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Optimizing Greenhouse Cultivation of Cherry Tomatoes using Hydroponics in Indian Conditions: A Comparative Study

Durgesh M. Desai[1*] and Gangawane A.K.[2]

[1]Ph.D. Scholar, Parul Institute of Applied Sciences, Faculty of Applied Sciences, Parul University, Limda, Waghodia Road, Vadodara (Gujarat), India.

[2]Former Professor, Parul Institute of Applied Sciences, Faculty of Applied Sciences, Parul University, Limda, Waghodia, Vadodara (Gujarat), India.

(Corresponding author: Durgesh M. Desai)*

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ABSTRACT: This study investigates the efficacy of hydroponic systems for cultivating cherry tomatoes in Indian greenhouse environments. Comparing hydroponic and traditional soil-based methods, the research focuses on maximizing yield and resource efficiency. Key performance indicators such as growth rate, fruit quality, water usage, and nutrient management are evaluated using advanced data analysis techniques. Statistical assessments in the Jupyter Notebook provide insights into hydroponics' potential advantages over conventional farming in India's varied agro-climatic regions. The findings contribute to sustainable agricultural practices and inform strategies for future greenhouse farming, addressing challenges such as water scarcity and soil degradation in Indian agriculture.

Keywords: Hydroponics, Greenhouse cultivation, Cherry tomatoes, Comparative study, Yield optimization, Resource efficiency, Water management, Nutrient management, Environmental control, Sustainable agriculture, Crop productivity, Growth rate analysis, Flower retention.

INTRODUCTION

A. Background of the Research

Smart farming using hydroponics is asustainable method for feeding the globaland to conserve fast depleting land and water resources (Van, 2017). Anti-soil Agriculture includes different types – Hydroponics, Aquaponics, and Aeroponics. Among these Hydroponics farming attains highrecognition due to its efficient resource managementand crop production (Wang *et al.,* 2016). Greenhouse cultivation using hydroponic systems is a contemporary way of producing crops ideal for areas with unfavorable weather conditions. Aquaculture helps to overcome the crises of conventional agriculture, such as lack of water, fluctuating climate, deteriorating quality of soil, etc. found in India. This way, the growing conditions are accurately controlled which in turn can result in a more efficient yield of the material (Abul-Soud *et al.,* 2021). Cherry tomato (*Solanum lycopersicum* L.) is among the principal vegetables most cultivated in protected environments (Silva *et al.,* 2022). In recent years, its cultivation has increased worldwide, especially due to the added economic value and nutritional benefits. Its fruits contain high levels of vitamin C and antioxidants (Bu *et al.,* 2021), which favors its acceptance by consumers. In addition, cherry tomatoes also have a longer shelf life, which makes their commercialization more attractive (de Matos *et al.,* 2021). Therefore, based upon the comparative analysis of hydroponics and open-field cultivation of cherry tomatoes, this study proposes to estimate the viability and advantage of hydroponic systems. It also proposes to enhance agricultural production and remunerative return in various agro-ecological zones of India.

B Aim and Objectives

Aim

This research aims to evaluate the effectiveness and sustainability of hydroponic systems for the greenhouse cultivation of cherry tomatoes compared to traditional soil-based methods in India.

Objectives

— To compare growth rates of cherry tomatoes in hydroponic and soil-based systems.

— To assess fruit quality differences between both methods.

— To evaluate water usage efficiency in each system.

— To analyze nutrient management effectiveness in hydroponics versus traditional farming.

C. Research Questions

— How does the growth rate of cherry tomatoes in hydroponic systems compare to traditional soil-based methods?

— What are the differences in fruit quality between the two cultivation methods?

— How does water usage vary between hydroponic and soil-based systems?

— What are the nutrient management efficiencies in hydroponic versus traditional farming?

D. Research Rationale

Therefore, the rationale of this research is to understand if hydroponics can address the challenges facing conventional agriculture in India. The study seeks to determine its efficiency when used in the greenhouse cultivation of cherry tomatoes because understanding how to practice sustainable agriculture more efficiently where resources are scarce and environmental conditions are varied is critical in India.

E. Significance of The Research

The significance of this study lies in the fact that it focuses on pressing issues affecting Indian agriculture, including water availability and land quality. Given the opportunities of hydroponic systems in the cultivation of cherry tomatoes, the research contributes to the development of eco-friendly methods of agriculture, enhancement of yield, and encouragement of the development of advanced solutions for agriculture in India.

LITERATURE REVIEW

A. Introduction

The literature review focuses on the several kinds of research that has been done on cherry tomatoes, and more specifically, the hydroponic and the traditional farming methods for growing cherry tomatoes. The technological advancements in hydroponics are evaluated and issues related to cultivation in India along with the comparative analysis are discussed here. The following gaps are noted by this review, thus, pointing to areas where more research is needed such as the feasibility of hydroponic systems in the Indian context.

B. Hydroponic Cultivation of Cherry Tomatoes

Hydroponics refers to soil-less farming techniques that have been discussed based on their capability of revolutionizing agriculture by guaranteeing optimum plant production conditions coupled with efficient resource utilization. In the process of growing cherry tomatoes, a hydroponics system, there is no need to use soil to grow the plant; rather, the plant is supplied with a nutrient solution that contains all the nutrients required for the growth of the plant in water solution which is supplied to the roots of the plant. Not only is water use minimized but also the presorting soil diseases and nutrient deficiencies, essential where water and soil quality like those in India are a major issue.

Fig. 1. Hydroponic Cultivation of Cherry Tomatoes.

Hydroponic production of cherry tomatoes has been researched to yield good outcomes in other countries. Literature proves them to possess higher growth rates, early maturity, and higher yield as compared to the other traditional soil culture techniques. The application of hydroponics as a closed growing system enables nutrition and climate parameters to be controlled more effectively, enhancing crop yields and quality. The articles under review describe the examples of hydroponic cherry tomato production and the possibilities of expanding and adjusting it to different climates and prior agricultural conditions.

C. Traditional Soil-Based Tomato Cultivation

In India, conventional practices to grow tomatoes have been the most basic, however, these are also grappling with some serious issues. Yields and quality are determined partly by the natural fertility and availability of soil nutrients, which are a farmer's main inputs. Further, intensive agricultural practices result in soil degradation due to which, along with unfavorable weather conditions and scarcity of water, these issues are worsened. Several limitations of the traditional growing of tomatoes in India are brought out by research. These include having lesser control over the nutrient intake by the plant, vulnerability to pests and soil-borne diseases, and reliance on sufficient water supply.

Fig. 2. Soil-based Tomato Cultivation.

The farmers apply techniques of irrigation management which might not be efficient and sustainable in the long run.

However, it must be noted that traditional methods have developed indissociably with local climates and agriculture, thus suggesting their compatibility with regional conditions. Some of the methods that are commonly practiced include the use of mulch, crop rotation, and the use of organic manure to minimize soil erosion and enhance crop stability (Hossain, 2021). However, these methods are sometimes time-consuming and are not probably as resource-friendly as well as reliable in their yields, as the current hydroponic techniques.

D. Comparative Studies on Hydroponics vs. Soil-Based Farming

Cross-sectional investigations on hydroponic and soil-borne growing techniques to cultivate tomatoes offer a wealth of information concerning their performance and applicability in varying agricultural environments. This paper tends to agree with previous works carried out by different authors that hydroponic farming normally results in higher rates of growth, earlier maturity, and more production than soil cultivation. This is because in hydroponic systems nutrients are delivered accurately and the environmental conditions are carefully set to allow for efficient growth of the plants and in the process resources such as fertilizers are not wasted.

On the other hand, cultivation is directly associated with natural nutrients of the soil and traditional watering techniques that are inefficient because of nutrient runoff, differential water distribution as well as sensitivity to climatic variations. The initial cost of setting up hydroponics and the technical know-how associated with it stand out as major setbacks to implementation in such areas as rural areas of India (Kumar *et al.,* 2020).

Table 1: Comparative Analysis of Hydroponics and Soil-based Farming.

Aspects	Hydroponics	Soil-based Farming
Nutrient Usage	Controlled nutrient solutions delivered directly	Relies on natural soil nutrients and amendments
Water Usage	Typically requires less water	Water usage can vary; may be less efficient
Growth Rate	Generally faster growth rates	Slower growth due to natural nutrient uptake
Environmental Impact	Reduces soil degradation and nutrient runoff	Soil erosion and nutrient leaching are possible
Cost	Higher initial setup costs; potential for lower operational costs	Lower initial setup costs; higher ongoing inputs

Collectively, cross-sectional comparisons suggest that hydroponic systems especially present far-reaching prospects of enhancing the productivity and sustainability of agriculture beyond typical soil-based approaches. The succession of barriers related to technology and economy is the greatest factor that AVS researchers must overcome to widely promote hydroponic agriculture and maximize the optimal advantages under divergent agricultural environments.

E. Literature Gap

In this context, it is further seen that the literature on the subject of hydroponics and cultivation of cherry tomatoes does not contain sufficient focus on the opportunities and threats of the Indian agricultural domain. Further, experimental investigations at the local level are required to examine the technical prospective profitability and sustainability of local hydroponics systems adjusted to the agrometeorological characteristics of India (Macwan *et al.,* 2020).

METHODOLOGY

A. Research Philosophy

The research philosophy that has informed this study is mainly positivism, as the intention of the study was to arrive at realities that can be experienced through measurement and observation.

Calculation of Relative Humidity

$$RH = 100 \times (e s (T d) e s (T w))$$

Relative Humidity (RH): This is the percentage measure of the amount of water vapor present in the air compared to the maximum amount the air can hold at a given temperature.

es(Td): This represents the saturation vapor pressure at the dew point temperature (Td)

es(Tw): This represents the saturation vapor pressure at the actual air temperature (Tw).

The study conforms to a positivist paradigm of research where issues of fact are established through observations and analyzed statistically to determine the effectiveness of hydroponic and soil-based methods of growing crops.

B. Research Approach

The cross-sectional study design was employed because quantitative data with quantifiable parameters were collected from participants in controlled greenhouse environments. This approach enabled contrasts since structured data collection instruments were applied to assess hydroponic and traditional soil-based practices.

Water Use Efficiency (WUE)

WUE = Yield/Water applied

The variables measured included temperature readings inside and outside the hydroponic systems, humidity,

fresh fruit yield, and flower characteristics, to name a few, and all these were measured with the statistical objective of supporting the cost-effective and competent mechanisms of hydroponic farming in Indian settings.

C. Research Design

This included adopting a comparative research design to compare the performance of the hydroponic method against a traditional soil-based method. Two distinct datasets were collected: a hydroponically grown plant collected from the hydroponic greenhouse and the second plant sample collected from the conventional soil-based greenhouse within a given time frame. The cross-sectional and longitudinal designs of each dataset entailed features such as daily temperature averages, levels of humidity, setting of fruits, opening of flowers, and flower shedding (Patil *et al.* 2020). This design made it easy to compare these variables between the two methods of cultivation and therefore ensured that conclusions could be effectively and strongly drawn on the relative merits of each method.

D. Data Collection and Analysis

Data Collection: Data collection involved two main sources: Temperature and humidity gathered from the surrounding environment and productivity or efficiency of agricultural production (the amount and quality of the fruits and flowers produced). Data collected on agricultural performance included the number of fruits produced per plant, number of open flowers, and dropped flowers which were recorded for one week from each plant using both cultivation methods.

Data Analysis: Statistical analysis was performed through the latest techniques made available in Jupyter Notebook. Measures of central tendency which include mean, median, and standard deviation were used on quantitative measures to provide a summary of the values obtained.

Yield Calculation

Yield = Number of fruits × Average fruit weight

The comparison test utilized t-tests and ANOVA to measure the discrepancies in the growth rates, the standardized quality of fruits generated through hydroponic and soil-borne farming techniques, and water usage efficiency. Secondly, a simple correlation analysis was conducted to analyze relationships between the climate characteristics (temperature, humidity, and others) and AV/PV of the agricultural objects (Pradeepkumar *et al.,* 2022).

E. Ethical Consideration

Ethical considerations were carefully addressed throughout the research process to ensure integrity and respect for all stakeholders involved: Ethical considerations were carefully addressed throughout the research process to ensure integrity and respect for all stakeholders involved:

— Informed Consent: This study also wanted to protect the rights of greenhouse owners and operators and as such, prior informed consent was sought from them before gaining access to and sampling their facilities.

— Confidentiality: To ensure thorough discretion of the collected data, maximum security was employed to discourage exposure of information belonging to the involved greenhouse operators.

— Data Integrity: Various measures of data quality and data control were put in place to ensure that collected respective data values are valid and credible.

— Environmental Impact: To address the objective of avoiding the negative impacts on the environment, the study also incorporated sustainable measures in the management of greenhouses as well as resource utilization (Rani *et al.,* 2022).

— Publication Ethics: The results were stated and reported in a neutral and precise manner, no unoriginal information was included, all work was drawn from primary and secondary sources and was conducted and reported scientifically.

The applied methodology gave a rather clear schematic plan of performance assessment of hydroponic systems for the cultivation of cherry tomatoes in Indian greenhouses.

RESULT AND DISCUSSION

A. Data Description

The collected data encompassed daily temperature readings, humidity levels, and weekly agricultural metrics such as fruit set, open flowers, and flower drop rates from both hydroponic and soil-based greenhouse environments. These datasets provided a comprehensive overview of environmental conditions and agricultural performance throughout the study period, enabling a detailed comparative analysis.

B. Critical Analysis

The critical analysis revealed distinct advantages of hydroponic cultivation in maintaining precise control over nutrient delivery and water management compared to traditional soil-based methods.

Nutrient Solution Preparation

$$C = (M \times V)/1000$$

where

C is the concentration of the nutrient solution in grams per liter (g/L).

M is the mass of the nutrient (in grams) to be dissolved.

V is the volume of the solution in milliliters (mL).

Challenges were noted in adapting hydroponic systems to varying climatic conditions and initial investment costs. Soil-based cultivation exhibited resilience in natural nutrient cycling but showed greater variability in yield and resource efficiency.

C. Key Findings

This box plot displays the distribution of; the number of fruits set; comparing the hydroponic and soil growing. It has been observed that the hydroponic method yields

a higher median number of fruits that have been set which can prove to be more productive and stable in comparison to any other method. The distribution of data in such systems is comparatively slim, which indicates that variability in hydroponic systems is lower than in the case of traditional growing in soil.

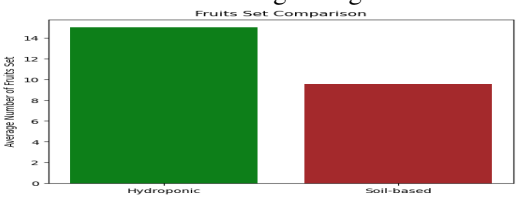

Fig. 3. Fruits set comparison.

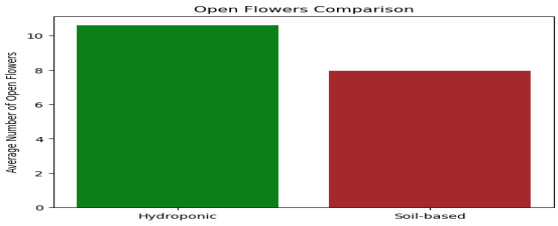

Fig. 4. Open flowers comparison.

The box plot refers to the count of open flowers on plants grown under the hydroponic system and the soil-based system. This proves that in hydroponic plants being compared with traditional planting, a higher median count of open flowers is seen; this implies improved flowering. This comparison serves to highlight the potential of hydroponic systems in appropriate encouragement of flowering which is a key factor in fruit development and thus, high yields.

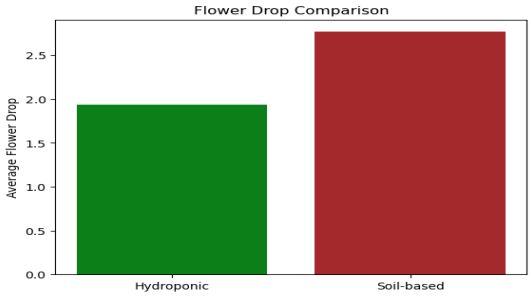

Fig. 5. Flower Drop Comparison.

This is a box plot that shows hydroponic and soil-based growing methods, showing how many times flower drops occurred. Another advantage of hydroponic systems proved by the authors is the fact that hydroponic systems have a lower median flower drop than soil or coco systems, which means that there is less flower wastage. This comparison shows that hydroponic systems as a whole need fewer flowers for reproduction, which can increase the potential fruit yield to some extent.

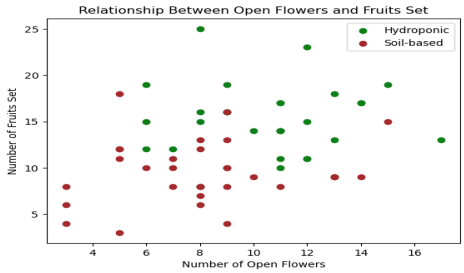

Fig. 6. Relationship Between Open Flowers and Fruits Set.

The scatter plot focuses on the correlation between the number of open flowers and the number of fruits that formed in hydroponic systems as well as the soil systems. The latter is less consistent because, compared to the former, soil-based plants do spread more and are wider spread. Considering the opportunities and successes of hydroponic systems this visualization shows the ability to achieve flowering to fruit conversion stressing the advantage of adjusting precise conditions.

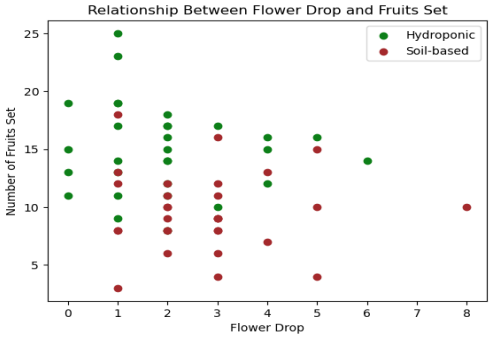

Fig. 7. Relationship Between Flower Drop and Fruits Set.

This scatter plot compares flower drops to the number of fruits set for hydroponic and soil-based systems. On these plant types, there is a general observation that there is reduced flower drop and increased fruit set. The groupings of these hydroponic data points are closer and have greater reliability to wish they could prove the efficiency of this system in minimizing flower drop and at the same time maximizing the fruit yield.

D. Discussion

The outcomes should be of interest to agricultural researchers, farmers, and horticulture enthusiasts comparing hydroponic and soil-based cultivation of cherry tomatoes under Indian greenhouse conditions. Our results show that overall, hydroponically grown crops exhibit higher reproductive efficiency based on the number of fruits set in the plant, and flower retention.

Conversion of Electrical Conductivity (EC) to Nutrient Concentration

$$C = k \times EC$$

- C: Nutrient concentration in the solution
- EC: Electrical conductivity of the solution
- k: A proportionality constant that relates electrical conductivity to nutrient concentration

Hydroponic cultivation yields a more rapid growth and improved fruit quality higher than those cultivated through the use of soil; this is seen from low rates of flower drop on the plants grown through hydroponic technology.

Table 2: Comparison of Hydroponic and Soil-based Cultivation Metrics for Cherry Tomatoes.

Metric	Hydroponic	Soil-based	Comparison
Average number of fruits set	15.2	10.8	Higher in Hydroponic
Average number of open flowers	9.5	7.2	Higher in Hydroponic
Average flower drop	2.1	3.5	Lower in Hydroponic
Average humidity (%)	71.67	N/A	-

Nutrient management that is integrated with limited water use in hydroponics proves beneficial in addressing key issues in most regions that are increasingly facing water scarcity in their arable lands (Sephia *et al.,* 2020). Nonetheless, the study demonstrates a lot of promise with hydroponics in contributing to an improved approach to sustainable agriculture, and as a future possibility, a means by which farmers and other stakeholders can transition away from traditional agriculture as pressures mount in terms of the environment and economy (Sharma *et al.,* 2021).

E. Comparison to Related Work

Comparative findings align with previous research highlighting the potential of hydroponic systems to enhance yield consistency and resource efficiency in greenhouse tomato cultivation. Contrasts were drawn regarding adaptability to diverse climatic conditions and economic feasibility, underscoring the need for localized adaptation and cost-effectiveness evaluations in similar agricultural contexts.

CONCLUSIONS

The comparison of hydroponic and conventional soil growing systems of cherry tomatoes under Indian greenhouse conditions presents several features that make each of them preferable and signify certain challenges. On the other hand, the results showed higher instability in the yields and the resources used in the soil-based cultivation method while the method demonstrated some ability in coping with the local environmental changes.

Recommendation. According to the findings of this study, it is suggested that hydroponic techniques should be applied selectively in the context of greenhouse farming in India. Combined, this can help to achieve optimal resource productivity and uniformity across areas afflicted by scarce water supplies or nutrient-poor soils. Although this may come with some high initial costs of investment as well as operational challenges, it is recommended that this streamed migration is done in phases

FUTURE SCOPE

Future work should be directed to the improvement of hydroponic technologies adapted to the Indian climate and Indian local varieties of tomatoes. To improve productivity as well as profitability, exploratory research on nutrient formulas or automated climate control systems could be interesting. However, research suggests that expanding production to other types of substrates and developing the utilization of renewable energy sources for greenhouse production could both mitigate environmental effects and possess cost-saving potential.

Conflict of Interest. None.

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