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Exploring the Feasibility of Turmeric Cultivation in Vertical Farms: An Indian Context

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***Abstract:** Turmeric is a high-value spice with growing global demand due to its medicinal, culinary, and industrial applications. Traditional cultivation in India faces challenges such as climate dependency, soil degradation, and inconsistent quality. Vertical farming, an innovative soilless cultivation method, offers potential solutions by optimizing resource use, enhancing yield, and ensuring year-round production. This paper evaluates the economic viability of turmeric vertical farming compared to traditional methods in India, analyzing cost structures, yield differentials, market positioning, and policy support. Findings suggest that while vertical farming entails higher initial investments, it provides superior returns through premium pricing, reduced post-harvest losses, and export-oriented high-curcumin produce. The study concludes with recommendations for scaling vertical turmeric farming through technological advancements and public-private partnerships.*
***Keywords:** vertical farming, turmeric cultivation, sustainable agriculture, agricultural economics*

I. INTRODUCTION

Turmeric (*Curcuma longa*), a golden-hued spice deeply woven into India's agricultural and cultural fabric, dominates the global spice trade, with India accounting for approximately 78% of world production. Despite this prominence, traditional cultivation methods face profound challenges. Farmers are constrained by a high dependency on monsoon rains, persistent soil degradation, widespread pest infestations, and significant yield volatility, typically harvesting 8–10 tons per acre. These vulnerabilities consistently threaten the livelihoods of smallholder farmers and the stability of the national supply. In response, vertical farming has emerged as a transformative alternative. By leveraging controlled environments, hydroponics, and aeroponics, this innovative approach optimizes resource use, demonstrates the potential for dramatically enhanced yields, and promises year-round production, irrespective of external climatic conditions. This paper examines the economic viability of vertical turmeric farming compared to conventional methods in India, analyzing cost structures, profitability, and market potential. While vertical farming demands high initial investments (₹10 lakh–₹1 crore/acre), its advantages—such as 90% water savings, 5.91% curcumin content (vs. 2.5–3% in soil), and premium pricing (₹500–1,000/kg)—position it as a sustainable alternative for India's agri-tech future. By evaluating these dynamics, this study aims to inform policymakers, entrepreneurs, and farmers about the potential of vertical farming to revolutionize turmeric cultivation, ensuring food security, export competitiveness, and climate resilience. To further contextualize this study, it is essential to recognize India's growing urbanization and shrinking arable land, which intensify the need for innovative agricultural solutions. Vertical farming presents a strategic opportunity to address these challenges by enabling turmeric production in urban and peri-urban areas, reducing transportation costs, and minimizing post-harvest losses that currently plague traditional supply chains. Moreover, with increasing global demand for high-quality, contaminant-free turmeric in pharmaceutical and nutraceutical industries, vertical farming's ability to consistently produce premium-grade crops offers India a competitive edge in international markets. This research not only compares the financial metrics of both cultivation methods but also explores how technological advancements and policy interventions could accelerate the adoption of vertical farming, potentially transforming India's agricultural landscape while aligning with sustainable development goals. The findings will contribute to ongoing discussions about modernizing Indian agriculture through climate-smart, economically viable alternatives to conventional farming practices.

II. METHODOLOGY

The study uses secondary data collected from government reports, academic journals, industry publications, and research papers to compare turmeric vertical farming with traditional cultivation in India. Due to limited primary field trials in vertical turmeric farming, especially in India, the study emphasizes published secondary research. Information on costs, yields, and market prices was taken from sources like the agricultural research institutes, and published case studies. Data on curcumin content, export trends, and farming inputs were also gathered from existing literature, study also looked at market demand and policy support from secondary sources.

III. LITERATURE REVIEW

India plays a dominant role in global turmeric production, contributing approximately 62% of the world's trade, with major growing regions including Andhra Pradesh, Tamil Nadu, Maharashtra, Odisha, and northeastern states like Assam and Meghalaya. (APEDA, 2018) Turmeric cultivation is traditionally carried out in open fields under rain-fed or irrigated conditions. Average yields range between 8–10 tons per acre under optimal conditions. However, traditional systems face serious constraints, including high dependency on monsoons, soil degradation, pest infestations (notably shoot borers and rhizome scales), and inconsistent curcumin content, which together limit productivity and marketability. Furthermore, post-harvest losses can reach 40–50%, particularly in regions lacking storage and processing infrastructure. (APEDA, 2018)

A comprehensive economic analysis in Assam it explores that among the major spices grown in the country turmeric occupies a major portion in terms of area and production. Turmeric is the 3rd important commercial spice in India after chili and garlic. The most popular varieties that are commercially cultivated in Assam is Lakadong and Megha Turmeric-1 because of its high curcumin content of 7.5 % and 6.8 % and high demand in the international market. This research indicates that economic analysis of turmeric production in Karbi Anglong and Dima Hasao district of Assam, it can be concluded that cultivation of turmeric was found productive and profitable in the study area with benefit cost ratio ranging from 1.70 to 1.85 in all the farm sizes. (Singh, Hazarika, Gogoi, Singh, & Singh, 2022)

Further agronomic research emphasizes the biological potential of turmeric improvement through germplasm selection. A study of 200 Curcuma longa accessions conducted by (Dudekula, et al., 2022) revealed considerable genetic variability in rhizome yield and curcuminoid content, ranging from 1.26% to 4.55%. Certain genotypes such as CL161 demonstrated both high rhizome biomass and favorable dry recovery, indicating strong potential for varietal improvement programs. This underscores the importance of using high-quality planting material to enhance the yield and biochemical composition of turmeric in both traditional and modern farming systems.

Study observed that growth and yield of crop are higher under mango and jackfruit trees than crop grown under sal tree. Farmers said that mango and jackfruit are providing partial shade which is suitable to the crop for their growth and rhizomes development. In hills farmers are planted turmeric across the slop. Farmers reported that planting of turmeric rhizomes across the slop control soil erosion during rainy season and improved productivity of crop. (Babu, Shukla, Tripaathi, & Prusty, 2015)

Despite its ancient cultural significance and growing global demand, the productivity and profitability of turmeric cultivation in India remain inconsistent. The literature points to the urgent need for region-specific varietal development, improved agronomic practices, and access to infrastructure to enhance market competitiveness. While vertical farming has not yet been widely adopted in turmeric production, this review of traditional systems helps build a baseline for comparison with emerging technologies.

IV. TRANSFORMING TURMERIC CULTIVATION THROUGH VERTICAL FARMING

This section presents a comprehensive analysis of existing research comparing vertical farming and traditional methods for turmeric cultivation in India, focusing on yield, quality, economic viability, and sustainability metrics.

Turmeric cultivation in India is predominantly carried out through traditional open-field farming, relying heavily on seasonal rainfall, soil quality, and manual labor. The crop is typically grown in regions like Maharashtra, Andhra Pradesh, Odisha, and Tamil Nadu, with sowing during the kharif season and harvesting after 7–9 months. While some high-yielding varieties such as Lakadong or Erode turmeric offer better market returns, farmers often face limitations including erratic monsoons, pest infestation, soil nutrient depletion, and significant post-harvest losses. Productivity averages 8–10 tons per acre under optimal conditions, and curcumin content generally ranges between 2.5% and 4% depending on genotype and cultivation practices. (Singh, Hazarika, Gogoi, Singh, & Singh, 2022)

Vertical farming introduces a paradigm shift by enabling year-round, soilless cultivation in controlled environments using hydroponics or aeroponics. These systems overcome the limitations of land, water, and climate by using multi-layered setups, recirculating nutrient systems, and artificial lighting. For turmeric, vertical farming has demonstrated promising results: yields can reach the equivalent of 80–100 tons per acre when scaled through vertical stacking, with curcumin levels exceeding 5.5%. Controlled environments also prevent soil-borne diseases and reduce pesticide reliance, producing cleaner, pharmaceutical-grade turmeric suitable for high-end export markets. (Nainar, 2021)

While traditional systems support rural livelihoods and require minimal capital, they are vulnerable to climate variability and price fluctuations. In contrast, vertical farming offers scalability and export competitiveness, albeit with high setup costs and energy demands. If integrated with renewable energy sources, digital sensors, and public subsidies, vertical farming can emerge as a sustainable alternative in urban and peri-urban zones, where arable land is scarce.

Moreover, the possibility of reducing water usage by over 90% makes vertical turmeric cultivation appealing amid growing concerns over agricultural water stress in India. (Chowdhury , Ahmed, & Debo Brata Paul, 2023)

Thus, while traditional farming will continue to play a vital role in India's turmeric economy, vertical farming represents a high-potential innovation to meet rising global demand, especially in premium and nutraceutical segments. Future policy and research should focus on making vertical farming more accessible to smallholders and cooperatives through shared infrastructure, training, and financial models.

V. TECHNOLOGICAL AND ECONOMIC POTENTIAL IN TURMERIC FARMING IN INDIA

A. Soil-less Cultivation: Mission Turmeric

In Bengaluru, former naval officer CV Prakash launched Mission Turmeric 2021, leveraging coco-peat grow-bags in shade houses to cultivate turmeric without soil. Pilot results were compelling: by the sixth month, a single plant yielded up to 4.45 kg, and by the seventh, up to 6.44 kg—far exceeding the typical 500–600 g per plant in open fields. Final harvests reached up to 8.17 kg per plant. Curcumin content soared to 5.91%, nearly doubling the norm for Salem turmeric, with no detectable heavy metals—boosting its appeal as a premium, contamination-free product. These outcomes demonstrate dramatic improvements in both yield and quality. (Nainar, 2021)

A one-acre soil-less setup requires an initial investment of around ₹35–36 lakhs for a 6 to 9 months cycle. Yet, it promises yields between 80 and 120 tonnes, with long-term cost reductions through seed reuse and multi-cycle use of coco-peat and grow-bags. (Wangchuk, 2021)

B. Vertical Integration with Cucurbits: Enhancing System Productivity

Controlled field experiments in Meghalaya showed that vertical integration of turmeric with cucurbits (e.g., bottle gourd or squash) increased system productivity by nearly 38.5%, with a benefit–cost ratio of 3.37 and improved soil fertility (higher organic carbon and nutrient availability) compared to monocropping. Hence, vertical integration of cucurbits with turmeric not only enhances the system productivity and monetary returns of dry terraces but also improves the soil fertility status over open cultivation of turmeric. (PANWAR, 2019)

C. Macro-Level Potential: Strategic Context and Cost Considerations

At the national level, vertical farming is gaining traction as part of India's sustainable agriculture roadmap. According to World Economic Forum insights, vertical farms offer significantly higher yields, 70–95% water savings, and reduced dependence on pesticides. Yet, setup costs are substantial—ranging from ₹60–70 lakhs per acre for basic systems to ₹1.5 crores for fully automated facilities. Energy can account for up to 40% of operating expenses. The Government of India has responded with credit-linked subsidies and long-term financing options for commercial horticulture and vertical farming projects. (Vardhan, 2022)

D. Key Technological Enablers and Integration Opportunities

Vertical turmeric farming's success hinges on integrating technologies such as drip fertigation, controlled environment management, and potentially AI/IoT systems to optimize resource efficiency. While not turmeric-specific, research in controlled-environment agriculture highlights the importance of energy-efficient lighting, temperature control, and renewable energy integration to manage costs and enhance economic viability. (Chowdhury , Ahmed, & Debo Brata Paul, 2023)

VI. DISCUSSION

The analysis of existing research reveals a fundamental trade-off between the low-input, community-centric model of traditional farming and the high-tech, efficiency-driven potential of vertical farming. Traditional systems, while requiring minimal capital investment and supporting vast rural livelihoods, are inherently vulnerable to a multitude of risks. These include soil degradation from continuous monocropping, significant yield volatility due to erratic monsoons and pest outbreaks, and substantial post-harvest losses estimated at 40-50% due to inadequate storage infrastructure. Furthermore, the quality of the produce, particularly its curcumin content, is highly variable (2.5-4%), often failing to meet the stringent standards required by high-value international pharmaceutical and nutraceutical markets, thereby limiting its profitability to commodity-level pricing. In stark contrast, vertical farming presents a paradigm shift by decoupling production from environmental constraints. By utilizing controlled environments, hydroponics, and vertical stacking, this system demonstrably addresses the core weaknesses of traditional cultivation.

Pilot studies, such as the Mission Turmeric 2021 initiative, have shown that yields can be increased by an order of magnitude, reaching the equivalent of 80-100 tons per acre, while simultaneously enhancing curcumin content to levels exceeding 5.5%. This consistent, high-quality, and contaminant-free output is the primary driver of economic viability, as it commands premium prices in export markets, effectively transforming turmeric from a bulk commodity into a specialized, high-value product.

However, the discussion must critically address the significant economic barriers to vertical farming's adoption. The exorbitant initial capital outlay, ranging from ₹35 lakhs to over ₹1 crore per acre, places this technology far beyond the reach of the average Indian smallholder farmer. This creates a risk of technological elitism, where vertical farming remains a venture for well-funded agri-tech startups or corporate entities, potentially marginalizing the very farmers it could benefit. Moreover, the operational economics are heavily burdened by energy consumption, which can constitute 40-60% of ongoing costs, making profitability highly sensitive to electricity prices and necessitating a strategic shift towards integrated renewable energy sources to ensure long-term sustainability.

Another critical dimension for comparison is the long-term environmental footprint, which extends beyond water usage. Traditional farming, when practiced without sustainable measures, can contribute to soil erosion and the leaching of fertilizers into waterways. Conversely, the closed-loop hydroponic systems in vertical farming virtually eliminate agricultural runoff, protecting local water tables. Yet, the carbon footprint of vertical farming is a complex issue; while it drastically reduces "food miles" for urban consumers, its reliance on manufactured infrastructure and significant energy consumption for artificial lighting and climate control could result in a higher embedded carbon cost per kilogram of produce unless powered by renewable energy sources, presenting a key sustainability trade-off that requires further lifecycle assessment.

Therefore, the future of turmeric cultivation in India may not lie in choosing one system over the other, but in developing a synergistic, multi-tiered agricultural framework. Traditional farming will continue to be the backbone of domestic supply and rural employment, especially with targeted improvements in post-harvest infrastructure and access to high-yielding, climate-resilient planting material. Vertical farming, meanwhile, can be strategically positioned to serve niche, high-value markets and urban centers, reducing the food miles and strain on rural resources. Policy interventions are crucial to bridge these worlds, focusing on creating innovative financial models such as farmer-producer organization (FPO)-led vertical facilities, public-private partnerships for shared infrastructure, and subsidies specifically directed towards renewable energy integration to mitigate operational costs and enhance the accessibility and scalability of this transformative technology.

VII. CONCLUSION

This study reviewed and compared traditional and vertical farming approaches in turmeric cultivation in India, with a focus on economic viability, technological feasibility, and sustainability. Traditional farming, while deeply rooted in rural livelihoods, continues to face limitations such as monsoon dependency, low curcumin content, high post-harvest losses, and declining profitability for smallholder farmers. Despite its low initial investment, it remains vulnerable to environmental and market fluctuations.

On the other hand, vertical farming presents a high-potential innovation that offers significant gains in yield, resource efficiency, and quality. Case studies and pilot data suggest that vertical turmeric farming can produce up to ten times more yield per acre, reduce water usage by over 90%, and deliver premium-grade turmeric with curcumin content exceeding 5.5%. However, high setup costs, energy dependency, and scalability remain critical challenges.

The review highlights that vertical farming should not be viewed as a replacement for traditional methods but as a complementary solution, especially in urban areas, or where export-oriented production is viable. Policymakers and researchers must focus on building cost-effective models, encouraging public-private partnerships, and expanding region-specific studies to validate the performance and economics of vertical turmeric farming at scale. With the right support, vertical farming could significantly contribute to a more resilient, high-value turmeric sector in India.

Furthermore, the discussion must consider the socio-economic structural impacts of each system. Traditional turmeric farming is deeply embedded in the rural agrarian economy, providing seasonal employment and supporting a vast network of local traders, processors, and transporters. A shift towards capital-intensive vertical farming, often located in or near urban centers, could disrupt these established rural value chains and livelihoods. However, vertical farming creates new, high-skill employment opportunities in areas such as system maintenance, climate control management, data analysis, and technological support, potentially attracting a younger, tech-savvy workforce to the agricultural sector and fostering a new era of "green-collar" jobs in urban agri-tech hubs.

Finally, the scalability and replicability of each model present distinct challenges.

Traditional farming practices are easily replicated by farmers using local knowledge and resources, but scaling up production is constrained by the availability of arable land and water. Vertical farming, in theory, offers immense scalability within a small physical footprint. However, its replication is hindered not just by cost, but by the need for highly specific technical expertise and reliable infrastructure, including uninterrupted electricity and internet connectivity. This creates a significant adoption barrier in regions with infrastructural deficits, potentially limiting its benefits to developed urban corridors and excluding more remote agricultural regions that could benefit from increased productivity.

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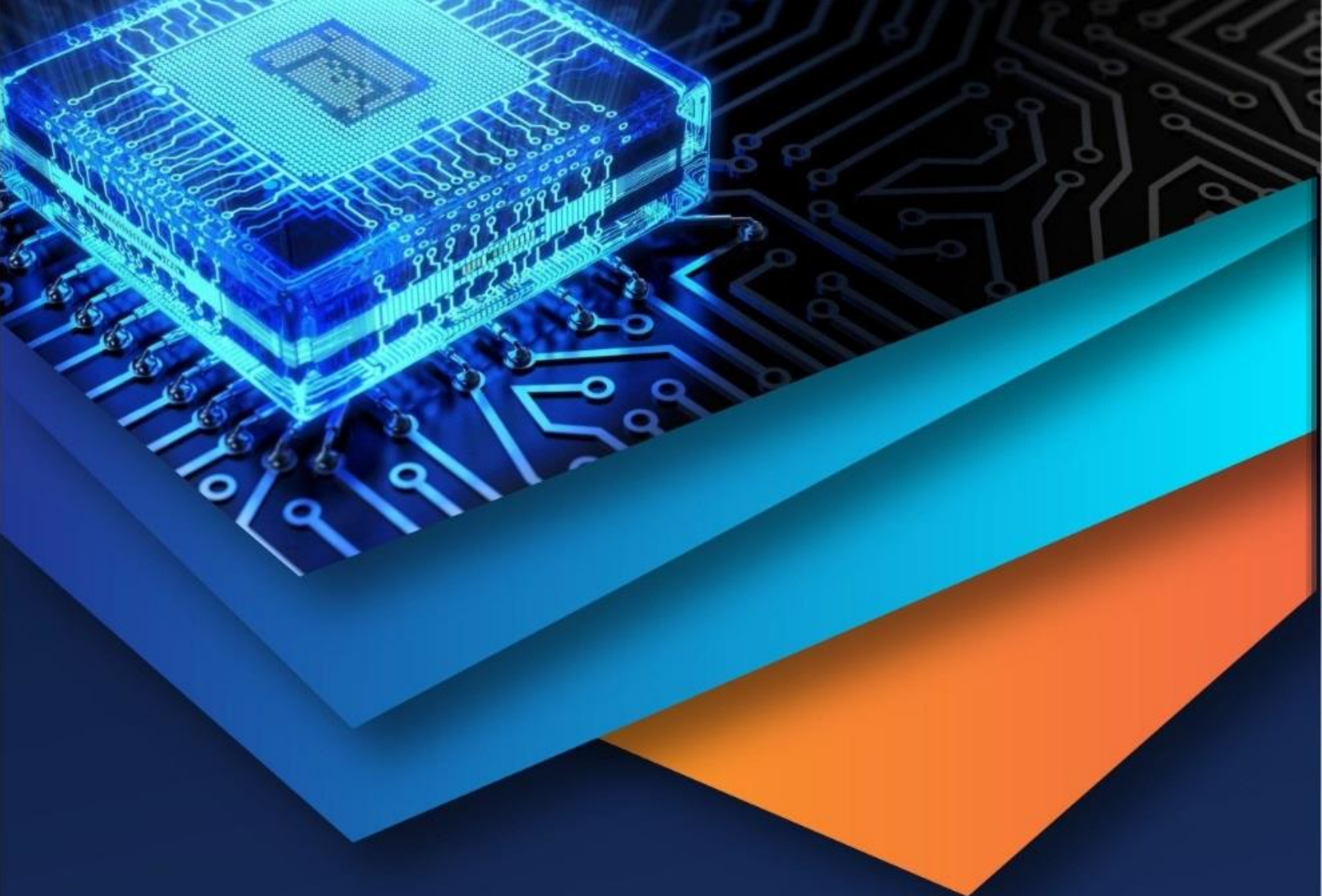

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