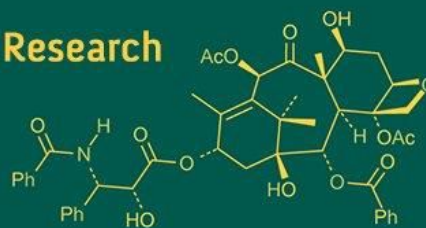
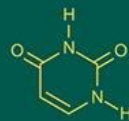
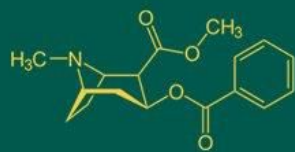


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(8): 264-270
www.biochemjournal.com
Received: 02-06-2025
Accepted: 05-07-2025

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Performance assessment of strawberry (*Fragaria × ananassa* Duch.) cultivated in different hydroponic techniques

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DOI: <https://www.doi.org/10.33545/26174693.2025.v9.i8Sd.5131>

Abstract

The present studies entitled, “Performance Assessment of Strawberry (*Fragaria × ananassa* Duch.) Cultivated in Different Hydroponic Techniques” were conducted during Rabi 2024-25 at Instructional Farm, Centre of Excellence for Vegetables, Agricultural Development Trust, Baramati, Maharashtra. The investigation aimed to evaluate the performance of strawberry in eight different hydroponic systems with respect to growth, flowering, yield and fruit quality traits. The experiment was laid out in a Completely Randomized Design (CRD) with three replication and eight treatments consisting of different hydroponic systems Viz. T₁: Flat bed NFT, T₂: A Frame NFT, T₃: Deep Water Culture (DWC), T₄: Dutch bucket Technique, T₅: Aeroponics, T₆: Growtower/Vertistack, T₇: Trough method and T₈: Control.

The results demonstrated that, Growtower/Vertistack produced the maximum height plants (28.10 cm). However, the Dutch bucket system significantly outperformed in plant spread (36.72 cm N-S and 38.91 cm E-W), number of crowns per plant (6.39) and leaf area (139.34 cm²). Strawberry yield characteristics were also maximized in this system, the highest number of fruit per plant (25.19), fruit length (44.14 mm), fruit circumference (135.42 mm) and individual fruit weight (24.61 g). Flowering began earliest in Flat bed NFT (34.06 DAT), but the Dutch bucket system sustained the longest flowering duration (90.58 days) and produced the earliest harvest in Flat bed NFT (64.06 days). The Dutch bucket treatment delivered the maximum yield per plant (613.44 g), yield per m² (6.79 kg) and yield per hectare (67.90 t).

Quality traits further favored the Dutch bucket system, which recorded superior fruit firmness (0.88 kg/cm²), total soluble solids (7.20 °Brix), reducing sugars (6.86 %) and shelf life (29.17 hours), along with the highest count of Extra Class fruits (4.66), although differences in ascorbic acid and individual sugar fractions were not statistically significant. Deep Water Culture performed poorly, likely due to insufficient root aeration.

In conclusion, the Dutch bucket system emerged as the most effective hydroponic method for optimizing strawberry growth, yield and quality under controlled cultivation. While Aeroponics and the Trough method also demonstrated potential, further multi-location and multi-season trials are necessary to validate consistency and Scope.

Keywords: Strawberry, hydroponic systems, dutch bucket, protected cultivation, yield performance, fruit quality

1. Introduction

Strawberry (*Fragaria × ananassa* Duch.) is a popular temperate fruit crop cultivated globally for its appealing flavor, high nutritional value and commercial importance. It is a hybrid species derived from *Fragaria chiloensis* and *Fragaria virginiana* and belongs to the family Rosaceae. The fruit is an excellent source of vitamin C, dietary fiber, folate, antioxidants and bioactive compounds such as anthocyanins, ellagic acid and flavonoids, contributing to its recognized health benefits (Giampieri *et al.*, 2013) [17].

In India, strawberries are grown on approximately 3,000 hectares with a production of around 14,000 metric tons. However, productivity remains relatively low at 7.8 MT/ha compared to countries like Mexico and China. Maharashtra is the leading strawberry-producing state, contributing nearly 56% of the national output, primarily from the Panchgani-Mahabaleshwar region (Bhosale *et al.*, 2021) [51].

To address productivity and quality constraints, hydroponics has emerged as a modern alternative that offers efficient water and nutrient use, soil-less cultivation and year-round production under protected environments (Resh, 2022) [15]. Hydroponic systems allow precise control over root-zone conditions, enhancing plant growth, reducing disease incidence and improving yield and uniformity.

Several hydroponic systems have been developed, including Nutrient Film Technique (NFT), Deep Water Culture (DWC), Dutch bucket, Aeroponics, Grow Tower/Vertistack and the Trough Method. Each system offers unique benefits for instance, NFT supports efficient nutrient delivery, Aeroponics maximizes oxygen and space use (Yafuso and Boldt, 2024) [19].

Despite global advances, comparative performance data of these systems under Indian agro-climatic conditions remain limited. This study was therefore designed to evaluate the performance of the strawberry cultivar 'Sweet Sensation' across eight hydroponic systems Flat bed NFT, A-frame NFT, Deep Water Culture, Dutch bucket, Aeroponics, Grow Tower, Trough Method and control (Grow Bag) within a polyhouse setup. The objective was to identify the most efficient system for sustainable, high-quality strawberry cultivation in Indian conditions (Mohamed *et al.*, 2022) [9]. The study aimed to study the growth, yield, quality and nutritional composition of strawberry in various hydroponic systems and to identify best hydroponics system for growth, yield and quality of strawberry production.

2. Experimental Methods

2.1. Experiment Details

The trial was conducted during the *Rabi* 2024-25 season at the Instructional Farm of the Centre of Excellence for Vegetables, Agricultural Development Trust, Baramati, Maharashtra. A completely randomized design (CRD) with three replication was used to evaluate eight treatments including eight hydroponic systems Flat bed NFT, A-Frame NFT, Deep Water Culture, Dutch bucket, Aeroponics, Grow Tower/VertiStack, Trough Method and control (grow-bag) each comprising 30 plants of strawberry 'Sweet Sensation' established within a polyhouse under protected cultivation.

2.2 Treatment details

The experiment included eight treatments comprising seven hydroponic systems and one control. The hydroponic systems were: Flat bed NFT (1.87m L x 6.0m W x 0.8m H), A-frame NFT (1.49m L x 6.0m W x 2.5m H), Deep Water Culture (DWC) (1.25m L x 12.3m W x 0.22m H), Dutch bucket (0.23 m L x 0.3m W x 0.25m H), Aeroponics (1.3m L x 6m W x 1.5m H), Grow Tower/Vertistack (0.34m L x 0.34m W x 0.20 m H) and Trough Method (0.4m L x 12.3m W x 0.2m H), each differing in design and dimensions. The control consisted of conventional grow bags.

2.3 Experimental Plot

The study was conducted during *Rabi* season 2024-25 at the Instructional Farm, Centre of Excellence for Vegetables, Agricultural Development Trust, Baramati, Pune. The site falls under Agro-Ecological Region 6 (Deccan Plateau), characterized by a semi-arid climate with average annual rainfall of 550-560 mm, mostly from the southwest monsoon. The mean monthly temperatures range from 22 °C in winter to 31.4 °C in summer, with relative humidity averaging 73%. During the experimental period, polyhouse

conditions were controlled, maintaining temperatures between 26-28 °C and relative humidity between 60-70%. Meteorological data were recorded at KVK Baramati.

2.4 Preparation of seedlings for hydroponics

The experiment used the 'Sweet Sensation' strawberry cultivar, propagated via tissue culture. This variety is known for medium to large fruit size, uniform plant establishment, early harvesting and good yield potential. Healthy seedlings were sourced from R.P. Agro Nursery, Shewalwadi, Tal-Haveli, Pune.

2.5 Transplanting

Transplanting of healthy, tissue culture-raised 'Sweet Sensation' strawberry seedlings was carried out on 10th November 2024. Transplanting healthy strawberry seedlings in net pots were shifted from the nursery and transplanted on 10th November 2024 on food-grade polystyrene raft boards. They were placed in the specific holes on the boards as per different treatments. Flat bed NFT system seedlings in net pots were placed in horizontal NFT channels with continuous nutrient film flow. The pots were inserted into pre-cut holes along the top of the channels. A-Frame NFT System Plants were transplanted on slanted A-frame structures fitted with NFT channels. The net pots were positioned at regular intervals in the channels for vertical space optimization. Deep Water Culture (DWC) Net pots were placed in holes on food-grade polystyrene raft boards, which floated on nutrient solution in shallow tanks. Roots were suspended directly in the aerated solution. Dutch bucket System plant was set into Dutch buckets filled with a clay balls, Nutrient solution was supplied intermittently via drip lines with drainage recovery. Aeroponic System net pots were fitted into vertical columns where plant roots were suspended in air and periodically misted with nutrient solution. Vertical Tower System transplants were inserted into vertical towers with stacked planting slots filled with cocopeat. Nutrients were delivered from the top and trickled down. Control (Grow Bags) Seedlings were transplanted placed inside cocopeat-filled grow bags. A supplied nutrient solution near the root zone through manually.

2.6 Nutrient Management

Strawberry plants were fertigated using a two-tank hydroponic nutrient solution system (Tank A and Tank B; 100 L each), tailored to vegetative and fruiting stages. During the vegetative stage, Tank A supplied calcium nitrate (8.1 kg), EDDHA iron (280 g), Mn-EDTA, Zn-EDTA and Cu-EDTA, while Tank B included potassium nitrate (3.5 kg), monopotassium phosphate, magnesium sulphate, borax and sodium molybdate. For the fruiting stage, the formulation remained largely similar, with slight adjustments and the addition of potassium sulphate (1.0 kg) to Tank B.

Fertigation targeted a solution pH of 5.4 and EC of 1.6, with a root zone pH of 5.5-6.0 and EC of 1.0. Nutrient solutions were monitored regularly and EC and pH were adjusted as needed to maintain optimal nutrient uptake. Solution A primarily contained macronutrients such as nitrogen, phosphorus, potassium, calcium and magnesium, while Solution B consisted of essential micronutrients including iron, manganese, zinc, copper and molybdenum. This balanced nutrient management ensured healthy plant growth and optimal fruit development throughout the cultivation period.

2.7 Measurement of Growth Parameters:

2.7.1 Plant height (cm)

The plant height was measured from the ground level first node to the tip of the plant with the help of measuring scale at 30, 60, 90 days and at harvest and was expressed in centimetre.

2.7.2 Plant spread (E-W and N-S) (cm)

Plant spread (cm) was determined by using a measuring scale to observe the canopy of the plant in both the East-West and North-South directions at 30, 60, 90 days and at harvest.

2.7.3 Number of crowns per plant

The strawberry plant features a short, thickened stem known as the crown, which contains a growing point at its top and produces roots at its base. Larger crowns are indicative of greater plant vigor and more rapid early growth, contributing to earlier and increased fruit production. The total number of crowns was recorded through visual inspection at 30, 60, 90 days and at harvest.

2.7.4. Number of runners per plant

The numbers of runners were counted in each plant selected at 30, 60, 90 days and at harvest.

2.7.5. Leaf area (cm²)

Five leaves were selected randomly from five observational plants and leaf area were calculated by using leaf area meter at 30, 60, 90 days and at harvest there was worked out and expressed in cm².

2.8 Measurement of flowering Parameters

2.8.1 Days to flower initiation

The days to flowering was measured by counting the days from the date of transplanting from each treatment to the opening of flower and was expressed as a number.

2.8.2 Flowering duration (Days)

Flowering duration was recorded by counting the number of days taken for first flower initiation to last flower to produce and the average was worked out.

2.9 Measurement of Fruit and Yield Parameters

2.9.1 Number of fruits per plant

The number of fruits per plant was counted by taking three plants per treatment and then average was calculated.

2.9.2 Fruit length (mm)

The length of five randomly selected fruits from each treatment was measured in millimetres (mm) by using vernier caliper from the calyx plug to the pointed end apex of the fruit.

2.9.3 Fruit circumference (mm)

Selection of strawberry fruits to maintain consistency, strawberries of uniform ripeness and size were selected. The maximum diameter (D) of each fruit was measured using a vernier caliper. The radius (r) was calculated as half of the diameter ($r = D/2$) and subsequently, the fruit circumference was determined by the formula,

$$C = 2\pi r$$

2.9.4 Average fruit weight (g)

The weight of five fruits was measured in grams and average was worked out.

2.9.5 Yield per plant (g)

The total yield per plant was recorded at each harvest by weighing the total number of fruits produced by each plant and expressed it in kilograms.

2.9.6 Yield per m² (kg)

Yield per m² was calculated by multiplying the number of plants per meter square from each hydroponic system by the yield per plant (g) and it is expressed in kg.

2.9.7 Yield per hectare (t)

The yield recorded per plot for each treatment was converted to yield per hectare using a multiplication factor and presented in tonnes per hectare (t/ha).

2.10 Experimental Design and Statistical Analysis

The data obtained for different treatments under Investigation will be subjected to statistical analysis as per procedure prescribed for completely randomized Design (CRD) as suggested by Panse and Sukhatme (1985)^[13].

3. Results and Discussion

3.1 Growth parameters

The data about the growth parameters such as plant height, plant spread (E-W and N-S), number of crowns, number of runners and leaf area is depicted in Table 1. Significant differences were observed among hydroponic systems at all stages. The maximum plant height was observed in the Grow Tower/Vertistack system at different growth stages viz., at 30, 60, 90 and 120 DAT, (10.68 cm, 15.76 cm, 20.79 cm and 28.10 cm). while, minimum plant height recorded in Deep Water Culture system with (9.35 cm, 13.45 cm, 17.63 cm and 24.56 cm) at 30, 60, 90 and 120 DAT.

The maximum plant spread East-West direction was recorded in the Dutch bucket system at different growth stages, at 30, 60, 90 and 120 DAT, (24.85 cm, 34.90 cm, 37.69 cm and 38.91 cm). While, the minimum plant spread was observed in Deep Water Culture system with spread of (11.65 cm, 13.71 cm, 18.62 cm and 26.24 cm) at 30, 60, 90 and 120 DAT.

The maximum plant spread in the North-South direction was observed in Dutch bucket system at different crop growth stages 30 DAT (16.41 cm), 60 DAT (25.74 cm), 90 DAT (33.21 cm) and 120 DAT (36.72 cm). However, the minimum plant spread was recorded in Deep Water Culture systems at 30, 60, 90 and 120 DAT (12.98 cm, 20.42 cm, 25.81 cm and 28.95 cm respectively).

The highest number of crowns was observed in the Dutch bucket system (2.43, 4.71, 5.37 and 6.39) at 30, 60, 90 and 120 DAT, respectively while, lowest number of crowns number was observed in Deep Water Culture system (1.48, 1.69, 2.41 and 3.58) at 30, 60, 90 and 120 DAT.

The lowest number of runners was recorded in Dutch bucket system (1.60, 2.65, 2.92 and 3.46) at 30, 60, 90 and 120 DAT while, highest number of runners was observed in Trough method (2.54) at 30 DAT, (3.94) at 60 DAT, (4.68) at 90 DAT and (5.74) at 120 DAT.

The maximum leaf area was recorded in the Dutch bucket system in all stages, with values of (48.89 cm²) at 30 DAT, (63.21 cm²) at 60 DAT, (137.19 cm²) at 90 DAT and

(139.34 cm²) at 120 DAT. While, minimum leaf area was observed in Deep Water Culture system (20.59 cm², 29.73 cm², 95.87 cm² and 98.91 cm²) at 30, 60, 90 and 120 DAT.

The significant variation in growth parameters such as plant height, plant spread, number of crowns, runners and leaf area across hydroponic systems can be attributed to the physiological advantages offered by specific system designs. The Dutch bucket and Aeroponic systems consistently promoted superior vegetative growth due to enhanced root aeration, precise nutrient delivery and optimal moisture balance, which are critical for root respiration, nutrient uptake and hormonal regulation particularly of auxins and cytokinins that govern cell elongation and organogenesis (Kumar *et al.*, 2021)^[8].

The Dutch bucket intermittent drip irrigation and well-drained media provide a balance between oxygen and moisture at the root zone, improving ATP production and nutrient absorption (Treftz and Omaye, 2015)^[17]. Similarly, Aeroponics, through misting roots suspended in air, ensures high oxygen availability, enhancing nutrient-use efficiency and stimulating vigorous shoot growth (Osman *et al.*, 2024)^[11]. The Grow Tower/Vertistack system also supported greater plant height due to reduced interplant competition and efficient space utilization. In contrast, Deep Water Culture (DWC) system exhibited the lowest performance in early vegetative growth due to hypoxic root conditions and nutrient dilution, which can limit energy production and disrupt metabolic activities essential for early crown and runner development (Panigrahi *et al.*, 2020; Rani *et al.*, 2023)^[12, 14]. These observations align with earlier studies emphasizing the impact of hydroponic root-zone conditions on canopy architecture, leaf area expansion and vegetative vigor in strawberries (Singh *et al.*, 2020)^[16].

3.2 Flowering parameters

The data about the flowering parameters such as, days to flower initiation, flowering duration is depicted in Table 7. Significant differences were observed among hydroponic systems at all stages. The minimum number of days for initiation of flower (34.06 days) was recorded in Flat bed NFT system. While, the maximum number of days to initiation of flowering (45.67 days) was reported in Deep Water Culture system. Among the treatments, Dutch bucket system demonstrated the longest flowering duration of (90.58 days), indicating an extended reproductive phase while less flowering duration was recorded in Deep Water Culture system (77.55 days).

Flower initiation and duration in strawberry were significantly influenced by hydroponic systems due to

differences in root-zone conditions and nutrient dynamics. Early flowering in the Flat Bed NFT and Dutch bucket systems can be attributed to better nutrient availability and hormonal balance, particularly cytokinins and gibberellins that promote floral induction (Singh *et al.*, 2020)^[16].

3.3 Fruit and yield attributing parameters

The data demonstrated that the fruit and yield attributing parameters is depicted in Table 8 and 9. Significant differences were observed among hydroponic systems at all stages. The Dutch bucket system recorded the highest number of fruits per plant (25.19), maximum fruit length (44.14 mm), maximum fruit circumference (135.42 mm) and the maximum average fruit weight (24.61 g). While, Deep Water Culture system was lowest with the number of fruits per plant (14.76), fruit length (28.50 mm), fruit circumference (89.17 mm) and average fruit weight (11.32 g).

The minimum days to harvest was recorded in Flat bed NFT (64.06 days). However, maximum days to harvest was found in Deep Water Culture (75.69 days).

Among all the systems evaluated, the Dutch bucket system observed highest number of picking (11.33), maximum yield per plant (613.44 g), yield per square meter (6.79 kg) and yield per hectare (67.90 tonnes). These findings clearly established Dutch bucket system as the most efficient hydroponic method for maximizing yield and harvesting efficiency in strawberry cultivation under protected conditions.

The superior fruiting performance observed in the Dutch bucket and Aeroponic systems can be attributed to favorable conditions that optimize water, nutrient and oxygen availability, crucial for fruit development. These systems provide consistent nutrient delivery and enhanced root aeration, promoting efficient photosynthate allocation, hormonal balance (cytokinins and auxins) and improved sink strength, which collectively enhance fruit set, size and weight (Kumar *et al.*, 2021)^[8]. The Dutch bucket system, with its media-based support and effective drainage, ensures steady moisture and ion uptake, leading to increased reproductive efficiency and yield per plant, per square meter and per hectare. In contrast, Deep Water Culture showed the poorest performance across all yield and quality parameters due to root hypoxia, lower nutrient use efficiency and suboptimal physiological activity (Panigrahi *et al.*, 2020)^[12]. These findings align with earlier studies highlighting that hydroponic systems with improved aeration and targeted fertigation significantly boost strawberry productivity and fruit quality (Osman *et al.*, 2024)^[11].

Table 1: Effect on plant height (cm) of strawberry in different hydroponic systems

Treatments	Plant height (cm)			
	30 DAT	60 DAT	90 DAT	120 DAT
T ₁ -Flat bed NFT	9.42	13.92	18.17	25.15
T ₂ -A frame NFT	10.01	14.21	19.02	26.48
T ₃ -Deep Water Culture	9.35	13.45	17.63	24.56
T ₄ -Dutch bucket	10.57	15.38	20.21	27.87
T ₅ -Aeroponics	10.26	14.63	18.53	26.05
T ₆ -Grow tower/Vertistack	10.68	15.76	20.79	28.10
T ₇ -Trough method	10.13	14.53	18.81	26.32
T ₈ -Control	9.64	13.74	17.92	21.13
SE(m)±	0.06	0.42	0.57	0.72
CD at 5%	0.19	1.26	1.71	2.16

Table 2: Effect on plant spread E-W(cm) of Strawberry in different hydroponic systems

Treatments	Plant spread E-W (cm)			
	30 DAT	60 DAT	90 DAT	120 DAT
T ₁ -Flat bed NFT	16.42	24.58	27.10	33.94
T ₂ -A frame NFT	19.28	28.19	32.27	37.61
T ₃ -Deep Water Culture	11.65	13.71	18.62	26.24
T ₄ -Dutch bucket	24.85	34.90	37.69	38.91
T ₅ -Aeroponics	23.92	33.45	36.82	38.79
T ₆ -Grow tower/Vertistack	20.31	25.43	29.37	34.20
T ₇ -Trough method	23.81	33.76	35.82	37.58
T ₈ -Control	18.79	26.81	30.12	34.82
SE(m)±	0.54	0.72	0.92	1.28
CD at 5%	1.63	2.18	2.77	3.83

Table 3: Effect on plant spread N-S (cm) of strawberry in different hydroponic systems

Treatments	Plant spread N-S (cm)			
	30 DAT	60 DAT	90 DAT	120 DAT
T ₁ -Flat bed NFT	14.02	21.77	28.31	31.99
T ₂ -A frame NFT	15.36	23.65	30.94	34.28
T ₃ -Deep Water Culture	12.98	20.42	25.81	28.95
T ₄ -Dutch bucket	16.41	25.74	33.21	36.72
T ₅ -Aeroponics	15.94	24.52	32.11	35.53
T ₆ -Grow tower/Vertistack	14.53	22.91	31.36	34.41
T ₇ -Trough method	15.11	23.48	30.14	35.08
T ₈ -Control	13.45	21.01	27.66	30.77
SE(m)±	0.43	0.60	0.72	0.83
CD at 5%	1.31	1.82	2.17	2.51

Table 4: Effect on number of crowns per plant of strawberry in different hydroponic systems

Treatments	Number of crowns per plant			
	30 DAT	60 DAT	90 DAT	120 DAT
T ₁ -Flat bed NFT	1.61	3.62	3.85	4.72
T ₂ -A frame NFT	1.75	3.87	4.20	5.23
T ₃ -Deep Water Culture	1.48	1.69	2.41	3.58
T ₄ -Dutch bucket	2.43	4.71	5.37	6.39
T ₅ -Aeroponics	2.38	4.42	5.28	6.31
T ₆ -Grow tower/Vertistack	2.24	3.95	4.63	4.71
T ₇ -Trough method	2.36	4.29	5.12	5.39
T ₈ -Control	1.55	2.59	2.76	4.37
SE(m)±	0.05	0.11	0.12	0.05
CD at 5%	0.16	0.35	0.36	0.17

Table 5: Effect on Number of runners per plant of strawberry in different hydroponic systems

Treatments	Number of Runners per plant			
	30 DAT	60 DAT	90 DAT	120 DAT
T ₁ -Flat bed NFT	2.45	3.58	4.41	4.55
T ₂ -A frame NFT	2.32	3.44	4.36	4.50
T ₃ -Deep Water Culture	2.08	3.30	3.75	4.98
T ₄ -Dutch bucket	1.60	2.65	2.92	3.46
T ₅ -Aeroponics	1.70	2.78	3.10	3.61
T ₆ -Grow tower/Vertistack	2.28	3.35	4.25	5.18
T ₇ -Trough method	2.54	3.94	4.68	5.74
T ₈ -Control	1.68	3.48	4.45	5.42
SE(m)±	0.06	0.07	0.06	0.09
CD at 5%	0.20	0.22	0.19	0.29

Table 6: Effect on Leaf area (cm²) of strawberry in different hydroponic systems

Treatments	Leaf area (cm ²)			
	30 DAT	60 DAT	90 DAT	120 DAT
T ₁ -Flat bed NFT	31.53	44.04	113.34	116.39
T ₂ -A frame NFT	36.37	44.48	113.49	116.63
T ₃ -Deep Water Culture	20.59	29.73	95.87	98.91
T ₄ -Dutch bucket	48.89	63.21	137.19	139.34
T ₅ -Aeroponics	45.38	59.98	134.74	138.72
T ₆ -Grow tower/Vertistack	38.36	43.76	111.65	114.87
T ₇ -Trough method	41.31	59.96	132.28	138.39
T ₈ -Control	31.57	45.28	120.50	123.64
SE(m)±	1.24	1.38	1.92	0.28
CD at 5%	3.72	4.16	5.77	0.85

Table 7: Effect on Days to flower initiation and Flowering duration (Days) of strawberry in different hydroponic systems

Treatments	Days to flower initiation	Flowering duration (Days)
T ₁ -Flat bed NFT	34.06	81.63
T ₂ -A frame NFT	39.45	83.91
T ₃ -Deep Water Culture	45.67	77.55
T ₄ -Dutch bucket	37.29	90.58
T ₅ -Aeroponics	39.73	86.15
T ₆ -Grow tower/Vertistack	41.04	80.60
T ₇ -Trough method	44.33	85.17
T ₈ -Control	45.37	82.45
SE(m)±	1.28	1.96
CD at 5%	3.85	5.90

Table 8: Effect on Number of fruits per plant, Fruit length (mm), Fruit circumference (mm), of strawberry in different hydroponic systems

Treatments	No. of fruits per plant	Fruit length (mm)	Fruit circumference (mm)	Average fruit weight (g)
T ₁ -Flat bed NFT	16.83	33.08	103.98	15.58
T ₂ -A frame NFT	19.37	35.29	111.84	17.08
T ₃ -Deep Water Culture	14.76	28.50	89.17	11.32
T ₄ -Dutch bucket	25.19	44.14	135.42	24.61
T ₅ -Aeroponics	23.89	41.32	129.49	22.80
T ₆ -Growtower/Vertistack	20.86	39.45	119.55	18.39
T ₇ -Trough method	21.34	41.35	131.50	20.13
T ₈ -Control	15.89	29.98	94.15	13.75
SE(m)±	0.21	0.96	3.08	0.18
CD at 5%	0.63	2.89	9.25	0.54

Table 9: Effect on Yield per plant (g), Yield per m² (kg), Yield per hectare (t) of strawberry in different hydroponic systems

Treatments	Yield/plant (g)	Yield/m ² (kg)	Yield/hectare(t)
T ₁ -Flat bed NFT	262.14	2.72	27.20
T ₂ -A frame NFT	331.02	3.39	33.76
T ₃ -Deep Water Culture	167.12	1.69	17.10
T ₄ -Dutch bucket	613.44	6.79	67.90
T ₅ -Aeroponics	543.85	5.99	59.90
T ₆ -Grow tower/Vertistack	383.56	4.62	46.50
T ₇ -Trough method	429.43	4.87	48.50
T ₈ -Control	218.49	2.62	26.20
SE(m)±	5.41	0.07	0.20
CD at 5%	16.24	0.22	0.62

Conclusion

The present investigation clearly demonstrates that different hydroponic systems exert a significant influence on the growth, flowering, yield and quality parameters of strawberry under protected conditions. Among the systems evaluated, the Dutch bucket system consistently outperformed others in terms of plant spread, leaf area and number of crowns, resulting in enhanced flowering duration, fruit size and yield metrics. This superior performance can be attributed to optimal root-zone aeration, balanced moisture retention and consistent nutrient delivery, which

collectively supported better physiological activity, hormonal regulation and overall vegetative and reproductive growth. Aeroponic and Trough systems also showed commendable results, particularly in runner production and fruit attributes. However, Deep Water Culture system recorded the poorest outcomes across most parameters, likely due to hypoxic conditions and nutrient dilution. These findings underscore the critical role of hydroponic design in optimizing plant performance and highlight the Dutch bucket system as a highly efficient method for commercial strawberry cultivation. Adoption of such systems can

significantly improve productivity, resource-use efficiency and fruit quality in controlled environment agriculture.

Acknowledgment

I sincerely express my heartfelt gratitude to the advisory committee members and the faculty of Dr. Sharadchandra Pawar College of Agriculture, Baramati for their consistent support, valuable guidance at this prestigious institution, which has greatly enriched my academic journey and research endeavours.

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