital device (Termo hygrometer-Germany made in Germany) (Figure1). The culture medium in the open hydroponic system was (50% cocopeat+50% perlite); however, the combined closed hydroponic system was without any culture medium (Figure 2). After preparing the nutrient solution, the EC and pH of the nutrient solution in both the combined 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 1.7 (dS m^{-1}) in the open system and ranged from 1.2 to 2.5 (dS m^{-1}) in the combined closed system. After resetting the EC of the nutrient solution in the combined closed hydroponic system, the pH of the nutrient solution was measured and adjusted using H_2SO_4 or NaOH in the range of 5.8–6.0 as required. In the open hydroponic system, the nutrient solution was transferred to the plant by pipes and drippers using a digital timer. Irrigation was done in the open system from 8 am to 6 pm during the day and in the combined closed hydroponic system, irrigation was done by gravity and the nutrient solution was transferred to the pots. The drainage water was collected and returned to the tank by using a pump and P.V.C pipe. The nutrient solution had a constant volume in the pots and flowed consistently during the day and night. A Resh nutrient solution was used to feed the plants (Resh, 2013) (Table 1). After preparing the nutrient solution, the electrical conductivity and pH of the nutrient solution were measured in two systems using a manual digital conductivity meter and a pH meter (Phantong et al, 2018).

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

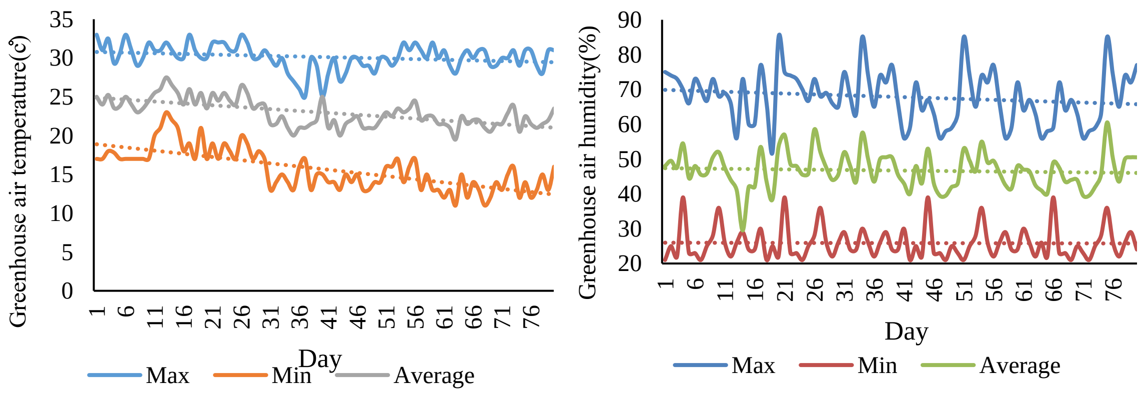

Fig. 2- The above figure: greenhouse temperature graph, the below figure: greenhouse humidity graph.

Table 1- Nutrient solution of Resh (2013)

High Consumption elements	Elements Consumption (ppm)	Low Consumption elements	Elements Consumption (ppm)
N	140	Mn	0.8
P	50	Cu	0.07
K	325	Zn	0.1
Mg	50	B	0.3
Ca	180	Mo	0.03
S	168	Fe	2

The pH of the nutrient solution was adjusted in two systems in the range of 5.8 - 6.0 and the electrical conductivity in the open system was 1.7 (dS m^{-1}) and the combined closed system was in the range of 1.2-2.5 (dS m^{-1}).

Measured variables

Normally, the cucumbers were harvested every 1–2 days, with the yield recorded each time, and all fruits harvested during the week were added together as the total yield in grams. Fruit length (cm) and fruit diameter (mm) after each harvest were recorded using a ruler and a caliper, respectively. Fruit volume was measured by fluid transfer (weight change). The amount of total soluble solids (Brix°) was measured with an Atago digital refractometer, A-PAL-1 (Voca et al., 2007). Total acidity in terms of percentage of malic acid was determined by titration method with 0.1 N sodium hydroxide solution until pH = 8.1 (Voca et al, 2007). The percentage of fruit dry matter was measured by a standard drying method in an oven at 70 ° C. Fruit firmness (N/mm) was measured by the Santam STM-1 hardness tester with a 0.8 mm probe at a speed of 20 m/s. The total carotenoid of the fruit (mg/100gr FW) at a wavelength of 450 nm was calculated (Arnon, 1967).

Carotenoids= (1000(A470)–1.8(chl a)–58.2(chl b)) /198 (1)

The total phenolic contents of the cucumber extracts were evaluated using the procedure explained by Benzie and Strain. (1996). The absorbance of the samples was read at 725 nm. The concentration of phenolic compounds (mg/kg) was calculated using the standard of gallic acid (Y=0.0095X-0.0502, R^2 = 0.9606). In this study, water productivity in two open and combined closed hydroponics systems was measured and recorded during planting from the beginning to the end of the experiment. Irrigation in the open system was adjusted based on the water drainage (20-25%) from the pots. In order to measure nutrient use efficiency, the volume of nutrient solution applied per plant was recorded on daily basis and the concentration of each nutrient in the applied nutrient solution was known (Fayezizadeh et al, 2021; Singh et al, 2019).

$$\text{Water Productivity: } \frac{\text{Yield (kg plant}^{-1})}{\text{Water applied (m}^3\text{ plant}^{-1})} \quad (2)$$

$$\text{Nutrient Use Efficiency: } \frac{\text{Yield (g plant}^{-1})}{\text{Nutrient applied (g plant}^{-1})}$$

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

Results and discussion

Fruit diameter and length

The effect of the hydroponics cultivation system had a significant difference on fruit diameter at 1% level. But the effect of cultivar and the interaction of cultivar and hydroponics system on fruit diameter was not significant. The effect of the hydroponics system on fruit length at 5% level and the effect of cultivar on fruit length at 1% level had a significant difference. The interaction effect of hydroponics system and cultivar on fruit length was not significant (Table 2). The highest and lowest fruit diameters were measured in the combined closed system (32.16 mm) and in the open system (30.97 mm). The highest and lowest fruit lengths were measured in RY cultivar (15.19 cm) and

Strong cultivar (14.73 cm), respectively. The highest and lowest fruit lengths were measured in the combined closed system (15.12 cm) and in the open system (14.89 cm) (Table 3). The findings are consistent with the results of Maboko et al, (2012). They stated that the length and diameter of fruits in the combined closed hydroponics system are more than open system. Cardoso et al. (2017), showed that increasing the concentration of potassium in the nutrient solution in the closed system increases the fruit diameter. Probably the longer length of the fruits of the RY cultivar is also a genetic characteristic of this cultivar. Fruit diameter had a significant correlation with fruit length (0.47*) and crop yield (0.55*) (Table 4). By increasing the diameter and length of the cucumber fruit, the weight of single fruit and ultimately the yield of the whole crop increases (Ahirwar et al, 2017).

Fruit volume and firmness

Based on the results, the effect of the hydroponic system, the cultivar and the interaction of the hydroponic system and the cultivar on fruit volume was not significant (Table 2). The effect of the hydroponics system and the effect of cultivar on fruit firmness showed a significant difference at the 5% level. The interaction of hydroponics system and cultivar did not have a significant on fruit firmness (Table 2). The highest and lowest fruit firmness were obtained to the open system (65.50 N/mm) and combined closed system (60.54 N/mm), respectively (Table 3). The highest and lowest fruit firmness were obtained in Strong cultivar (65.87 N/mm) and Yalda cultivar (58.47 N/mm), respectively (Table 3). The results of this study are consistent with the results of Fayezizadeh et al. (2023) and Saito et al. (2008), they concluded that increasing the concentration of the nutrient solution in the closed system is an important factor influencing the firmness of the fruit by reducing the absorption of calcium (Ca^{2+}). The calcium is non-moving in the plant and mainly moves in the plant by water in the phloem. Therefore, with increasing the concentration of the nutrient solution, the osmotic potential of water decreases, and the transfer of water to the fruit decreases. Genetic factors in different cultivars can make a significant difference in fruit quality traits such as fruit firmness between cucumber cultivars. Fruit firmness had a significant correlation with fruit diameter (0.489*) (Table 4). The growth process of cucumber fruit affects the firmness and composition of the cell wall. The fruit firmness of all cucumber decreased with increasing fruit diameter. This decrease in firmness is mainly due to the activity of some endogenous enzymes related to the destruction of the cell wall, which increases during the fruit growing season. In addition, changes in fruit firmness are associated with the degradation of the middle layer of parenchymal cells, leading to a significant increase in pectin dissolution (Shehata et al., 2021).

Titratable acidity, dry matter and fruit carotenoids

The effect of the hydroponic system, the cultivar and the interaction of the hydroponic system and the cultivar on titratable acidity, percentage of dry matter and fruit carotenoids were not significant (Table 2).

Phenolic compounds

The effect of hydroponics cultivation system, the effect of cultivar, and the interaction effect of hydroponics cultivation system and cultivar on phenolic compounds of fruit made a significant difference at a 1% level (Table 2). The highest and lowest levels of phenolic compounds were measured in the RY cultivar (2191.13 mg gallic acid/gr FW) and Yalda cultivar (1232.16 mg gallic acid/g FW), respectively (Table 5). Also, the highest and lowest concentration of phenolic compounds were obtained in the combined closed system (1811.78 mg gallic acid/gr FW) and in the open system (1374.26 mg gallic acid/gr FW), respectively (Table 5). The findings are consistent with the results of Antolinos et al. (2020). They stated that different concentrations of nutrient solution in the NFT system increased fruit phenol content in vegetables. Kumaric acids, ferulic acid, and caffeic acid are among the main phenolic compounds in cucumber (Ongena et al, 2000).

Total Soluble solids

The effect of hydroponic system on the total soluble solids was significantly different at the level of 1% (Table 2). The effect of cultivar and the interaction of the hydroponic system and cultivar on the total soluble solids did not show a significant difference. The highest and lowest of soluble solids were obtained in a combined closed system with average (3.00° Brix) and open system with average (2.50° Brix), respectively (Table 5). The findings are consistent with the results of with the results of Kaur et al. (2018). The combined closed system had higher values and better quality in terms of ascorbic acid and soluble solids in the fruit. Schmautz et al. (2016), stated that plants can regulate themselves osmotically, because with increasing the concentration of the nutrient solution, the amount of sugars, organic acids, and mineral salts increases and osmotically negatively affects and ultimately prevents the deficiency of various tissues. The yield had a significant correlation with TSS (-0.489) (Table 4). The increase in TSS may due to be the dissolution of cellulose and hemicellulose in the cell wall or water loss. Therefore, considering that about 97% of cucumber fruit is water, with increasing sugars and loss of fruit juice, crop yield will decrease (Shehata et al., 2021).

Crop yield

Based on the results of the analysis of variance, the effect of the hydroponics cultivation system and the effect of cultivar on the fruit yield of cucumber showed a significant difference at a 1% level. The interaction effect of hydroponics cultivation system and cultivar on yield was not significant (Table 2). The highest and lowest fruit yields were obtained in the combined closed system with an average (4043.11 g) and in the open system with an average (3296.88 gr), respectively (Table 5). The RY cultivar with average (3858.00 g) and Yalda cultivar with average (3421.66 g) had the highest and lowest fruit yields, respectively (Table 5). The findings are consistent with the results of Roza-Rodriguez et al. 2020 and Fayezizadeh et al. (2021). They concluded in an experiment to determine the efficiency of water consumption and tomato fertilizer in greenhouse conditions under both open and closed hydroponic systems. The closed hydroponic system (recirculation of nutrient solution) 13.50 kg more fruit compared to open system (with non-circulating nutrient solution) produced. The yield of cultivars in different hydroponics systems is different and this can be the result of diversity and genetic characteristics that exist between different cultivars under different cultivation conditions (Fayezizadeh et al. 2023).

Water productivity

The effect of the hydroponic systems at the 1% 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 (Table 2). The highest water productivity occurred in the combined closed hydroponic system with an average consumption of 72.05 kg/m^3, whereas the lowest water productivity occurred in the open hydroponic system with an average of 39.82 kg/m^3 (Table 5). The combined closed hydroponic system showed an increased water productivity by 80.93% in this system. The findings in this study correspond with those of Verdoliva et al. (2021), and Al-Shrouf, (2017), that they compare water and fertilizer use efficiency in open and closed hydroponic systems and conclude that closed irrigation systems reduce water loss and increase water use efficiency compared to open systems. Therefore, closed hydroponic systems are more efficient in terms of water consumption efficiency and are also able to produce higher quality products.

Nutrient use efficiency

Based on the results, the amount of fertilizer consumed in the open system and in the combined closed system was 9.26 gr plant^{-1} and 5.09 gr plant^{-1} respectively, and the combined closed system increased nutrient use efficiency by 81.92% compared to the open system. These results are due to the recirculation of the nutrient solution in a combined closed system since this allows reducing the water and fertilizers used. Nutrient uptake by plants is affected by several factors, such as ionic concentration in the nutrient solution, pH, the selectivity of the roots, and oxygen concentration of the nutrient solution, climate, and plant development stage (Lopez et al. 2011;

Kempen et al. 2017). The uptake of nutrients is affected by the balance existing among them, which in closed systems is the main factor to maintain optimal plant nutrition (Moreno-Perez et al. 2015). The findings in this study correspond with those of Fayezizadeh et al. (2021) and Rosa-Rodríguez et al. (2020), which reported in the closed hydroponic system the amount of fertilizers decreased during the tomato crop cycle, in comparison to the open system and this was because of the recirculation of the nutrient solution.

Table 2- Variance analysis for studied traits as a function of cucumber (C) cultivars and Hydroponics systems (H)

		Mean Squares					
Source of variance	DF	Fruit length	Fruit diameter	Fruit volume	Fruit firmness	Fruit dry weight	Fruit carotenoids
Replication	2	0.078 ns	0.165 ns	37.389ns	24.833 ns	0.284 ns	0.132 ns
H	1	0.229*	6.349**	6.722 ns	110.558*	0.344 ns	0.041 ns
Error	4	0.107	0.402	104.222	25.663	0.060	0.785
C	2	0.356**	0.299 ns	321.056 ns	95.014*	0.151 ns	1.076 ns
H×C	2	0.060 ns	0.097 ns	132.056 ns	34.800 ns	0.224 ns	0.165 ns
Error	6	0.027	0.445	79.944	13.788	0.203	0.342
(%) CV		1.09	2.11	7.93	5.89	14.94	18.13
Source of variance		Phenolic compounds	Total soluble solids	Titratable acidity	Water productivity		Crop yield
Replication	2	0.008 ns	0.245 ns	8.877 ns	0.489 ns		13388.667 ns
H	1	0.167 **	1.125*	22.894 ns	4672.222**		2505814.222**
Error	4	0.039	0.138	3.271	1.153		30784.833
C	2	0.438 **	0.095 ns	31.304 ns	75.608**		301960.667**
H×C	2	0.439 **	0.195 ns	48.124 ns	8.136ns		61333.556 ns
Error	6	0.019	0.080	56.534	2.227		16649.778
(%) CV		5.13	10.70	19.52	29.37		3.51

Note. **, *, ns: significant effect at 1%, 5%, and no significant effect, respectively.

Table 3- Comparison of the mean of the physical characteristics of fruit with Duncan test.

Treatment	Fruit firmness (N/mm)	Fruit volume (cm^3)	Fruit diameter (mm)	Fruit length (cm)
Hydroponic system				
Closed system	60.54^{b}	112.00^{a}	32.16^{a}	15.12^{a}
Open system	65.50^{a}	113.22^{a}	30.97^{b}	14.89^{b}
Cultivar				
Strong	65.87^{a}	104.16^{a}	31.48^{a}	14.73^{b}
Yalda	58.47^{b}	116.66^{a}	31.82^{a}	15.10^{a}
RY	64.72^{a}	117.00^{a}	31.40^{a}	15.19^{a}
System× Cultivar				
Open× Strong	68.91^{a}	105.33^{a}	31.03^{bc}	14.73^{b}
Open× Yalda	58.31^{b}	121.66^{a}	31.19^{abc}	14.90^{ab}
Open× RY	69.27^{a}	112.66^{a}	30.71^{c}	15.05^{ab}
Closed× Strong	62.82^{ab}	103.00^{a}	31.93^{abc}	14.73^{b}
Closed× Yalda	58.64^{b}	111.66^{a}	32.46^{a}	15.30^{a}
Closed× RY	60.17^{b}	121.33^{a}	32.10^{ab}	15.33^{a}

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

Table 4- Correlation coefficient* between studied characters.

	1	2	3	4	5	6	7	8	9	10	11
1	1										
2	-0.313	1									
3	0.594**	-0.081	1								
4	-0.126	0.400	-0.203	1							
5	-0.193	0.017	0.085	-0.299	1						
6	0.382	-0.123	0.012	-0.228	-0.309	1					
7	-0.372	0.558*	-0.105	0.416	0.302	-0.169	1				
8	-0.489*	0.130	-0.448	0.121	0.358	-0.210	0.226	1			
9	-0.299	0.296	0.078	0.337	0.222	-0.325	0.139	0.473*	1		
10	-0.114	-0.121	-0.489*	0.413	0.087	-0.050	-0.074	0.555*	0.280	1	
11	-0.084	-0.541*	0.424	0.168	-0.28	0.018	0.686**	0.380	0.926**	-0.313	1

**: Correlation is significant at the 0.01 level, *. Correlation is significant at the 0.05. N=12, 1- Fruit firmness(N/mm), 2- fruit volume(cm^3), 3- Total soluble solids content(Brix◦), 4- Phenolic compounds (mg galic acid/kg), 5- Titratable acidity (mg Citric acid/100gr Fw), 6- Fruit dry matter (%), 7- Fruit Carotenoids (mg/100gr Fw), 8-Fruit diameter (cm), 9- Fruit height(cm), 10- Yield (gr), 11- Water productivity (kg/m^3).

Table 5- Comparison of the mean for total soluble solids (TSS, Brix◦), Phenolic compounds (PC, mg galic acid/kg), titratable acidity (TA, mg Citric acid/100gr Fw), fruit carotenoids (FC, mg/100gr Fw), fruit dry weight (FDW, g), yield (Y, g) **and water productivity (WP, Kg/m^3) with Duncan test**

	TSS	PC	TA	FC	FDW	Y	WP
Hydroponic system							
Closed system	3.00^{a}	1811 ^{a}	39.63^{a}	4.48^{a}	2.87^{a}	4043^{a}	72.0^{a}
Open system	2.5^{b}	1374. ^{b}	37.33^{a}	4.38^{a}	3.15^{a}	3296^{b}	39.8^{b}
Cultivar							
Strong	2.63^{a}	1355.78^{b}	36.73^{a}	3.95^{a}	3.16^{a}	3730^{a}	56.0^{b}
Yalda	2.73^{a}	1232.16^{b}	41.08^{a}	4.76^{a}	2.84^{a}	3421^{b}	52.3^{c}
RY	2.88^{a}	2191.13^{a}	37.70^{a}	4.58^{a}	3.02^{a}	3858^{a}	59.4^{a}
System× Cultivar							
Open× Strong	2.83^{ab}	1555.59^{b}	36.73^{a}	3.96^{a}	3.51^{a}	3462^{c}	41.2^{c}
Open× Yalda	2.83^{ab}	1203.01^{b}	36.73^{a}	4.85^{a}	2.81^{a}	2952^{d}	35.1^{d}
Open× RY	3.33^{a}	1364.20^{b}	38.66^{a}	4.35^{a}	3.12^{a}	3476^{c}	43.1^{c}
Closed× Strong	2.43^{b}	1155.97^{b}	36.73^{a}	3.95^{a}	2.81^{a}	3998^{ab}	70.9^{b}
Closed× Yalda	2.63^{ab}	1261.31^{b}	45.43^{a}	4.67^{a}	2.88^{a}	3891^{b}	69.4^{b}
Closed× RY	2.43^{b}	3018.05^{a}	36.73^{a}	4.81^{a}	2.92^{a}	4239^{a}	75.7^{a}

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

Conclusions

Knowing the methods for increasing water productivity, nutrient use efficiency, and the quality of the product in a controlled environment is very important. One of the new methods that increased the efficiency of water, fertilizer consumption, yield, and TSS in cucumber was the combined closed system consisting of several different closed hydroponic systems. This system was able to increase water productivity (80.81%), nutrient use efficiency (81.92 %), and yield (22.63%) of greenhouse cucumber, compared to the usual drip irrigation method. The highest yield and quality of fruit such as length, diameter, and TSS were obtained in the combined closed system. The RY cultivar produced by the Shahid Chamran University of Ahvaz improved fruit quality and yield compared to other cultivars. It seems that this efficiency could be increased because, by increasing temperature and decreasing humidity in the greenhouse, evaporation and transpiration are reduced. By using the environmental management system (EMS), it is possible to better control the environment for increasing photosynthesis, yield, and water productivity. In future research, the integration of humidity control, temperature, carbon dioxide, and new irrigation methods with the use of an intelligent climate control system can control many environmental stresses.

Ethical approval

Not applicable.

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Consent to participate

Consent was obtained from all individual participants included in the study.

Consent to publish

The participant has consented to the submission of the case report to the journal.

Credit authorship contribution statement

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Hossein Darai and Naser Alemzadeh Ansari. The first draft of the manuscript was written by Hossein Darai and Naser Alemzadeh Ansari and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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