



RESEARCH ARTICLE

# Hydroponic system of cultivation and runner removal enhanced plant growth and yield of strawberry cultivars

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## Abstract

Hydroponics is gaining popularity among growers due to changing climatic conditions and the shrinking of resources, particularly land and water. The present study was conducted at SKUAST-K, Shalimar during the months of February to June of 2021 and 2022 to determine the effects of hydroponics and runner removal on plant growth traits of strawberry cultivars with 8 treatment combinations comprised of 3 factors with 2 levels of each viz., variety, growing system and runner removal. The NFT system of hydroponic was used to grow strawberry plants. Treatments were arranged in RCBD with 4 replications. Findings revealed that V2 (Camarosa) had higher plant growth compared to V1 (Sweet Charlie). Significantly higher plant growth was also recorded under a hydroponic system (S2) than a traditional one (S1). Runner removal (R1) additionally benefitted the plant by diverting food energy used in runner growth to the main shoot and resulted in better shoot and root growth. Second-order interaction of treatments further clarified that V2 × S2 × R1 resulted in maximum shoot growth (plant height - 20.15 cm, shoot biomass - 7.20 g/plant and RGR - 0.58 g/g/week) compared to the minimum values of these parameters recorded with V1 × S1 × R0. The highest number of runners (7.92/plant) with maximum runner length (85.32 cm) was recorded with V1 × S1 while their minimum values were evident with V2 × S1. However, V2 × S1 registered the highest fresh weight (6.13 g/plant) and dry weight (0.45 g/plant) of runners along with the number of propagules (6.93/runner) against their minimum values recorded with V1 × S1. V1 × S2 × R1 resulted in the highest number of fruits (23.32/plant), fruit breadth (3.31 cm) and fruit yield (288.00 g/plant) compared to other interactions.

## Keywords

biomass; hydroponics; RGR; runner removal; strawberry

## Introduction

Soil is generally the most available growing medium for plants. It provides anchorage, nutrients, air, water, etc., to the plant for its growth and successful completion of life. However, at the same time, soils also pose serious limitations to plant growth and potential productivity. It has been estimated that about 50% of the arable land around the world will become unusable for cultivation by 2050, chiefly due the global climate change (1). Consequently, food production has to be increased by 110% to meet the high demand of the increasing world population (2). The presence of disease-

causing organisms, unsuitable soil reaction, unfavourable soil compaction, poor drainage, degradation due to erosion, etc., further aggravate the situation. Conventional crop growing in soil (Open Field Agriculture) is becoming somewhat difficult as it requires large space, a lot of labour and a large volume of water (3). In addition, in some places, like metropolitan areas, soil is not available at all for crop growing or in some areas, there is a scarcity of arable lands due to their unfavourable geographical or topographical conditions (4). Because of all these problems, there is a need to develop some other viable options for food production that cover the fast-growing demand of the increasing world population with less cost and minimum use of natural resources.

Efforts have been made to develop efficient food production techniques that enable to fulfil the current and future needs of healthy food for the general population. One of them is the soilless farming system, called hydroponics, which may be defined as the practice of growing plants in a nutrient solution with or without a soilless substrate to provide physical support (5-8). Hydroponic food production systems significantly reduce the consumption of resources with increased quantity and quality of food due to increased cropping intensity and better growing conditions for nutrient uptake and plant growth, especially under greenhouse structures (9). Moreover, hydroponic products are almost free from hazardous chemicals as there is no or minimum use of weedicides and pesticides. This system of cultivation also offers unique benefits such as the capability to control water availability, pH and nutrient concentrations in the root zone (9, 10). Being a sustainable food source, soilless food-producing systems have been gaining momentum and drawing the attention of many producers, consumers and scientists (10-13). In addition to the growing system, the removal of runners in strawberries is a key crop management practice to manipulate the sink/source ratio for improved yield and quality (8, 14). Plant growth, yield and quality traits of strawberry cultivars also varied greatly under traditional cultivation systems (15). However, information available on varietal variation in these traits under a hydroponic system of cultivation is scanty, particularly in Kashmir conditions, as no such work has been done so far under a hydroponic system. Therefore, the present study was conducted to determine the effects of hydroponics, runner removal and cultivars on plant growth and yield attributes of strawberry cultivars.

## Materials and Methods

### Location

The experiment was conducted during the months of February to June of 2021 and 2022 at the Division of Basic Science and Humanities, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar (Jammu and Kashmir). The experimental site was situated at an elevation of 1600 m (5249 feet) above mean sea level (MSL) with an average annual rainfall of around 645 mm (25.4"). The experi-

mental area can be generally described as cool in the Spring and Autumn, mild in the summer and cold in the winter. July is the hottest month in this region with mean minimum and maximum temperatures of 16 °C and 32 °C respectively. December-January is considered the coldest months with a mean minimum temperature of -1.6 °C to -3.0 °C and a mean maximum temperature of 1.6 °C to 7.3 °C.

### Plant materials and conduct of the trial

Two strawberry cultivars viz., Sweet Charlie (V1) and Camarosa (V2) were grown traditionally (S1) as well as under the NFT (Nutrient Film Technique) system of hydroponics (S2), where in a very shallow stream (film) of water containing all nutrients required for plant growth circulates between the growing channels (troughs) and the nutrient reservoir. The NFT system used in the present experiment was a 3-layered structure run on a framework made up of PVC pipes and iron angle. Each layer of the NFT had four PVC pipes with 13 holes of 2.5-inch diameter (Plate 1). Uniform size and vigour of strawberry propagules having 2-3 true leaves of Sweet Charlie and Camarosa cultivars were obtained from the division of Fruit Science, Faculty of Horticulture (SKUAST-K), Shalimar. All the propagules were divided into 2 sets for growing them hydroponically and traditionally under a field. Propagules were dipped in 0.2 % solution of Bavistin for 10 min and transplanted in the netted cups already filled with cocopeat, vermiculite and perlite with a 1:1:1 ratio (Plate 2). Transplanted netted cups were kept in the trays having half standard hydroponic nutrient solution (16) containing all the essential (macro and micro) nutrients required by the plants for their growth and development, maintained in the laboratory till the establishment of the plant. After establish-



**Plate 1a.** Nutrient film technique (NFT) of hydroponics used for the present study.



**Plate 1b.** Strawberry crops grown under the NFT system of hydroponics.



**Plate 1c.** Hydroponically grown strawberry crops in bearing.

ment, the cups were transferred to a hydroponic system where in supply of half-standard hydroponic solution was continued for up to 20 days. Thereafter, full strength of nutrient solution was supplied throughout the course of plant growth. Pre-treated strawberry propagules were also transplanted in the field at a spacing of 30 × 30 cm. Circulation of the nutrient solution was made 4 times daily for 1 h. Intercultural operations like irrigation and weeding, in

field-grown crops were carried out regularly as needed. Half of the plants were allowed to produce and grow their runners (R0) while the other half of the plants were not allowed to grow runners (R1) i.e., they were removed as and when appeared on plants. The experiment was laid down in randomized complete block design (RCBD) with 4 replications.

#### **Recording of data and statistical analysis**

Plant height was measured from the base of the crown to the growing tip of the plant at the time of final picking. Plant spread was measured from North to South and East to West directions and the average of both directions was taken as spread of the plants. Above-ground plant biomass was recorded by drying them in an oven at 80 °C till obtaining a constant dry weight. Plant relative growth rate (RGR) for the initial slow growth, vigorous vegetative growth and reproductive growth phases was calculated following the standard method (17).

$$\text{RGR (g/g/day)} = \frac{2.302(\log_e W_2 - \log_e W_1)}{T_2 - T_1}$$

Where,  $W_1$  = plant dry weight (g) at time  $T_1$ ;  $W_2$  = plant dry weight (g) at time  $T_2$ ; Loge = natural logarithms (Logarithms to the base of 2.3026).



Root volume was determined by the water displacement method using a graduated cylindrical flask (18). The root length was measured from the collar to the tip of the root. Root dry weight was estimated by drying them in a hot air oven at 60 °C till the constant weight was obtained. The number of trusses on fully developed plants was counted and averaged as per plant. Numbers, length, fresh weight and dry weight of runners per plant were estimated



**Plate 2.** Strawberry crop grown under field condition.

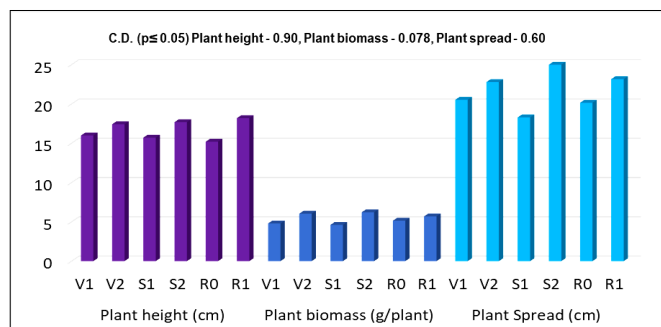
where in runners were allowed to produce and grow. In addition, the number of propagules per runner was also recorded by simple counting. Data were subjected to statistical analysis using R software with analysis of variance. Means were compared at  $P \leq 0.05$  level of significance.

## Results

### Plant growth traits

Experimental evidence indicated that above-ground plant growth was significantly influenced ( $p \leq 0.05$ ) due to the

treatments. The main effects of the treatments (Fig. 1) clarified that the variety Sweet Charlie (V2) showed higher plant height (17.42 cm), plant spread (22.79 cm) and plant biomass (6.05 g/plant) compared to lesser plant height (15.99 cm), spread (20.53 cm) and biomass (4.80 g/plant) of Camarosa (V1). Likewise, hydroponically grown plants (S2) exhibited higher plant height (17.69 cm), spread (25.02 cm) and biomass (6.22 g/plant) compared to a plant height (15.72 cm), spread (18.29 cm) and biomass (4.62 g/plant) in the traditional growing system (S1). Also, runner removal (R1) resulted in a higher plant height (18.20 cm), spread (23.16 cm) and biomass (5.70 g/plant) compared to lesser plant height (15.20 cm), spread (20.15 cm) and biomass (5.15 g/plant) in plants with no runner removal (R0).



**Fig. 1.** Individual effects of variety, growing system and runner removal on above ground plant growth of strawberry.

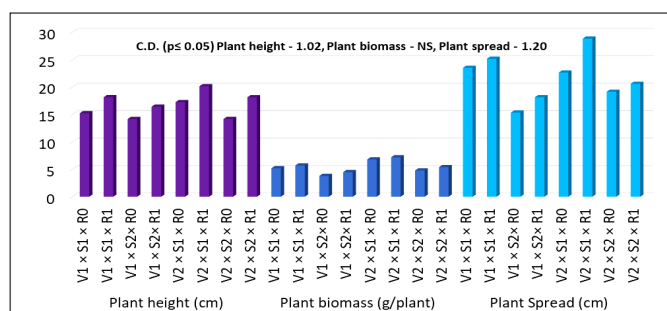
The first-order interactions of different treatments (Table 1) also indicated significant differences ( $p \leq 0.05$ ) with respect to plant height, plant spread and biomass. Data with respect to  $V \times S$  revealed that  $V2 \times S2$  resulted in the highest plant height (18.69 cm), spread (25.72 cm) and biomass (7.00 g/plant) followed by  $V1 \times S1$  with plant height, spread and biomass of 16.68 cm, 24.32 cm and 5.45 g/plant respectively against the minimum plant height (15.29 cm), spread (16.73 cm) and biomass (4.15 g/plant)

**Table 1.** Effects of First-order interaction of treatments on above-ground plant growth of strawberry

Treatments	Plant height (cm)	Plant biomass (g/plant)	Plant Spread (cm)	RGR (g/g/week)		
				(0-15 days)	(15-30 days)	(30-45 days)
First order interaction of treatments						
V1 × S1	15.29	4.15	16.73	0.36	0.44	0.24
V1 × S2	16.68	5.45	24.32	0.45	0.54	0.35
V2 × S1	16.15	5.10	19.86	0.44	0.53	0.31
V2 × S2	18.69	7.00	25.72	0.55	0.65	0.45
CD (p≤ 0.05)	0.81	0.11	0.84	0.013	0.014	0.011
V1 × R0	14.70	4.50	19.41	0.39	0.47	0.25
V1 × R1	17.28	5.10	21.64	0.43	0.52	0.30
V2 × R0	15.70	5.80	20.89	0.47	0.57	0.38
V2 × R1	19.14	6.30	24.69	0.52	0.61	0.42
CD (p≤ 0.05)	0.81	NS	0.84	NS	NS	NS
S1 × R0	14.17	4.30	17.24	0.38	0.47	0.28
S1 × R1	17.27	4.95	19.35	0.42	0.50	0.31
S2 × R0	16.23	6.00	23.06	0.48	0.57	0.35
S2 × R1	19.14	6.45	26.98	0.53	0.62	0.41
CD (p≤ 0.05)	0.81	0.11	0.84	NS	NS	NS

recorded with  $V1 \times S1$ . Interaction of  $V \times R$  indicated that  $V2 \times R1$  registered the highest plant height (19.14 cm) and spread (24.69 cm) followed by  $V1 \times R1$  against the minimum plant height (14.70) and spread (19.41 cm) registered with  $V1 \times R0$ . So far as  $S \times R$  interaction is concerned,  $S2 \times R1$  produced greater plant height (19.14 cm), spread (26.98 cm) and biomass (6.45 g/plant). Interaction of  $S1 \times R1$  exhibited the second highest plant height (17.27 cm), however,  $S2 \times R0$  ranked second with a recorded plant spread and plant biomass of 23.06 cm and 6.00 g/plant respectively against the minimum plant height (14.17 cm), plant spread (17.24 cm) and plant biomass (4.30 g/plant) of  $S1 \times R0$ .

Data with respect to second-order interactions of  $V \times S \times R$  (Fig. 2) further revealed that maximum plant height (20.15 cm) and spread (28.81 cm) were observed with  $V2 \times S2 \times R1$ . Whereas, the treatment combination  $V2 \times S2 \times R1$  was significantly followed by  $V1 \times S2 \times R1$  and registered the plant height and spread value of 18.14 and 25.15 cm respectively. Interaction of  $V1 \times S1 \times R0$  resulted in minimum plant height (14.17 cm) and spread (15.34

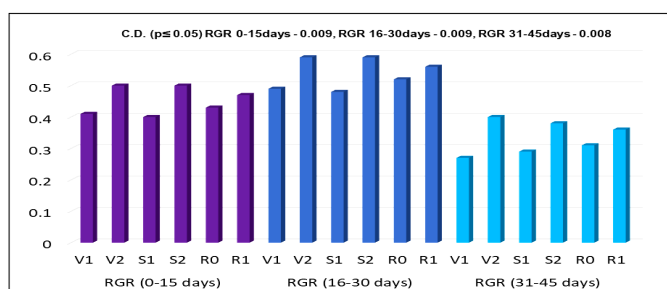


**Fig. 2.** Effects of second-order interaction of treatments on above-ground plant growth of strawberry.

cm).

### Plant relative growth rate (RGR)

Different treatments also influenced plant relative growth rate (RGR) significantly ( $p \leq 0.05$ ) where  $V2$  exhibited higher RGR during all the growth period *viz.*, 0-15 days (0.50 g/g/week), 15-30 days (0.59 g/g/week) and 30-45 days (0.40 g/g/week) as compared to a lower RGR of 0.41, 0.49 and 0.27 g/g/week  $V1$  during the respective growing periods. Likewise, the hydroponic ( $S2$ ) growing system exhibited greater RGR during 0-15 (0.50 g/g/week), 15-30 (0.59 g/g/week) and 30-45 days (0.38 g/g/week) compared to a lower RGR during respective periods (0.40, 0.48 and 0.29 g/g/week) under the traditional system ( $S1$ ) respectively. Removal of runners ( $R1$ ) resulted in an improved plant RGR (0.47, 0.56 and 0.36 g/g/week) compared to a lower RGR (0.43, 0.52

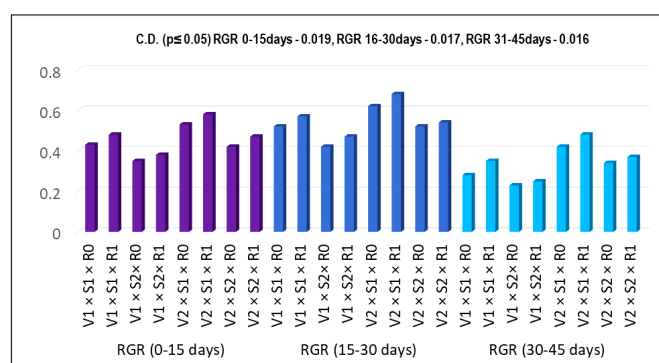


**Fig. 3.** Individual effects of variety, growing system and runner removal on shoot relative growth rate (RGR) (g/g/week) during different phases of growth in strawberry.

and 0.31 g/g/week) with no runner removal ( $R0$ ) during respective growing periods (Fig. 3).

The first-order interactions (Table 1) of  $V \times S$  reflect that  $V2 \times S2$  resulted in maximum RGR of 0.55, 0.65 and 0.45 g/g/week during 0-15, 15-30 and 30-45 days respectively followed by  $V1 \times S1$  with RGR values of 0.45, 0.54 and 0.35 g/g/week against the minimum RGR values of 0.36, 0.44 and 0.24 g/g/week during the respective days of measurements. However, the interaction of  $V \times R$  as well as  $S \times R$  could not exert any significant difference in RGR throughout growing periods.

The second-order interaction of the treatments (Fig. 4) further revealed that  $V2 \times S1 \times R1$  resulted in the highest RGR of 0.58, 0.68 and 0.48 g/g/week during the 3 growing periods respectively followed by  $V2 \times S2 \times R0$ , whereas, the

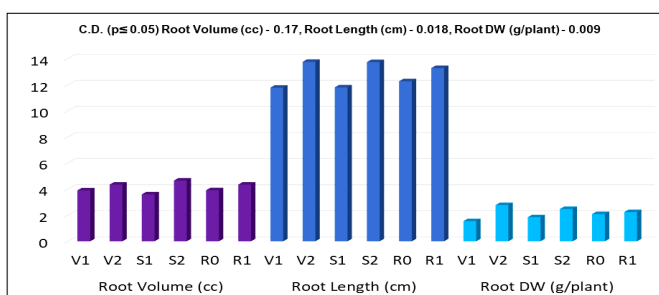


**Fig. 4.** Effects of Second-order interaction of treatments on shoot relative growth rate (RGR) (g/g/week) during different phases of growth in strawberry.

minimum values of RGR (0.35, 0.42 and 0.23 g/g/week) during respective periods of plant growth were recorded with  $V1 \times S1 \times R0$ .

### Root growth

Like above-ground plant growth, variety, growing system and runner removal (Fig. 5) also influenced root growth ( $p \leq 0.05$ ) and  $V1$  showed lesser root volume (3.91 cc), length (11.78 cm) and dry weight (1.55 g/plant) compared to  $V2$  with root volume, length and dry weight of 4.35 cc, 13.76 cm and 2.78 g/plant respectively. Hydroponics system ( $S2$ ) also resulted in higher root volume (4.66 cc) length (13.74 cm) and dry weight (2.48 g/plant) compared to a lower root volume (3.60 cc), length (11.80 cm) and dry weight (1.85 g/plant) obtained in traditional system ( $S1$ ). Runner



**Fig. 5.** Individual effects of variety, growing system and runner removal on root growth of strawberry.

removal ( $R1$ ) again exerted a positive effect on root growth by producing higher root volume (4.35 cc), length

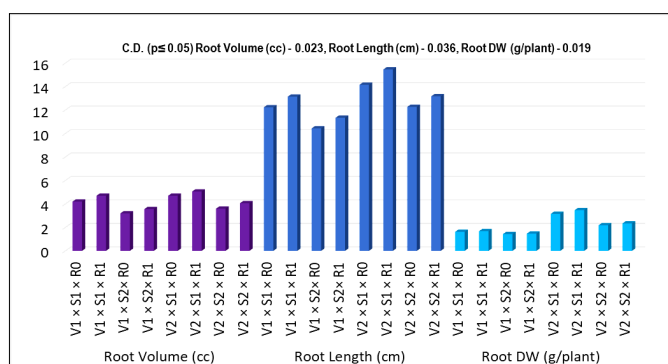
**Table 2.** Effects of first-order interaction of treatments on root growth attributes of strawberry

Treatment	Root Volume (cc)	Root Length (cm)	Root DW (g/plant)
V1 × S1	3.38	10.89	1.45
V1 × S2	4.45	12.68	1.65
V2 × S1	3.83	12.72	2.26
V2 × S2	4.88	14.80	3.31
<b>CD (p ≤ 0.05)</b>	<b>0.09</b>	<b>0.025</b>	<b>0.013</b>
V1 × R0	3.70	11.33	1.52
V1 × R1	4.13	12.24	1.57
V2 × R0	4.15	13.21	2.66
V2 × R1	4.56	14.31	2.90
<b>CD (p ≤ 0.05)</b>	<b>0.08</b>	<b>0.025</b>	<b>0.013</b>
S1 × R0	3.40	11.35	1.80
S1 × R1	3.81	12.25	1.90
S2 × R0	4.45	13.19	2.38
S2 × R1	4.88	14.30	2.57
<b>CD (p ≤ 0.05)</b>	<b>0.19</b>	<b>0.025</b>	<b>0.013</b>

(13.28 cm) and dry weight (2.24 g/plant) in comparison to the plants with no runner removal (R0).

Looking into the data on 2-way interaction (Table 2) with V × S, it can be stated that V2 × S2 resulted in the highest root volume (4.88 cc), length (14.80) and dry weight (3.31 g/plant) followed by V1 × S2 against the minimum root volume (3.38 cc), length (10.89) and dry weight (1.45 g/plant) under V1 × S1. The combined effect of V × R revealed that V2 × R1 gave rise to the maximum root volume, length and dry weight of 4.56 cc, 14.31 cm and 2.90 g/plant followed by V2 × R0 against the minimum root volume (3.70 cc), length (11.33 cm) and dry weight (1.52 g/plant) recorded with V1 × R0. Among the different interactions of S × R the maximum root volume (4.88 cc), length (14.30 cm) and dry weight (2.57 g/plant) were recorded with S1 × R1 followed by S1 × R0 against the most inferior root volume (3.40 cc), length (11.35 cm) and dry weight (1.80) in S1 × R0.

Root volume, length and dry weight also varied significantly ( $p \leq 0.05$ ) under second-order interaction (Fig. 6)

**Fig. 6.** Effects of second-order interaction of treatments on root growth in strawberry.

wherein V2 × S1 × R1 acquired the highest root volume (5.06 cc), length (15.46 cm) and dry weight (3.47 g/plant) and was significantly followed by V2 × S1 × R0 compared to

the least root volume (3.20 cc), length (10.44 cm) and dry weight (1.43 g/plant) recorded with V1 × S2 × R0.

### Runner growth

Information effect of variety and growing conditions on runner growth provided in Table 3 depicts that variety V1 produced more number (7.54/plant) as well as total length (82.76 cm) of runners compared to variety V2. However, a higher fresh (5.33 g/plant) and dry (0.36 g/plant) weight of runners was recorded with V2 compared to smaller fresh (4.43 g/plant) and dry (0.29 g/plant) weight with V1. V2 also recorded a higher number of propagules (5.54/plant) com-

**Table 3.** Effects of first-order interaction of treatments on yield attributing characters of strawberry

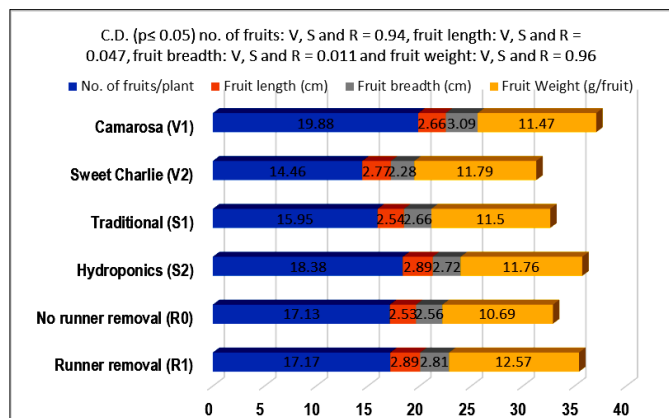
Treatment	No. of fruits/plant	Fruit length (cm)	Fruit breadth (cm)	Fruit Weight (g/fruit)
V1 × S1	17.81	2.64	3.11	11.71
V1 × S2	21.94	2.68	3.07	11.23
V2 × S1	14.08	2.44	2.20	11.30
V2 × S2	14.83	3.09	2.36	12.28
<b>CD (p ≤ 0.05)</b>	<b>1.34</b>	<b>0.067</b>	<b>0.016</b>	<b>0.016</b>
V1 × R0	19.99	2.47	2.90	10.64
V1 × R1	19.76	2.84	3.29	12.30
V2 × R0	14.33	2.59	2.22	10.74
V2 × R1	14.58	2.94	2.34	12.84
<b>CD (p ≤ 0.05)</b>	<b>1.21</b>	<b>0.057</b>	<b>0.016</b>	<b>0.016</b>
S1 × R0	16.98	2.33	2.57	10.67
S1 × R1	14.91	2.75	2.74	12.34
S2 × R0	17.34	2.74	2.55	10.72
S2 × R1	19.43	3.03	2.88	12.80
<b>CD (p ≤ 0.05)</b>	<b>1.34</b>	<b>0.067</b>	<b>0.016</b>	<b>0.016</b>

pared to V1 (4.54/plant). Talking about growing systems, S2 produced a greater number (6.92/plant), total length (68.81 cm), fresh weight (5.87 g/plant) and dry weight (0.39 g/plant) of runners along with the higher number of propagules (6.09/plant) compared to smaller values of these attributes with S1.

A perusal of the data with respect to the interaction of treatments (V × S) revealed that V1 × S2 recorded the highest number (7.92/plant) as well as total length (85.32 cm) of runners followed by V1 × S1 against the minimum number (4.13/plant) and total length (47.10 cm) of runners recorded with V2 × S1. However, the highest fresh (6.13 g/plant) and dry (0.45 g/plant) weight along with the maximum number of propagules (6.93/plant) was recorded with V2 × S2 followed by V1 × S2 against the minimum values of runner's fresh (3.24 g/plant) and dry (0.24 g/plant) weight along with the number of propagules (3.83/plant) recorded with V1 × S1.

### Fruit growth and yield

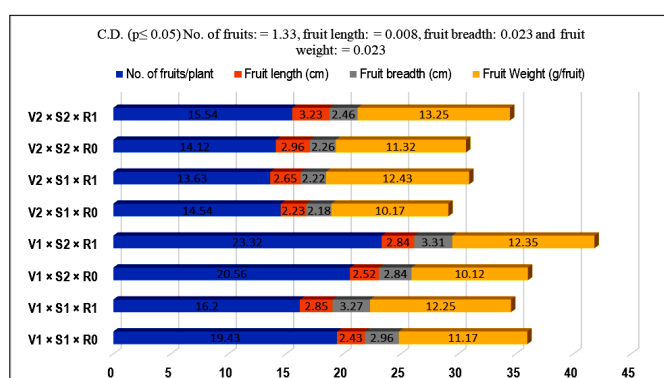
The information with regard to the main effects of treatments (Fig. 7) indicates that V1 exhibited a higher number of fruits (19.88/plant) and fruit breadth (3.09 cm) while V2 exhibited a lesser number of fruits (14.46/plant) with more



**Fig. 7.** Individual effects of variety, growing system and runner removal on yield attributing characters of strawberry.

fruit length (2.77 cm) and individual fruit weight (11.79 g/plant) V1. A comparison of growing systems showed that S2 showed a higher number of fruits (18.38/plant) fruit length (2.89 cm), fruit breadth (2.72 cm) and fruit weight (11.76 g/fruit) as compared to S1. Similarly, R1 produced a higher number of fruits (17.17/plant) with larger length (2.89 cm) and breadth (2.81 cm) coupled with higher fruit weight (12.57 g/fruit) compared to significantly lower values of these attributes under R0.

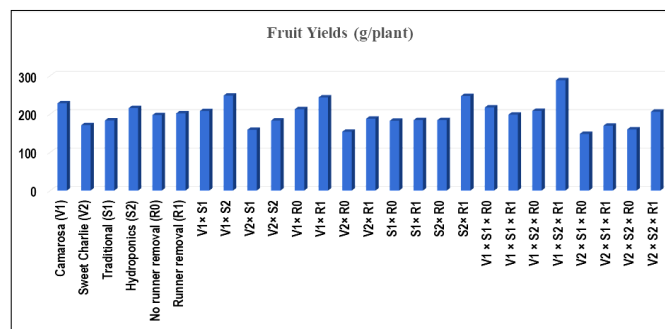
A perusal of the data (Table 3) regarding  $V \times S$  among the first-order interaction showed that  $V2 \times S2$  resulted in the highest fruit length (3.09 cm) and fruit weight (12.28 g/plant) with greater number of fruits (21.94/plant). Among  $V \times R$ ,  $V2 \times R1$  produced the highest fruit length (2.94 cm) and fruit weight (12.84 g/fruit) while  $V1 \times R1$  yielded the maximum number of fruits (19.76/plant) with the highest fruit breadth (3.29 cm). Considering the data pertaining to the interaction of  $S \times R$ , it can be stated that  $S2 \times R1$  resulted in the maximum number of fruits (19.43/plant), fruit length (3.03 cm), breadth (2.88 cm) and fruit weight (12.80 g/fruit) compared to other interactions in the set.



**Fig. 8.** Effects of Second-order interaction of treatments on yield attributing characters in strawberry.

The second order interaction (Fig. 8) of all the treatment factors ( $V \times S \times R$ ) indicated that  $V2 \times S2 \times R1$  registered the maximum number of fruit (23.32/plant), fruit length (3.23 cm) as well as individual fruit weight (13.25 g/fruit). However,  $V1 \times S1 \times R1$  produced maximum fruit breadth (3.31 cm). while as the lowest fruit breadth (2.18 cm) was noted with  $V2 \times S1 \times R0$ .

The information with regard to the main effects

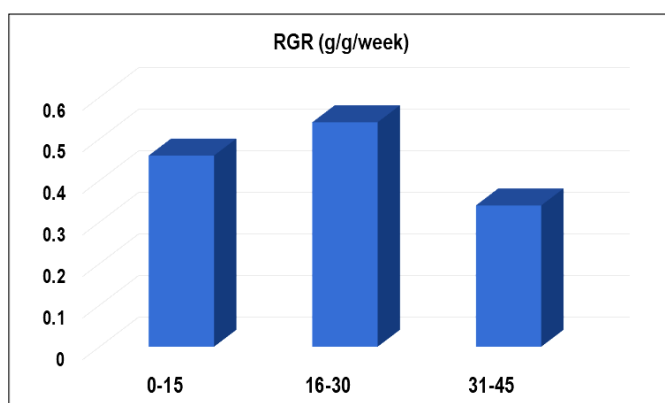


**Fig. 9.** Effects of variety, growing system and runner removal on fruit yield of strawberry.

of treatment on the fruit yield of strawberries (Fig. 9) clarified that V1 exhibited a higher fruit yield (227.88 g/plant) compared to V2. Also, S1 produced a lesser fruit yield (183.83 g/plant) compared to a higher yield (215.44 g/plant) in the S2 system of cultivation. Similarly, runner removal (R1) recorded a higher fruit yield (201.57 g/plant) compared with a lesser yield of fruits (197.0 g/plant) recorded under R0. The two-way interaction of the data further verified the results of individual treatment effects. The highest yield record was made with the interaction  $V1 \times S2 \times R1$  gave a fruit yield of 288.00 g/plant against the minimum yield of (147.87) under  $V2 \times S1 \times R0$ .

## Discussion

Plant height is regarded as an index of crop management but this is not sufficient to quantify strawberry vigour as it is only an auxiliary indicator. Plant spread indicates the leafiness of the plants that determine the amount of light interception to be used for photosynthesis. Plant dry weight provides a precise measurement of biomass, eliminating fluctuations caused by water content and is directly related to photosynthetic productivity. The difference in plant growth between the varieties may be attributed to the differences in one or more DNA sequences of their genetic makeup (19). The improved growth of plants under a hydroponic system may be attributed to the fast uptake of water and minerals due to the steeper gradient of water potential between the nutrient medium and root cell sap. Increased water absorption maintains the cell turgidity that helps in cell enlargement and cell division which ultimately increases the growth of plants. Higher vegetative growth of strawberries under hydroponics has also been reported in earlier research (20) that has been reported to



**Fig. 10.** Relative growth rates, RGR (g/g/week) of the strawberry plant during different growth periods.

improve WUE (21). The reason for enhanced plant growth due to runner removal may be attributed to the alteration of the source-sink ratio as the growth of runners requires additional energy from the plant (8) that may be diverted to the plant for their own growth. The results are also in conformity with those of earlier workers (14, 22, 23).

The RGR of the present study through the growing period (Fig. 10) clearly indicates that the RGR was slower during the initial periods (0-15 days) and increased during 16 – 30 days of the growing period and then again declined during the 31 – 45 days of plant growth and even gone behind the plant RGR observed during initial periods (0 – 15 days) of plant growth.

The growth analysis in terms of RGR proved to be a valuable tool for investigating differences in plant growth characteristics. It is the rate of accumulation of new dry mass per unit of existing dry mass. The faster an individual accumulates biomass, the more carbon is available to increase the growth of roots and shoots for greater access to light and soil nutrients, which in turn enables greater biomass accumulation (24). The present study also reveals that variety, growing system and runner removal individually or in their possible combinations significantly influenced the RGR of strawberries. An increased RGR of hydroponically growing plants has also been reported by earlier researchers (25, 26). The increased RGR under the hydroponic system of cultivation may be attributed to enhanced nutrient and water uptake (27, 28).

Relatively a lesser RGR during the initial phase of plant growth might be due to the less availability of plant surfaces to make food i.e., leaves as source. However, due to the progressive increase in photosynthetic surface area (source leaves), there was availability of more food that resulted in greater value of RGR during the mid-phase of plant growth. However, a sharp decline of RGR during the last phase of plant growth may be attributed to the diversion of assimilates towards an additionally developed reproductive sink. Earlier studies also reported that the relative growth rate (RGR) during the vegetative stage was  $300 \text{ mg g}^{-1} \text{ d}^{-1}$  and dropped at the initiation of flowering buds to  $60 \text{ mg g}^{-1} \text{ d}^{-1}$  (29).

Roots, also called as the “hidden half” of plants (30) are meant primarily for resource acquisition, although other abilities such as nutrient storage and plant anchorage are also important (31). For healthy growth, plants must absorb all essential mineral elements via the roots (32). Therefore, an extensive root system is critical for improved biomass production, yield and yield stability. Studies (33) established a close relationship of root dry weight with plant height and aboveground plant dry weight. In hydroponics, the nutrient solution can either be saturated with air prior to its use or changed frequently, or air can be continuously supplied in solution throughout plant life (34-36). The performance of roots grown in different types of soilless growing systems markedly improved over traditional soil growing systems which can be attributed to the air and water balance in the root environment under soilless cultivated plants (37). It has also been reported that

hydroponically grown seedlings of *Gleditsia tricanthos* L. var. *inermis* exhibited longer roots in comparison to soil-grown seedlings (38).

The differences in runner growth due to variety may be attributed to their genetic makeup. However, increased runner growth under the hydroponic cultivation system might be the result of amplified water and nutrients that caused cellular elongation and cell division finally resulting in improved runner growth.

Different strawberry genotypes or varieties possess unique genetic traits that influence their growth, development and yield potential. The increased fruit numbers and individual fruit weight under the hydroponic system of cultivation can be attributed to improved plant growth due to the fast uptake of water and minerals due to the steeper gradient of water potential between the nutrient medium and root cell sap. In strawberries, runners are known as strong sinks for leaf assimilates, water and nutrients in competition with developing flowers and fruits (39, 40). Runner removal possibly saves the energy utilized for its growth that might have been utilized for better plant growth and reproduction and resulted in higher yield through increased number of fruits and individual fruit weight. Our results regarding the higher number of fruits in Camarosa are in agreement with earlier reports (41). Relatively, a higher fruit length of the Sweet Charlie variety has also been reported in other studies (42). Our findings regarding the 2 growing systems are also consistent with earlier researchers (43, 44). Other workers also reported that runner removal in strawberries increased total and marketable yield and the number and size of fruits (23).

## Conclusion

Growing of strawberry varieties under the NFT system of hydroponics with complete runner removal at regular intervals resulted in significant improvement in plant growth and fruit yield of strawberries. However, two strawberry cultivars viz., Camarosa and Sweet Charlie responded differently under the hydroponic system of cultivation. Camarosa, despite lower plant growth, resulted in a higher number of fruits and improved yield. As such cultivation of Camarosa strawberries under the NFT system of hydroponics along with regular runner removal may be recommended to obtain enhanced fruit yield of strawberries.

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## Authors' contributions

SM conducted the trial of the experiment and recorded various observations on plant growth, quality analysis and yield. FAK conceived the idea and chalked out the detailed layout plan of the work. GC helped in the development of

the technical programme and discussion part of the article. SAB guided the for-laboratory analysis of different physiological and biochemical attributes. SN helped in the conduct of the experiment and draft of the article. SAM made the statistical analysis of the data. AK provided the propagation materials (propagules) and helped in the growing of strawberries in the field. SG took care of disease and pest issues of the crop. FK and MA were actively involved in the preparation of diagrams and a survey of literature. All authors read and approved the final manuscript.

## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interests to declare.

**Ethical issues:** None

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