Colegio de Postgraduados

Strawberry (*Fragaria* × *ananassa* Duch.) production in a vertical hydroponic greenhouse system

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ABSTRACT

Objective: A vertical hydroponic greenhouse system (VHGS) was designed and built to evaluate two strawberry varieties (Festival and San Andreas), in two planting densities per pot (40 and 54 plants/m^2) and three elevation levels (high, medium, and low).

Design/Methodology/Approach: At 126 days after transplanting (dat), the Festival variety showed significant differences in the number of leaves and in the crown diameter.

Results: The vertical hydroponic greenhouse system had a high fruit yield (21 kg m^2): *i.e.*, this production system is up to 35% more efficient than the open field cultivation system or the multi-tunnel greenhouse system. There was a positive correlation between the number (r^2=0.89), diameter (r^2=0.54), and weight (r^2=0.40) of the fruits and the total yield. Planting density did not show a significant effect on plant growth, yield, and fruit quality. The vertical pot system did not show differences between elevation levels. This production system is a viable option for populations in places with a scarcity of water and to obtain fruits with guaranteed food safety.

Keywords: pot, substrate, soilless cultivation, intensive production, vegetables.

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INTRODUCTION

The current agricultural model —based on large, cultivated areas and the excessive use of water— will probably be threatened in the coming decades and will become unsustainable. Vertical farming can offer a solution to this problem (Despommier, 2010; Benke and Bruce, 2017). In view of the abovementioned situation, different architectural arrangements that use the hydroponic technique have been studied, including pyramidal systems, metal frames, and vertical bag arrangements (Resh, 2001) in which most horticultural crops can be produced, including lettuce, tomatoes, and strawberries (Frazier, 2017). The crop medium of this systems can consist of only water or different substrates —such as

minerals, wool, coconut fiber, or perlite—, with a nutrient solution that provides adequate nutrition (Kratky, 2005; Jones, 2016). In addition, Sánchez del Castillo (2014) indicates that hydroponic systems allow high crop densities, an adequate balance of nutrients, and water savings. For example, the density of strawberry plants grown in open field cultivation systems is 6.5 to 8 plants m^2, while the planting density in vertical hydroponic greenhouse system can be increased up to three times (Ozeker *et al.*, 1999). The strawberry plant can be produced in a vertical system, given its physio-morphological characteristics (Despommier, 2010). The fruit value of strawberry has increased the cultivation area and this phenomenon has made Mexico one of the most important producers worldwide (SIAP, 2017). In Mexico, the most commonly used strawberry varieties are Festival, Sweet Charlie, Galexia, Camino Real, Albión, Camarosa, Aromas, Ventana, and Diamante (SAGARPA, 2018). The San Andreas variety is new, and it has been used in the country only in recent years (Eurosemillas, 2018). Therefore, a vertical hydroponic greenhouse system that uses pots can be an option for strawberry production in a protected environment, increasing the plant density and consequently the production. The objective of this work is to evaluate two strawberry varieties, two planting densities per pot, and three elevation levels, in a vertical hydroponic greenhouse system without climate control.

MATERIALS AND METHODS

Description of the experimental site

The study was carried out in a 756-m^2 double tunnel greenhouse with passive ventilation, during March to October 2017, in the municipality of Salinas de Hidalgo, San Luis Potosí. The temperature and relative humidity conditions were recorded with a Hobo 2-channel datalogger; the data were arranged using the HOBOware software and finally exported to Microsoft® Excel.

Strawberry plant pretreatment

Bare root plants of the San Andreas and Festival varieties were subjected to cold treatment (3 °C for 60 days). Subsequently, the plants were disinfected with 1 ml/L of Ridomil Gold, the roots and damaged leaves were removed, and the vigorous plants of homogeneous size were selected. Finally, they were transplanted.

Hydroponic system

The plants were established in a vertical hydroponic greenhouse system with pots. This system was made of a supporting tube (fixed to the ground with concrete), where six 15-L round pots were placed one on top of the other. The pots were immobilized with two flat bars to avoid direct contact with the substratum placed immediately below. The supports were interconnected with a gutter system (made from a 10” tube) to drain excess irrigation water. Five kg of coconut fiber per pot were used as a substrate. The system had 48 columns with 5 pots per column, for a total of 240 pots. The columns were established 0.50 m apart from each other, with 1 m between rows (triangular plant spacing). The irrigation system consisted of a 2,500-L water tank (rainwater), a ¼ HP pump, a main distribution line (16 mm hose). Three 4-L h1 self-compensating drippers were placed in each column, with a

4-outlet drip irrigation manifold. Each one was connected to the micro tubing and finally to a dripper on stake. Each self-compensating dripper was connected to two pots; therefore, the micro tubings were cut into three different lengths: 0.25 m, 0.60 m, and 1.10 m.

Irrigation program and nutrient solution

For the first three days, the plants were irrigated only with rainwater. The initial nutrient solution was applied on a later date. The nutrient solution used was developed by Hewitt and Smith (1974) and Caruso *et al.* (2011). During the vegetative stage (*i.e.*, 1 to 140 days after transplanting (DAT)), the nutrient solution had a 6.0 (±0.3) pH and a 1.3 dS m^{-1} electrical conductivity. During the reproductive stage (*i.e.*, 141 to 210 DAT), the nutrient solution had a 1.5 dS m^{-1} electrical conductivity, which was applied to 100-400 mL $plant^{-1}$/day. The nutrient supply was managed with an open system. Volume, pH, and electrical conductivity were measured twice a week to avoid salinization of the coconut fiber (Depardieu *et al.*, 2016).

Plant behavior variables

Data on the number of leaves and crown diameter —considering the multiple crowns of the plant as one and measuring the widest part with a digital vernier— were recorded according to Cantliffe *et al.* (2007). The number of runners, flowers, and fruits, as well as the fresh and dry weight of the plant, were also measured. The variables were measured every 15 days. Fruit weight, fruit diameter, and fruit yield (g $plant^{-1}$ and kg m^2) were measured after the harvest. Soluble solids from strawberry juice were measured with an ATAGO optical refractometer (Brix 0.0-33.0%), according to the NMX-FF-062-SCFI-2002 standard. The fruits were harvested every week.

Experimental design

A randomized complete block design was used. It consisted of 12 treatments, 6 repetitions, and a factorial arrangement. The following factors were tested: a) two strawberry varieties (“Festival” and “San Andreas”); b) two planting densities per pot (three and four plants per pot; 54 plants m^2 and 40 plants m^2, respectively); and c) three elevation levels in the vertical system (high, medium, and low). Data were taken from one plant per experimental treatment. The statistical analysis of the results was carried out using a general linear model, a regression procedure, and a correlation analysis with Duncan’s multiple range test (alfa=0.05) using the SAS 9.4 statistical software.

RESULTS AND DISCUSSION

Temperature and humidity in the greenhouse

From March to June, the temperature recorded a 35 °C average maximum and a 15 °C average minimum; from July to October, the temperature reached a 32 °C average maximum and a 14.5 °C average minimum. The relative humidity (RH) from July to October recorded a 91.1% average maximum and a 32.1% average minimum (Figure 1). The maximum temperatures during this period reached 38 °C, although this peak lasted less than 4 hours.

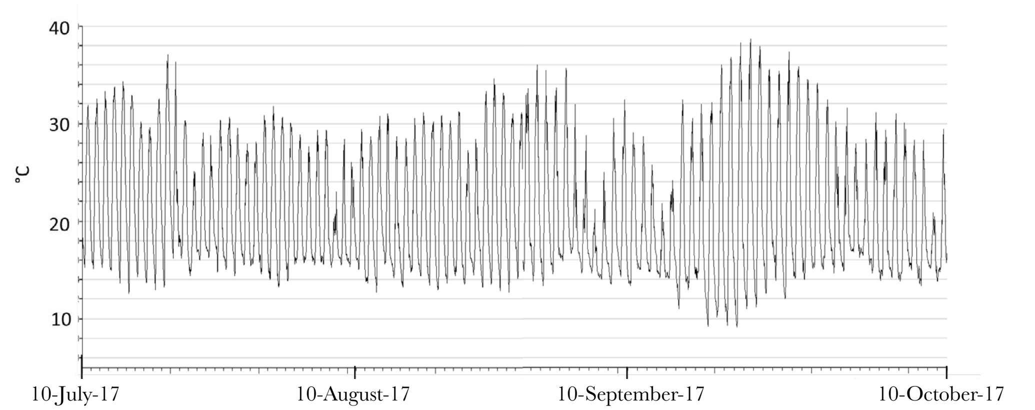

Figure 1. Distribution of the daily temperature inside the greenhouse, from July to October 2017.

As reported by Hidaka *et al.* (2017) and Radin *et al.* (2011), a minimum difference of three degrees in the average temperature leads to a lower production in the strawberry cultivar. However, Ledesma and Sugiyama (2005) reported that there are strawberry cultivars that have greater genetic tolerance to high temperature stress, such as the Nyoho variety.

Vegetative behavior of strawberry plants

The plants had good vegetative development during the first 45 days, but the flowering was delayed up to 98 days after transplanting (DAT). Hidaka *et al.* (2017) determined that flowering begins at 45 DAT. The delay may be attributed to photoperiod-related high temperatures, since low temperatures and short days induce differentiation of the floral bud (Miyoshi *et al.*, 2013). Temperatures below 2 °C and above 35 °C for prolonged periods cause weakened pollen, floral abortion, and fruit malformations (Bianchi, 1999). In addition, Ledesma and Kawbata (2016) reported that high temperature stress (temperatures greater than 32 °C for more than 4 hours) causes a decrease in fruit size and weight in strawberry varieties. The Festival and San Andreas varieties probably responded favorably to this stress.

In relation to growth, from 42 to 126 DAT, the plants showed significant differences in the number of leaves between strawberry variety (Figure 2). At 140 DAT, after a rejuvenation pruning, the plants were stimulated to develop leaves and flowers, homogenizing the number of leaves per plant (without differences between treatments). This result differs from the findings of Casierra-Posada *et al.* (2012), who reported an outstanding growth in the Chandler cultivar when more than 38% of the leaves were pruned. From 42 and 210 DAT, the Festival variety surpassed other varieties (Figure 3) in crown diameter (1.4-4.3 cm). Damaged leaves were eliminated every 15 days to control pests and that, when *Tetranychus urticae* appeared (May-August), abamectin was alternated with cypermethrin in doses of 1 ml L^{-1}. After one pruning (140 to 154 DAT), there was greater exposure to sunlight, producing more foliage in the upper part of the crop, matching the results obtained by Furlani and Junior (2007) with a vertical crop system.

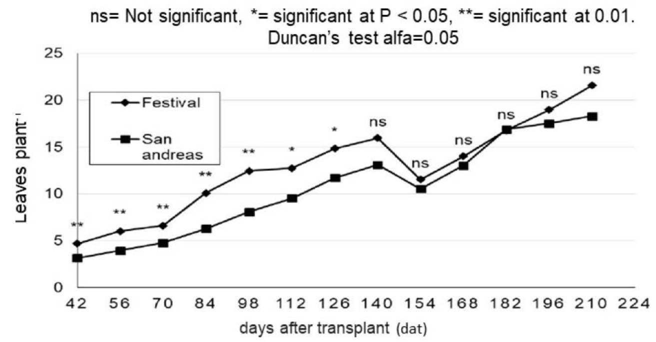

Figure 2. Number of leaves per plant of two strawberry varieties in a vertical hydroponic greenhouse system.

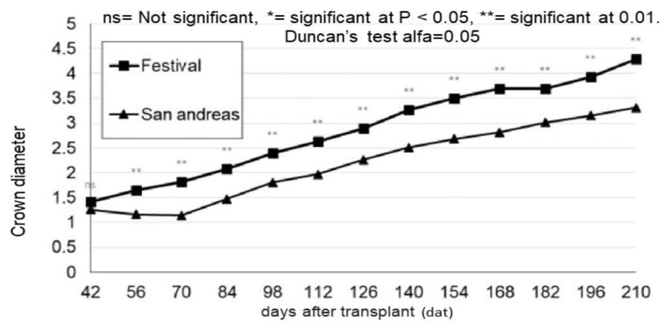

Figure 3. Crown diameter (cm) per plant of two strawberry varieties in a vertical hydroponic greenhouse system.

Strawberry plant yield

In this variable, no significant differences have been found between the varieties (Figure 4) and even the yield of the Festival variety tends to decrease at the end of the crop. The San Andreas variety showed a slight increase at the end of the plant cycle. Festival recorded its maximum production at 168 DAT (77.5 g plant^{-1}), before the production began to decline. San Andreas recorded its maximum production at 210 DAT (63.7 g plant^{-1}); at 140 DAT, a fall in production can be observed, which indicated that a pruning was required to stimulate flowering.

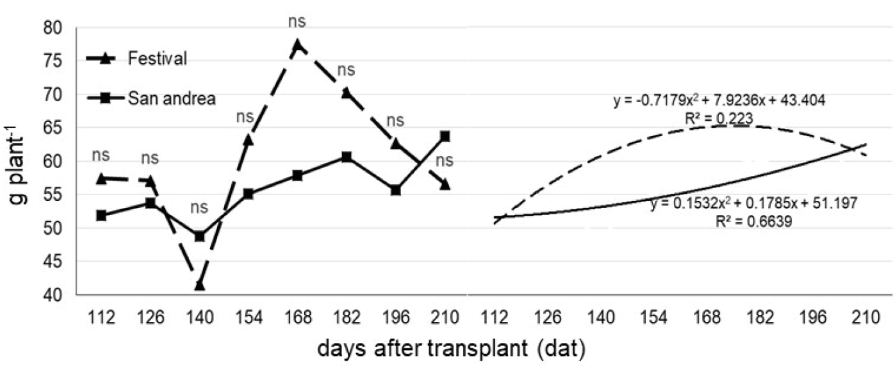

Figure 4. Fruit yield (g plant-1) of two strawberry varieties in a vertical hydroponic greenhouse system, through the analysis of: a) GLM and b) Linear Regression.

There were no significant differences in the tested levels of the density factor for any of the variables measured. The high elevation level showed a significant difference in the number of leaves at 112 DAT. This trend was observed at the end of the experiment (Figure 5), likely as a consequence of to the high radiation received at the most exposed level.

In regard to the cumulative yield of strawberry, the Festival variety stood out (Table 1), per variety, density, and elevation level. Fernandez *et al*. (2001) found no correlation between the yield of three strawberry varieties in North Carolina (USA) with the number of leaves per plant; their results match the findings of this work. The highest yield in this work was 492 g/plant, lower than the results reported by Menzel and Smith (2014) in an open field cultivation system in Australia, during 4.5 months of production (650-960 g plant^{-1} with the Festival variety). However, Karimi *et al*. (2013) found a lower yield (281.8 g plant^{-1}) in three production systems with the same variety (Festival).

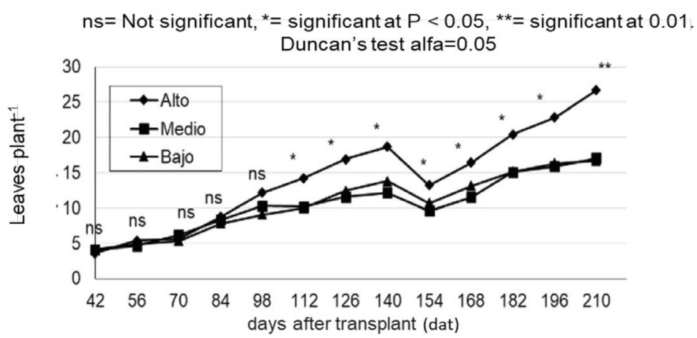

Figure 5. Number of leaves per strawberry plant at three elevation levels in a vertical hydroponic greenhouse system.

Table 1. Cumulative yield of strawberry in weight per plant and by effect of the three elevation levels, two strawberry varieties, and two planting densities per pot in a vertical hydroponic greenhouse system.

Factor/Level	**Yield (fruit)**	
	g plant^{-1}	**kg m^{-2}**
Varieties	ns	ns
Festival	486.04	22.8
San Andrea	447.26	21.0
Densities	ns	ns
3	482.02	22.6
4	454.70	21.3
Elevations	ns	ns
High	492.74	23.1
Middle	490.94	23.1
Low	425.33	20.0

ns=Not significant. Duncan's test alfa=0.05.

Correlation between foliage and yield variables

The Pearson correlation analysis determined a high correlation (r^2=0.898) between total yield and number of fruits, matching the findings of Grijalba (2015) regarding the Albión and Monterrey varieties (r^2=0.89 and r^2=0.93). On the one hand, a positive correlation (r^2=0.729) was found between fruit diameter and fruit weight, which was similar to the findings of Furlani and Junior (2007), since the larger the fruit diameter, the larger the size, and therefore a greater fruit weight is obtained. On the other hand, an average correlation (r^2=0.552) was found between the number of leaves against crown diameter; from these results, the influence of the crown diameter can be inferred. Finally, a medium correlation was found between the total yield and fruit diameter and fruit weight (Table 2).

Table 2. Pearson's correlation coefficient of the dependent variables by effect of the following factors: two strawberry varieties, two planting densities per pot, and three elevation levels, in a vertical hydroponic greenhouse system.

	nhoj	nflr	dcor	nest	nfru	dfru	Pfru	cfru	gbrx	Rtot
Nhoj	1.000	0.241	0.552	0.003	0.014	−0.104	−0.079	0.097	−0.125	−0.018
Nflr	0.241	1.000	0.215	0.022	0.335	−0.022	−0.011	0.032	−0.048	0.276
Dcor	0.552	0.215	1.000	0.060	0.133	−0.022	0.025	−0.041	−0.181	0.112
Nest	0.003	0.022	0.060	1.000	−0.261	0.060	0.002	0.128	0.044	−0.205
Nfru	0.014	0.335	0.133	−0.261	1.000	0.171	0.133	−0.146	−0.074	0.898
Dfru	−0.104	−0.022	−0.022	0.060	0.171	1.000	0.729	−0.446	0.132	0.545
Pfru	−0.079	−0.011	0.025	0.002	0.133	0.729	1.000	−0.381	0.103	0.405
Cfru	0.097	0.032	−0.041	0.128	−0.146	−0.446	−0.381	1.000	−0.214	−0.276
Gbrx	−0.125	−0.048	−0.181	0.044	−0.074	0.132	0.103	−0.214	1.000	−0.032
Rtot	−0.018	0.276	0.112	−0.205	0.898	0.545	0.405	−0.276	−0.032	1.000

nhoj=number of leaves, nflr=number of flowers, dcor=crown diameter, nest=number of runners, nfru=number of fruits, dfru=fruit diameter, pfru=fruit weight, cfru=fruit quality, gbrx=total soluble solids, rtot=fruit yield.

CONCLUSIONS

A vertical hydroponic greenhouse system (VHGS) was designed and built to evaluate two strawberry varieties (Festival and San Andreas. The vertical hydroponic greenhouse system had a high fruit yield (21 kg m^{-2}): *i.e.*, this production system is up to 35% more efficient than the open field cultivation system or the multi-tunnel greenhouse system. There was a positive correlation between the number (r^2=0.89), diameter (r^2=0.54), and weight (r^2=0.40) of the fruits and the total yield. This production system is a viable option for populations in places with a scarcity of water and to obtain fruits with guaranteed food safety.

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