

Growth and Physiochemical Performance of Red Cherry Tomato in Soil and Soilless Cultivation Systems

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ABSTRACT

In modern protected cultivation several approaches are being used such as hydroponics, vertical farming, aeroponics and aquaponics. It is very important to evaluate the high-value crops under these methods to maximize their productivity and to minimize the risk of crop failure because of environmental factors under open-field conditions. In this study, seeds of *Solanum lycopersicum* var. *cerasiforme* (Red Cherry tomato) were sown in pro-trays for raising the seedlings. One-month-old saplings were then transplanted into two soilless systems developed in the polyhouse of the Department of Botany, Dayalbagh Educational Institute situated in District Agra of Uttar Pradesh, India namely, NFT hydroponic and vertical hydro-

ponic, both supplied with Hoagland nutrient solution in triplicates. A control experiment was conducted under open-field conditions using recommended agronomic practices in a Randomized Block Design. Growth, biochemical, and yield parameters were recorded and compared across systems. Results of the study revealed that plants grown under both hydroponic systems showed superior performance compared to the control. Average plant height reached 179.46 cm in NFT and 165.86 cm in vertical systems. Fruit yield parameters also improved, with mean fruit weights of 33.70 g in NFT and 31.07 g in vertical systems. Fruit dimensions were greater in hydroponic systems, measuring 3.23×2.66 cm in NFT and 2.56×1.99 cm in vertical farming. Maximum fruit production was observed in NFT (4800.81 g/plant), followed by vertical (3767.13 g/plant) and control (1967.57 g/plant). The highest SPAD (85.58) and NDVI (0.86) values were recorded in NFT at flowering. Photosynthetic rate ($14.36 \mu\text{mol m}^{-2} \text{s}^{-1}$) and stomatal conductance ($0.118 \text{ mol m}^{-2} \text{s}^{-1}$) were also highest in NFT. Soil-grown fruits had higher ascorbic acid (29.86 mg/100 g) but lower sugar content (6°Brix) compared to soilless systems (9.36°Brix in NFT and 9.06°Brix in vertical). Lycopene content peaked in NFT fruits at 90 and 105 days (294.24 and 305.70 mg/g, respectively). Overall, NFT hydroponics proved to be the most effective system for enhancing growth, physiochemical parameters and yield of cherry tomato compared to vertical hydroponics and open-field cultivation. These findings highlight the

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potential of NFT hydroponics as a superior system for enhancing plant growth and fruit quality compared to conventional cultivation.

Keywords Cherry tomato (*Solanum lycopersicum* var. *cerasiforme*), Growth, Yield, Physiochemical, Hydroponics, Nutrient Film Technique (NFT), Vertical farming, Soilless cultivation, Yield.

INTRODUCTION

The global population is projected to reach nearly 9 billion by 2050 as stated by the Food and Agriculture Organization (FAO) of the United Nations (FAO 2009, Akram 2025). As a result, there will be a greater demand for food worldwide. Furthermore, global issues linked with climate change like heat, droughts, floods, salinization, heavy metals, lack of clean water, and nutrient imbalance in open-field conditions are expected to intensify in the future (Wrachien and Goli 2015, Rodarte 2024, Rajendran *et al.* 2024). Soilless farming under protected cultivation may provide a revolutionary solution to these problems and also an efficient sustainable and productive alternative to conventional farming (Maluin *et al.* 2021).

Water scarcity and inadequate agricultural land are major issues in the current scenario. However, water quality and changed soil properties can affect the crop productivity and concentrations of secondary metabolites in agricultural produce (Woznicki *et al.* 2021). In these situations, hydroponic technique under protected conditions might be a better option than conventional irrigation methods, making water use more efficient for crop production (Costa *et al.* 2018). Thus, such techniques can help to preserve exhaustible resources and ensure food safety (Pomoni *et al.* 2023, Panotra *et al.* 2024).

Some prominent problems related to soil cultivation—such as salinity, poor soil structure, soil-borne diseases, pest attacks, and environmental fluctuations—have called for the implementation of protective farming under polyhouses by adopting hydroponic techniques (Roosta *et al.* 2025, Cardoso *et al.* 2017, Santos *et al.* 2017). In an open-field system, nutrient requirements are crop-specific, and

failure to meet them can result in poor growth or yield loss (Hayden 2006). By contrast, soilless systems provide a sustainable way to enhance production while reducing excessive fertilizer use (Santos *et al.* 2017, Singh *et al.* 2019). Furthermore, traditional cultivation alone will not be able to meet the demands of the growing global population. So, it is clear, that lots of effort is needed to develop protocols that will be optimum for area specific conditions as production changes from location to location particularly due to different crop varieties, plant architecture management systems, nutrient solution constitution and quality of supplied water.

Among soilless cultivation systems, hydroponics is the most common method practised globally (Macwan *et al.* 2020, Fussy and Papenbrock 2022). In this method roots are immersed in a nutrient-rich solution, ensuring continuous nutrient availability throughout the cropping period and also reduces the water stress. This technology provides structural support for plants by providing an artificial medium to reduce water loss from evaporation and percolation (Abdelhak 2024, Grewal *et al.* 2011, Patra *et al.* 2022). Moreover, by precisely managing nutrient supply, indoor hydroponic farming enhances crop productivity and improves quality, particularly in terms of secondary metabolites. Additionally, it reduces problems associated with environmental fluctuations such as soil variability and seasonal changes.

This system can be adopted in urban areas by utilizing rooftops, degraded lands and industrial wastelands sites to enhance production per capita in the country. This technology is highly productive, amenable to automation, conserves water, and can improve the marketability of produce (Spray and Spray 2019, Viviano 2017). Hydroponic systems can increase the production of exotic crops, reducing imports and helping the nation become Aatmanirbhar (self-reliant) in agriculture. Although discussions are ongoing regarding the application of urban hydroponics under both protected cultivation and natural conditions, the effectiveness of these techniques still needs to be validated under Indian climatic conditions.

Tomato consumption has been increasing world-

wide in recent years (Abdellatif *et al.* 2017). Cherry tomatoes (*Solanum lycopersicum* var. *cerasiforme*) are among the most important cultivated tomato varieties and are widely known for their deep red color, small size, juicy flesh, sweet taste and high nutritional value. These properties make this fruit suitable for preparing a variety of dishes. It is regarded as a protective food because of its high nutritional value i.e., minerals (K, Mn, P, Cu, Ca, Fe and Zn), a range of vitamins (A, B-complex, C, E, K), carotenoids, particularly lycopene, and flavonoids, which act as antioxidants (Silva *et al.* 2022, Yang *et al.* 2023).

Cherry tomatoes are becoming popular worldwide due to good health benefits and favorable cost-to-benefit ratio (Ilahy *et al.* 2016, Perveen *et al.* 2015). Though cherry tomato is a popular hydroponic crop worldwide but limited research has been conducted in India on its hydroponic cultivation practices (Kumar *et al.* 2024). In this system, the growth medium (organic, inorganic, or inert) contributes to crop development at varying rates. Techniques such as NFT (Nutrient Film Technique) and VFS (Vertical Farming System) enable the production of high-quality agricultural products in less time compared to conventional systems.

Hence, the present study aims to evaluate the yield and quality of red cherry tomatoes grown in soil versus hydroponic systems (NFT and VFS). This experiment was conducted in the Polyhouse of the Department of Botany, Dayalbagh Educational Institute, Agra, Uttar Pradesh, India.

MATERIALS AND METHODS

The experiments were conducted in soil (open-field as control, Fig. 1) and in two soilless systems, namely NFT hydroponic (Fig. 2) and vertical hydroponic (Fig. 3). Each soilless system was replicated three times and supplied with Hoagland nutrient solution. Seedlings of red cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) were produced in pro-trays. One-month-old seedlings were transferred into the two soilless systems. At the same time, seedlings were transplanted into the open-field plots, following recommended agronomic practices under a Randomized Block Design, during the first week of December.

Nutrient film technique (NFT)

In the NFT hydroponic system, pots were arranged in seven rows (18 pots per row) and interconnected through drip and fertigation lines. The primary drip line was connected to the water reservoir tank (Fig. 2). The drip pump's water flow rate was approximately 2L h⁻¹. For the supply of fertilizer, a standard water-lifting cooler pump was used, capable of lifting water up to 8 feet. A fiber sheet was used to support the net pots and to protect the roots from direct sunlight. The main valve, attached to the sub-irrigation drip line (SIDL) controlled water flow through both the main drip line and SIDL.

Vertical farming system (VFS)

In this system, seventeen layers of pipelines were installed vertically along both walls of the polyhouse, extending up to the girder height (15 feet). Each pipeline was 17.5 feet long and contained 17 holes for transplant seedlings, with a spacing of 12 inches between holes (Fig. 3).

Water and fertilizer supply mechanism

For fertilizer supply, the Hoagland solution was prepared by dissolving plant nutrients in 5 L of tap water and later diluted to 20 L. This solution was subsequently supplied using an electric pump of 1 kW. The fertilizer and irrigation to the plants was provided through a sub-drip irrigation system. Each row was provided with a drip line with spaces 12 cm apart. The drippers had a drip flow rate of 2 L/hr. The drip method was in use, for 2 hrs per day.

Nutrient treatment

Nutrient doses were applied at four growth stages, namely seedling, vegetative, flowering and fruiting. The recommended doses of fertilizer (RDF) were 120:25:180 (N:P:K) for the seedling stage, 150:40:220 for the vegetative stage, 180:50:270 for the flowering stage, and 200:50:300 for the fruiting stage, following Haifa nutrient recommendations (2020). Micronutrient requirements were met using a commercial micro booster formulation (15 g in 20 L water), applied until harvest. The nutrient solution



Fig. 1. Open-field block preparation. **Fig. 2.** NFT system designed by pots. **Fig. 3.** VFS system designed by PVC pipeline.

was maintained at pH 5.8–6.2 and electrical conductivity (EC) 1.5–2.8 dS m⁻¹, monitored using a Systronics Water Analyzer (Model 371).

Climatic conditions

All recommended climatic parameters were maintained within the polyhouse (Table 1). Temperature and relative humidity were regulated using cooling pads, foggers, and ventilation fans under protected conditions. Data were recorded for both the polyhouse and open-field conditions using a thermometer and hygrometer (Camuffo *et al.* 2010).

Data collection and analysis

Growth attributes: Plant height was measured manually using a measuring tape. Leaf area was recorded with a LI-COR leaf area meter and NDVI (Normalized Difference Vegetative Index) was taken using a green seeker sensor.

Yield attributes: Individual fruit weight, size (length and diameter), number of flower clusters per plant, number of fruits per plant and fruit yield per plant were recorded manually.

Physiological parameters: Stomatal conductance and photosynthetic rate were measured using an Infrared Gas Analyzer (IRGA, LI-6800, LI-COR,

Lincoln, Nebraska, USA).

Biochemical parameters: Total chlorophyll content was recorded by SPAD meter (Fontes and Araujo 2006). Determination of sugar content using brix refractometer, ascorbic acid using method of Najwa and Azrina (2017), modified by Nielsen (2024). Lycopene content was quantified by spectrophotometry (Anthon and Barrett 2006).

Ascorbic acid analysis

Ascorbic acid content was measured using the dye 2, 6 dichlorophenolindophenol (DCPIP) titration method (Najwa and Azrina 2017). Healthy red cherry tomato fruits were collected from polyhouse and open-field, and rinsed thoroughly with distilled water. A 0.01 g portion of each sample was accurately weighed, homogenized in a mortar and pestle with 6% metaphosphoric acid and filtered through muslin cloth. An aliquot of 10 mL fruit extract was transferred into a conical flask and titrated against DCPIP dye solution until solution changed from colorless to pink. The vitamin C content was calculated using the formula given by Alzahrani *et al.* (2019):

$$\text{Ascorbic acid content (mg / 100 g sample)} = \frac{X \times Y \times 100}{W}$$

Where, X= Volume of dye required to titrate the aliquot (mL), Y = Vitamin C equivalent of dye solu-

Table 1. Micro-climatic parameters maintained in the polyhouse (Singh *et al.* 2019).

Parameters		Vegetative stage	Flowering stage	Fruiting stage
Temperature (°C)	Day time	22-27	20-22	22-28
	Night time	15-19	15-18	18-22
Humidity (%)		50-65	55-60	60-75

tion (mg/mL), W = Weight of sample in aliquot of filtrate (g).

Lycopene analysis

Fresh tomatoes were obtained from open-fields and both hydroponic cultivation systems, and rinsed with distilled water. Fruits were then dried in a hot air chamber at 60°C, ground into fine powder and utilized for lycopene estimation. A 0.25 g portion of sample was dissolved in 1.5 mL of solvent mixture (Hexane:ethanol:Acetone, 2:1:1 v/v/v). The solution was centrifuged at 280 rpm for 30 min, after this 0.45 mL distilled water was added to induce phase separation. The lycopene layer was separated in tube, then OD was measured at 503 nm using a UV spectrophotometer (Shimadzu UV-1800). Lycopene content was calculated using the formula (Anthon and Barrett 2006).

$$\text{Lycopene (mg/kg)} = \frac{1.717 \times A_{503} \times V}{W}$$

Where: V = Volume of HEA solution (mL); W = Sample weight (mg); A_{503} = Absorbance at 503 nm. All experiments were conducted in triplicate and data were statistically analyzed by SPSS software (version 26).

RESULTS AND DISCUSSION

Growth parameters: Plant height under NFT, VFS and open-field (control) conditions was measured at 15-day intervals. Figs. 4-6 represent the growth of red cherry tomato under different experimental conditions. The maximum height was recorded at

105 DAT in the NFT hydroponic system (179.46 cm, Fig. 7A), followed by VFS (165 cm) while the lowest (117.96 cm) was noted under open-field conditions. Flowering initiation phase observed between 15 and 45 DAT, while fruit set was started after 50% flowering was completed, i.e., 60 and 75 DAT. Similar results were reported by Najeema *et al.* (2018) and Pavithra *et al.* (2023).

An increasing trend in leaf area was observed from vegetative to the fruiting stage across cultivation methods. The maximum leaf area (999.57 cm²) was recorded in the NFT system at vegetative stage, which further increased to 2388.45 cm² at the fruiting stage followed by VFS with 796.12 cm² at vegetative and 2071.51 cm² at the fruiting stage. The lowest leaf area was noted in open-field conditions (Fig. 7B). These results are comparable to those reported by Kumar *et al.* (2023).

The NDVI values were determined during three different stages of plant growth in both hydroponic systems and the open-field. The NDVI values at the vegetative, flowering and fruiting stages were 0.713, 0.863 and 0.796, respectively, in the NFT hydroponic system followed by 0.703, 0.836 and 0.753 in the VFS system. These values were higher as compared to open-field conditions (Fig. 7C). Kim *et al.* (2010) and Ihuoma and Madramootoo (2019) suggested that NDVI shows a positive correlation with plant water content, nitrogen content and biomass which supports the findings of present study.

Yield parameters

Formation of flowers was observed on the 45th day



Fig 4



Fig 5



Fig 6

Fig. 4. Open-field.

Fig. 5. VFS vegetation.

Fig. 6. NFT vegetation.

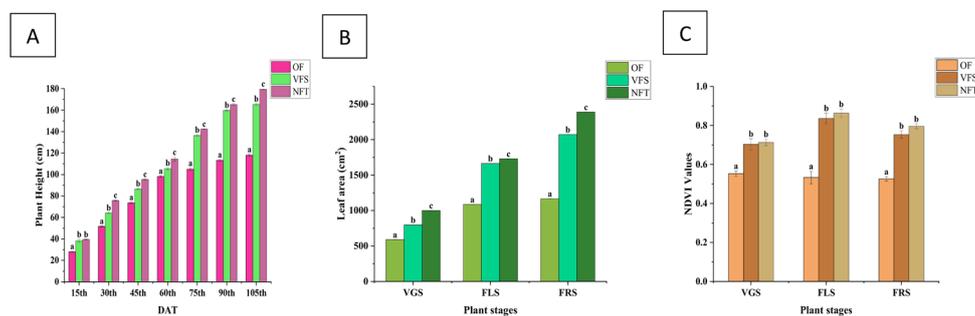


Fig. 7. (A) Plant height at different days after transplantation, (B) leaf area at different plant stages, (C) NDVI (Normalized difference vegetative index) values at different plant stages in NFT, VFS and open-field culture systems. Data are the mean values of 3 replicates. Different letters represent Duncan's Multiple Range Test (DMRT) which are found significant ($p < 0.05$).

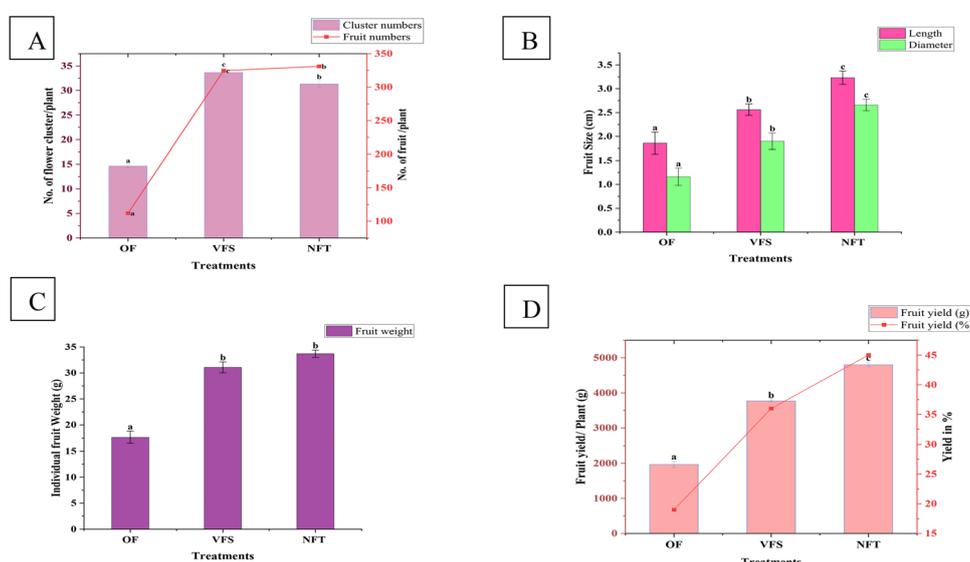


Fig. 8. (A) Flower number in clusters, and fruits number per plant, (B) fruit size (length \times diameter), (C) fruit weight individually, (D) yield of fruit per plant and yield percentage in NFT, VFS and open-field culture systems. Data shown in figure are the mean \pm SE values of 3 replicates. Different letters represent Duncan values which are found significant ($p < 0.05$) at 95% level in the Analysis of variance.

after transplantation in all treatments although their numbers were different in all tested methods. Maximum number of flowers (33.66/plant) was observed in VFS followed by NFT (31.33/plant) and open-field condition (14.66/plant) (Fig. 8A). These findings indicate that the VFS system provided more suitable conditions for flower cluster formation.

Maximum number of fruits per plant (331) was recorded in NFT followed by 324 in VFS and 112 in open-field systems respectively (Fig. 8A). Similar

findings were reported by Cheena *et al.* (2018), Chouhan *et al.* (2018) and Sabindas *et al.* (2021). Fruit size was measured as length \times diameter (cm). The largest fruits were observed in the NFT-system-grown plants (3.23 cm in length and 2.66 cm in diameter) compared to VFS and control (Fig. 8B). Similar results were reported by Um *et al.* (2025).

A significant difference in fruit weight was noted among different tested culture systems. Observation revealed that NFT system was most supportive to this

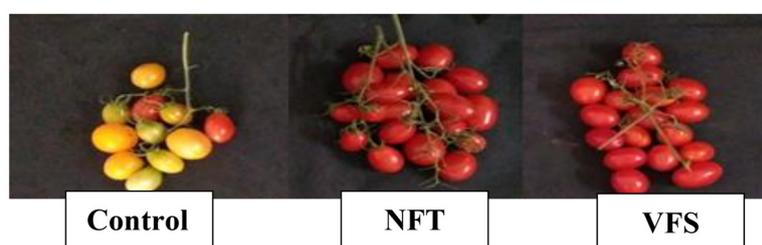


Fig. 9. Yield of Red cherry tomato fruit /plant in different methods.

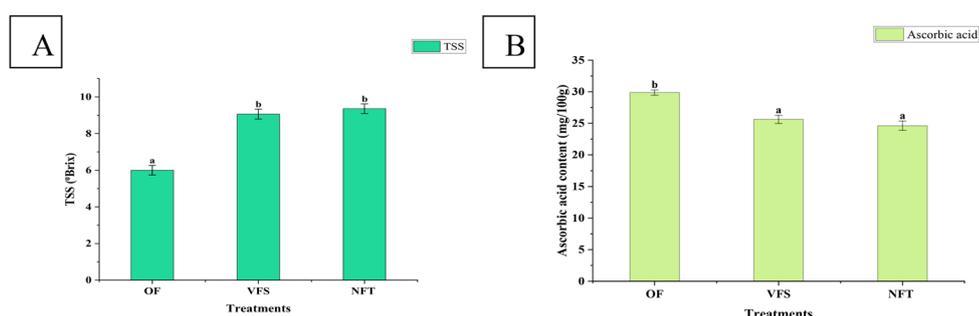


Fig. 10. (A) Total soluble solids (TSS), (B) Ascorbic acid content. Data are represented as mean values \pm standard error. Different letters indicate statistically significant differences according to Duncan's multiple range test ($p < 0.05$). Number of replications: $n = 3$. ANOVA results confirm that values with different letters differ significantly at the 95% confidence level.

parameter as compared to VFS and open-field system with average fruit weight 33.7, 31.07 and 17.66 g respectively (Fig. 8C). Similar trend was reported by Ali *et al.* (2021) and Quamruzzaman *et al.* (2017).

Total fruit yield per plant was highest in NFT (4800.81 g) followed by VFS (3767.13 g) and open-

field system (1967.57 g) (Fig. 8D, Fig. 9). These results align with Ali *et al.* (2021), Mehraj *et al.* (2014), Singh *et al.* (2013) and Chandra *et al.* (2014).

The superior yield performance of NFT system can be attributed to its pulsating water flow, which enhances root aeration and oxygen availability, thereby

Table 2. Physiological and biochemical parameters of red cherry tomato in different culture conditions at different plant stages.

*Data are the mean values of 3 replicates. Different letters represent Duncan values which are found ($p < 0.05$) at 95% level according to the ANOVA test.

Treatments	Physiological parameters (mean \pm SE)*					
	Photosynthetic rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$)			Stomatal conductance ($\text{mmol m}^{-2} \text{s}^{-1}$)		
	VGS	FLS	FRS	VGS	FLS	FRS
OF	9.58 \pm 0.31 ^a	10.71 \pm 0.39 ^a	10.05 \pm 0.10 ^a	0.044 \pm 0.007 ^a	0.051 \pm 0.002 ^a	0.049 \pm 0.001 ^a
VFS	12.23 \pm 0.30 ^b	14.02 \pm 0.51 ^b	13.93 \pm 0.33 ^b	0.082 \pm 0.002 ^b	0.087 \pm 0.002 ^b	0.085 \pm 0.000 ^b
NFT	13.29 \pm 0.21 ^b	14.36 \pm 0.56 ^c	13.86 \pm 0.56 ^b	0.088 \pm 0.002 ^a	0.102 \pm 0.003 ^c	0.094 \pm 0.005 ^b
	Biochemical parameters (mean \pm SE)*					
	Chlorophyll content (SPAD)			Lycopene content (mg/g)		
	VGS	FLS	FRS	75 th DAT	90 th DAT	105 th DAT
OF	70.78 \pm 0.88 ^a	68.38 \pm 0.42 ^a	57.62 \pm 0.93 ^a	150.92 \pm 0.85 ^a	153.79 \pm 0.93 ^b	158.07 \pm 0.8 ^b
VFS	75.86 \pm 1.04 ^b	79.05 \pm 0.29 ^b	70.96 \pm 0.59 ^b	242.57 \pm 0.52 ^a	280.3 \pm 0.71 ^b	301.69 \pm 0.64 ^c
NFT	80.29 \pm 0.48 ^b	85.58 \pm 0.16 ^c	74.18 \pm 0.28 ^b	250.19 \pm 0.58 ^a	294.24 \pm 0.83 ^b	305.7 \pm 0.75 ^c

improving nutrient uptake and biomass accumulation. In contrast, VFS requires a high-power water pump to maintain the optimum flow rate (5.5 L/min, Zheng *et al.* 2019) making it less efficient and more prone to fluctuations in nutrient delivery. Consequently, NFT system consistently outperformed VFS and open-field systems in growth and yield parameters (Schmautz *et al.* 2016).

Physiological parameters

Plants grown under NFT exhibit the highest photosynthetic rate and stomatal conductance across vegetative, flowering and fruiting stages compared to VFS and open-field systems (Table 2). Higher stomatal conductance was observed in all stages of the plants grown in NFT system with noted values (0.88, 0.1026 and 0.094 mmol m⁻² s⁻¹ at vegetative, flowering and fruiting respectively) over the VFS and open-field.

Biochemical parameters

NFT also supported superior biochemical performance, with maximum chlorophyll content (80.29, 85.58 and 74.18 SPAD) during the vegetative, flowering and fruiting stages respectively (Table 2). The peak chlorophyll content at flowering suggests enhanced nitrogen assimilation, consistent with findings by Fontes and Araujo (2006) and Ionut *et al.* (2024). Lycopene content increased progressively from 75th to 105th DAT across all systems, with the highest values recorded in NFT (305.70 mg/g) and followed by VFS (301.69 mg/g) and open-field conditions (158.07 mg/g). These values are substantially higher than those reported by Yang *et al.* (2023); Tan *et al.* (2025), who noted 56.25 mg/kg.

Total sugar content in NFT-grown fruits was 33.82% and 35.94% higher than in VFS and open-field systems respectively (Fig. 10A), supporting earlier findings by Schmautz *et al.* (2016), Higashide (2013); Gyadi and Phookan (2018) and Bishnoi (2020). Interestingly, vitamin C content was highest in open-field fruits (29.62 mg/100 g), compared to VFS (25.61 mg/100 g) and NFT (24.46 mg/100 g) (Fig. 10B). This may be attributed to higher light intensity and natural nutrient availability in open-field conditions, which favor ascorbic acid accumulation

(Dahaj *et al.* 2012, Gruda *et al.* 2025, Mami *et al.* 2008). These results highlighted that the NFT system of cultivation was favorable for all tested growth, yield, physiological and biochemical parameters of red cherry tomato fruits.

CONCLUSION

The NFT hydroponic system was consistently outperformed VFS and open-field cultivation in terms of plant height, leaf area, and NDVI values as well as yield attributes including plant biomass accumulation, flower cluster number, fruit number, fruit size, fruit weight, and total yield per plant. This superior performance can be attributed to the continuous supply of water and nutrients in a readily available form, which minimizes fluctuations in nutrient uptake and reduces abiotic stress. The thin film of nutrient solution in NFT ensures optimal root aeration, thereby supporting physiological parameters such as photosynthetic rate, stomatal conductance and biochemical traits including chlorophyll, lycopene content and total soluble solids. Excluding vitamin C content (higher in open-field), the NFT system was most supportive across all growth and quality parameters. On the other hand, the VFS system although provided advantages in flower initiation and space utilization but experienced slightly limited growth due to intermittent nutrient delivery as compared to NFT.

Open-field cultivation, while favorable for vitamin C accumulation due to higher light intensity, but showed the lowest values across all other parameters, likely due to exposure to environmental stresses such as variable temperature, soil heterogeneity, and water deficits. These findings highlight the potential of NFT hydroponics as a sustainable and efficient cultivation system for cherry tomato. Results of present study are aligned with (Rani 2023) who demonstrated that NFT-based hydroponics significantly increased the growth and yield of tomato compared to other hydroponic systems, owing to better nutrient-use efficiency and reduced water stress. In another study, Um *et al.* (2025) highlighted that NFT-grown tomatoes exhibited enhanced physiological maturity and uniformity, linked to optimized nutrient and water delivery. Similarly, Al-Gaadi *et al.* (2025) reported that hydroponically grown tomatoes showed superior

photosynthetic performance and water-use efficiency compared to conventional systems. Furthermore, UAV-based imaging studies confirmed that vegetation indices such as NDVI are reliable predictors of tomato biomass and yield, reinforcing the positive correlation observed in the present study.

Collectively, present study proven that the NFT hydroponic system provides a more favorable micro-environment and can be recommended as an efficient and sustainable method for enhancing cherry tomato cultivation under the agro-climatic conditions of Agra district (semi-arid zone) in Uttar Pradesh, India.

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