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Short communication

Response of strawberry cv. Festival grown under vertical soilless culture system

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ABSTRACT

Strawberry is being promoted for year round production due to its highly desirable taste, flavour and health properties, and it is possible through soilless cultivation. A study on production of strawberry cv. Festival under vertical growth system with four tiers on soilless medium in a passively ventilated greenhouse was attempted. Significant differences were observed for the growth parameters, *viz.*, number of leaves, leaf area, crown diameter and biomass production. Of the four tiers, first tier planting tended to show the enhanced plant growth and photosynthesis rate with early flowering, higher fruit yield of improved fruit quality than lower tiers tested.

Key words: Growth, strawberry, photosynthesis, fruit quality, vertical farming, yield.

Strawberry (*Fragaria x ananassa* Duch.) is one of the most popular fruits around the world due to its highly desirable taste and flavour. It is widely cultivated due to its genetic diversity, highly heterozygous nature and broad range of environmental adaptations (Sharma and Sharma, 8). The increased demand for strawberries throughout the year is met through soilless cultivation. The future of soilless culture will depend on the development of new production systems and substrates that are competitive in costs and returns with conventional agriculture (Takeda, 15). The type of containers and their arrangement inside the polyhouse determine the growth and yield of strawberry plants. The only way to utilize the greenhouse volume in strawberry production is to set up a vertical production system (Verti-Gro system) (Linsley-Noakes *et al.*, 7). However, sub-optimal environmental conditions in the lower sections, result in reduced plant growth and yield (Takeda, 9). Hydroponic culture Verti-Gro system for growing high value crops has been in commercial practice in countries like United States of America, Japan, Australia and Italy. The system enables efficient energy and greenhouse volume utilization (Al-Raisy *et al.*, 1). Hence, it is important to find the most suitable soilless cultivation system for strawberry to maximize the utilization and distribution of light and culture media within the system to enhance production without affecting the fruit quality. Keeping all these benefits and constraints in view, the present investigation was conducted to study the growth, light availability, gas exchange, yield and quality of strawberry cv. Festival cultivated in vertical growth system with soilless media.

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The present study was carried out in a passively ventilated greenhouse established by the Division of Fruit Crops, ICAR-Indian Institute of Horticultural Research, Bengaluru is situated at a latitude of 13.15°N, and longitude of 77.49°E and at an altitude of 890 m above mean sea level. The minimum and maximum day/ night temperature inside the greenhouse ranged from 11.06 to 20.28˚C and 31.75 to 40.33˚C, respectively, and relative humidity between 40 to 90% during the crop growth period.

Healthy plugs of strawberry cv. Festival were planted in vertical growth system, which consisted of four vanilla round shaped 2.8 l capacity pots, placed one above the other with the help of a metal pole. The bottom pot was placed at 45 cm from the ground and subsequent pots were placed 20 cm apart from each other by placing PVC pipe as sleeves between the two pots. The total height of the column was 172 cm with pots placed in four tiers. The pot at the top position was considered as first tier and subsequent pots down the column as second to fourth tiers. Four vertical growth systems were arranged in a row at 100 cm distance and distance between two rows was 70 cm. Each pot accommodated four plants and a total of 16 plants were maintained per column. The pots were filled with soilless media (coir peat 60% + 40% perlite; v/v). Nutrient solution, containing all the macro- and micro-nutrients (N-128, P-58, K-211, Mg-40, Ca-104, S-54, Fe-5, Zn-0.25, B-0.7, Mn-2.0, Cu-0.07, Mo-0.05 ppm each) formulated in our laboratory for strawberry cultivation was supplied to each pot at the rate of 8 l h^{-1} discharge capacity through microtubes from lateral lines using an automated drip irrigation system. During day time, the timer was adjusted to supply nutrient solution for 15 min. at every 3 h interval from a 400 l capacity plastic tank.

Leaf characteristics like petiole length, number of leaves and leaf area were recorded at 160 days after planting (DAP). Total leaf area per plant was measured at 160 DAP using leaf area meter (LI 3100, LI-COR, USA). Growth parameters such as crown diameter, shoot and root fresh and dry weights were recorded at 160 DAP. The dry weights were obtained after drying the samples in oven at 80ºC. Time taken for the first flowering in plants was recorded as and when flowering occurred in each treatment. Total numbers of flowers, total number of fruits, total fruit weight, percent marketable fruits, average fruit size (length and diameter) were recorded at appropriate times. The fruit total soluble solids (TSS) were determined by using hand refractometer (Erma Ltd. Japan). The values were corrected at 25ºC and expressed as ˚Brix. Titratable acidity was determined by macerating 10 g of fruit sample in distilled water. The pulp was filtered through muslin cloth and made up to 10 ml with distilled water and 5 ml of filtrate was titrated against standard NaOH using phenolphthalein indicator. The value was expressed in terms of malic acid as per cent titratable acidity (Anon, 2). The observations on gas exchange characteristics were recorded by portable photosynthesis system LC pro (ADC Bioscientific Ltd. UK) as ambient light between 9300 to 1100 h at 120 DAP. Availability of PAR in each Verti-Gro system tier was measured with quantum sensor present in the leaf chamber of portable photosynthesis system.

Strawberry plants grown at different Vertical growth system tiers showed significant differences in growth parameters. At 160 DAP, highest petiole length was observed in plants grown in fourth tier and lowest in first tier (Table 1). The progressive reduction in PAR from first to fourth tier (Table 2) could have influenced petiole length in lower tiers. In strawberry, low light intensity resulted in formation of longer petiole. Significantly higher number of leaves and maximum leaf area was observed in the first tier and it gradually decreased down with the tiers and lowest number of leaves and leaf area was observed in the fourth tier. Higher leaf area per plant was due to higher number of leaves per plant in first tier. High irradiance was necessary to increase leaf area of strawberry (Ceulemans *et al.*, 4) and the higher number of leaves directly contributes to the increase in leaf area (Jagadeesh, 6).

The observations on gas exchange characteristics recorded at 120 DAP, showed the maximum photosynthesis rate (3.75 µmol $CO_2 m^{-2} s^{-1}$) in the first tier and minimum (1.68 µmol CO_2 m^{-2} s^{-1}) in the fourth tier. This could be attributed to maximum PAR incidence on leaf surface of the plants grown in first tier which markedly declined in lower tiers. In the first tier, highest PAR of 146.66 µmol m^{-2} s^{-1} was available at 120 DAP. In Verti-Gro system, Takeda (9) observed

Table 1. Leaf characteristics of strawberry cv. Festival grown at 160 DAP in different tiers under vertical soilless culture system.

Tier position	Petiole length (cm)	Av. No. of leaves plant^{-1}	Leaf area (cm^2 plant^{-1})
Tier 1	11.03^c	39.00^a	2002.64^a
Tier 2	11.03^c	37.08^a	1884.75^b
Tier 3	12.91^b	34.33^b	1775.50^c
Tier 4	13.75^a	32.16^c	1614.08^d
CD at 5%	0.74	2.08	76.91

NS = Non-significant; Means followed by different letters in a column indicate significant difference at $p \leq 0.05$ according to Duncan's multiple-range test.

Table 2. Net photosynthesis rate (p_N), stomatal conductance (*gs*), transpiration rate (e) and available photosynthetic active radiation (PAR) at 120 SAP in the different tier positions.

Tier position	P_N (µmol CO_2 m^{-2} s^{-1})	g_s (µmol m^{-2} s^{-1})	E (µmol m^{-2} s^{-1})	PAR (µmol m^{-2} s^{-1})
Tier 1	3.75^a	0.09^a	3.36^a	146.7^a
Tier 2	1.82^b	0.09^a	2.89^a	120.0^b
Tier 3	1.66^b	0.09^a	2.99^a	93.00^c
Tier 4	1.68^b	0.08^a	2.93^a	74.70^c
CD at 5%	1.37	NS	NS	17.06

NS = Non significant; Means followed by the different letter in a column indicates significant difference at $p \leq 0.05$ according to Duncan's multiple-range test.

the irradiance reaching the plants at the bottom of the column was only 10% of the levels measured at top due to shading effect of upper tiers. Hence, light intensity and its distribution are the limiting factors with the present technique Verti-Gro system (Villiers*,* 11). The transpiration rate and stomatal conductance were not affected by tier position in the Verti-Gro system (Table 2). The reasons could be due to uniform temperature and humidity inside the greenhouse at the time of recording gas exchange observations.

The plant growth and development at different tiers of the Vertical growth system was also significantly influenced. Highest crown diameter was recorded in the first tier and lowest in the fourth tier (Table 3). Takeda (9) earlier reported, production of smaller strawberry crown at the lower section in Verti-Gro system due to low light availability. Shoot and root fresh and dry weights were also highest in the first tier and lowest in fourth tier (Table 3). The higher biomass in shoot and root was due to higher photosynthesis rate and leaf area per plant observed in the first tier. The strawberry cv. Camarosa grown in smaller column size

Table 3. Fresh and dry biomass and crown diameter of strawberry cv. Festival grown at 160 DAP in different tiers under vertical soilless culture system.

Tier position	Shoot fr. wt. (g)	Shoot dry wt. (g)	Root fr. wt. (g)	Root dry wt. (g)	Crown dia. (mm)
Tier 1	55.34[a]	15.41[a]	17.27[a]	4.41[a]	31.00[a]
Tier 2	53.44[a]	13.73[b]	16.56[a]	4.01[ab]	29.58[a]
Tier 3	47.96[b]	13.42[c]	14.65[b]	3.55[bc]	26.33[b]
Tier 4	46.05[b]	12.69[c]	13.12[c]	3.28[c]	25.83[b]
CD at 5%	3.55	0.91	1.11	0.55	3.08

Means followed by different letters in a column indicate significant difference at $p \leq 0.05$ according to Duncan's multiple-range test.

(6 pots/ column) of Verti-Gro system produced higher shoot fresh weight as compared to plants grown in bigger column size (8 pots/ column), with decreased light penetration in lower section of the Verti-Gro system (Al-Raisy *et al.*, 1).

Availability of PAR, total leaf area per plant, photosynthesis rate and biomass significantly influenced the days taken for flower initiation among the tiers. Plants in first tier took least number of days for flower initiation and highest number of days was required for plants in fourth tier (Table 4). In cv. Chandler the flower initiation in plants cultivated at the top of the Verti-Gro column was 17 days earlier than middle tier and 37 days earlier than bottom tier (Takeda, 15). Tier position significantly influenced the total number of flowers per plant, highest being in the first tier and lowest in the fourth tier. In cv. Geneva light intensity of 430 μmol m^{-2} s^{-1}, almost doubled the number of flowers per plant compared to 220 μmol m^{-2} s^{-1} (Dennis *et al.*, 5). In the present study also the shading effect of upper tiers caused low PAR availability in the lower tiers and consequent reduction in photosynthesis rate, leaf area and biomass, which resulted in the reduction in number of flowers. Maximum number of fruits was obtained in the first tier and minimum in the fourth tier. Due to low light, strawberry plants grown in middle and bottom tier did not develop optimal branch crowns and subsequently produced less number of fruits as compared to plants in the top tier (Takeda, 9).

The position of tier also had significant influence on average fruit weight. Plants in first tier produced significantly higher fruit weight as compared to other tiers and the lowest fruit weight was recorded in the fourth tier (Table 4). The gain in average fruit weight could be attributed to higher photosynthesis rate recorded in the first tier, which provided higher photosynthates to the developing fruits, thus increasing individual fruit weight. The cv. Chandler under higher light intensity produced larger fruits as compared to low light intensity (Villiers, 11).

The fruits produced in the first tier were of high quality with significantly higher length and diameter, total soluble solids (TSS), lower titratable acidity compared those produced on lower tiers (Table 4). The better quality fruits could be due to higher photosynthates available to the developing fruits in the first tier as higher light availability caused higher photosynthesis rate. In strawberry, fruit TSS ranged from 5 to 8°Brix at different sections of Verti-Gro system and it increased as the light intensity increased (Vasilakakis *et al.*, 10). High TSS content in strawberry fruits was strongly related to the leaf: fruit ratio (Carlen *et al.*, 3). Hence, for maximum utilization of the growing site, Vertical growth system is found to be the best option for commercial production as well as home gardening. Among the four tiers of the vertical growth system, significant differences were observed in growth parameters mainly due to differences in PAR availability. Higher PAR availability resulted in higher photosynthesis rate and better growth of the plants in the first tier. Thereby leading to early flowering, higher number of flowers, fruits, total

Table 4. Days to flower initiation, yield characteristics and fruit quality of strawberry cv. Festival under vertical soilless culture system.

Tier position	Days taken for flower initiation	Total No. flowers $plant^{-1}$	Total No. of fruits $plant^{-1}$	Total fruit weight $plant^{-1}$ (g)	Av. fruit wt. (g)	Av. fruit length (mm)	Av. fruit dia. (mm)	Marketable fruits (%)	Total soluble solids (°B)	Titratable acidity (%)
Tier 1	57[c]	29[a]	18[a]	195[a]	11.47[a]	30.75[a]	26.25[a]	68.33[a]	10.51[a]	0.81[c]
Tier 2	60[b]	25[b]	14[b]	145[b]	10.64[a]	28.25[a]	25.91[a]	60.50[b]	10.15[a]	0.83[bc]
Tier 3	60[b]	24[b]	14[b]	140[b]	10.55[a]	28.08[b]	25.50[a]	59.41[b]	9.62[b]	0.91[c]
Tier 4	65[a]	21[c]	13[b]	102[c]	8.02[b]	25.83[c]	22.08[b]	49.08[c]	8.44[c]	1.04[a]
CD at 5%	2.62	1.97	2.16	29.9	1.92	1.52	1.04	6.21	0.49	0.09

Means followed by the different letter in a column indicates significant difference at $p \leq 0.05$ according to Duncan's multiple-range test.

fruit weight, average fruit weight and better quality fruits compared to other lower tiers.

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