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RESEARCH ARTICLE

Agri-Tech startups transforming vegetable supply chains in Coimbatore

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Abstract

This research investigates the transformative role of digital agri-tech startups in optimizing vegetable supply chains in Coimbatore District, Tamil Nadu, India, with an emphasis on improving agricultural productivity and farmer welfare. Despite a marked 45% decline in agri-tech sector investments between the financial years 2021-2022 and 2022-2023, attributed to global interest rate hikes and economic uncertainties, startups such as WayCool, Farmers Fresh Zone and Farm again have demonstrated significant potential in enhancing supply chain efficiency and supporting farmer livelihoods through technological innovations. Employing a mixed-methods approach, this study integrates both qualitative and quantitative data derived from surveys, field visits, and interviews. Key performance indicators analyzed include Price Spread, Marketing Efficiency, Cost-Benefit Ratio and Productivity. Advanced econometric tools, including logistic regression and propensity score matching, were used to assess the impact of technology adoption on farmers' outcomes. The results reveal that farmers utilizing digital platforms for crops such as onion and tomato achieved higher market prices, improved marketing efficiency and superior financial performance compared to those employing the conventional methods. Despite persisting challenges like resistance to technology adoption and inadequate internet connectivity, the findings emphasize the potential for substantial growth in the sector, driven by technological innovations. The study emphasizes the need to develop user friendly digital platforms, strengthen internet and technological infrastructure, and enhance government support through financial incentives and clear policy frameworks to encourage the broader use of agri-tech solutions. Overall, the research highlights the significant potential of digital agricultural technologies to improve farming practices, increase farmer earnings, and serve as a model that can be adapted to similar agricultural regions.

Keywords

agri-tech startups; digital agriculture; supply chain efficiency; sustainable agriculture

Introduction

The rapid expansion of agri-tech startups in India has significantly influenced the agricultural sector, particularly by improving supply chain efficiency and promoting sustainable practices. Recent venture capital investments in India's agri-tech sector reached an unprecedented US$ 1279 million, highlighting the growing interest in this field (1). However, this momentum has recently reversed, with a 45% decline in investments to US$ 706 million, reflecting a broader global trend influenced by rising interest rates and increased investor caution amid economic uncertainties (2). These fluctuations emphasize the volatile and evolving nature of agri-tech investments, suggesting the need to consider external economic factors carefully when evaluating the sector's growth potential (3).

Fig. 1 illustrates that on a global scale, the agri-tech sector has experienced similar challenges, with funding decreasing from US$ 19.6 billion to US$ 17.7 billion. This decline is largely attributed to the U.S. Federal Reserve's interest rate hikes and a more cautious investment approach driven by global economic and geopolitical uncertainties (4). Despite these setbacks, the sector demonstrates resilience, with projections indicating global agri-tech market growth from US$ 18.12 billion to US$ 43.37 billion, driven by technological advancements and a growing emphasis on sustainable food production (5). This suggests that while short-term fluctuations may impact investment trends, the long-term outlook for agri-tech remains positive.

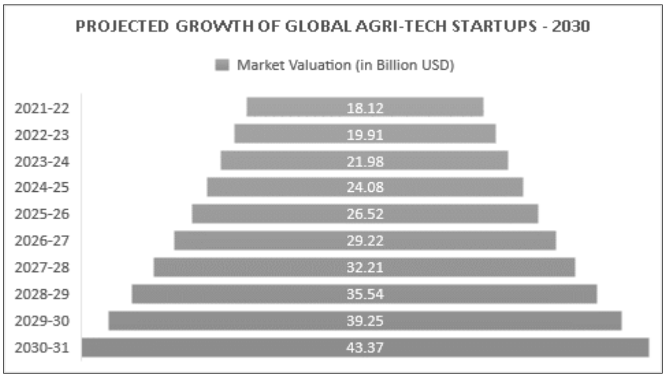

Fig. 1. Projected growth of global agri-tech startups by next decade.

In India, the agri-tech sector has shown notable growth recently, with funding increasing from US$ 84 million to US$ 1279 million (6). However, the industry has also seen a reduction in average deal sizes and a more cautious approach by domestic venture capital firms, reflecting a more conservative investment climate (7). By August 2023, only 26% of the capital allocated for the fiscal year had been invested and over 50% of respondents predicted a prolonged "funding winter" (8). This conservative investment environment highlights agri-tech startups' challenges in securing funding amid global economic fluctuations (9).

Agri-tech startups are revolutionizing agriculture through the integration of advanced technologies, including urban farming, automation, and data-driven solutions (10). Despite challenges such as the COVID-19 pandemic and climate change, the sector has shown remarkable resilience. Leading players like AgroStar and BigHaat have emerged, offering digital solutions and marketplaces tailored to farmers' needs (11). These startups are tackling critical issues like climate-related disruptions and market access for smallholder farmers through technological innovations and strategic partnerships (12).

This study aims to explore the transformative impact of digital agri-tech startups on vegetable supply chains in Coimbatore District, Tamil Nadu, a region of strategic importance in South India's agricultural landscape. It seeks to address several key questions: how digital agri-tech startups have influenced supply chain efficiency in Coimbatore's vegetable farming sector, which technological interventions have been most effective in enhancing supply chain resilience, and how these startups have addressed challenges such as climate change and market access for smallholder farmers.

While existing literature provides valuable insights into the broader impact of digital technologies on agriculture, there remains a noticeable gap in localized studies that focus on specific regions and their unique challenges (13). Recent research emphasizes the importance of granular studies that account for the diverse agroecological zones across India (14). This study aims to fill this gap by concentrating on Coimbatore, offering new insights into how digital agri-tech solutions can be effectively scaled across various regions.

The contribution of this research lies in its localized focus, adding new knowledge to the fields of agricultural technology and supply chain management. By examining the specific impacts of digital agri-tech solutions in Coimbatore, the findings are poised to inform policy and investment decisions, particularly in areas such as digital literacy and the fostering of public-private partnerships (15). These insights are crucial for enhancing supply chain resilience, especially in the face of climate change and economic volatility (16). The practical implications of this research are significant, identifying opportunities to scale successful agri-tech models to other regions, thereby contributing to the broader goal of sustainable agricultural development (17).

Moreover, the study underscores several practical implications for policymakers, investors, and agri-tech entrepreneurs. One key finding is the urgent need for inclusive digital literacy programs to ensure that smallholder farmers can fully benefit from technological innovations (18). Additionally, the research highlights the potential advantages of public-private partnerships in strengthening supply chain resilience (19). However, it also brings attention to the challenges posed by a cautious investment climate and the necessity of developing scalable solutions that can adapt to diverse agroecological zones (20). Addressing these challenges is critical to unlock the full potential of digital agri-tech solutions in transforming the agricultural sector.

Materials and Methods

Coimbatore District is renowned for its diverse agricultural sector, with vegetable farming being a major economic contributor. Despite its significance, the region faces challenges such as inefficiencies, lack of transparency, and post-harvest losses within its vegetable supply chain. To address these issues, digital technologies like IoT monitoring and blockchain are being adopted. Supported by the Tamil Nadu government and several agri-tech startups, these technologies aim to improve productivity and reduce waste. Fig. 2 illustrates notable agri-tech startups in Coimbatore, such as WayCool, Farmers Fresh Zone, Farmagain, Mayagreens Services, FarmFirst, and Naturebowl, offer innovative solutions ranging from autonomous farm systems to AI-driven market linkage platforms. The district’s annual vegetable production is approximately 507920 tonnes, with key trading hubs including Uzhavar sandhai, Gandhi market, and Mettupalayam

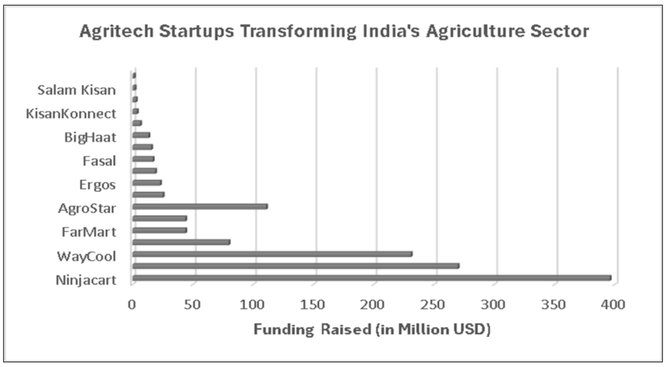

Fig. 2. Agri-tech startups disrupting agricultural landscape in India.

wholesale market. Increasing consumer demand for safe, non-toxic, and organic vegetables is influenced by factors like income levels, pricing, and health considerations. However, traditional supply chain management struggles with limited irrigation, high production costs, post-harvest losses, and price volatility, underscoring the need for improvements in crop varieties, pest management, cold storage, and digital platform utilization.

Fig. 3 illustrates that the research explores the impact of digital agricultural technology on the vegetable supply chain in Coimbatore District, Tamil Nadu, India. The primary aim is to assess the cost-effectiveness of digital agri-tech methods compared to traditional farming practices, focusing on productivity gains and economic benefits, particularly within the tomato and onion supply chains. By examining key performance indicators, such as supply chain efficiency, the study evaluates how digital agri-tech solutions enhance profits and income for farmers, while also considering various stakeholders including farmers, wholesalers, retailers, and consumers.

The case study of WayCool Foods, established in 2015 and headquartered in Chennai, Tamil Nadu, provides insight into a leading agri-commerce company specializing in sourcing, processing, and distributing vegetables. Collaborating with over 200000 farmers, WayCool leverages technology streamline supply chains, reduce food wastage, and enhance farmer livelihoods. With operations extending across South India and Maharashtra, WayCool employs advanced technologies for crop planning, input management, and market connectivity, addressing food loss and boosting farmer revenues.

To assess the impact of digital agri-tech solutions, a mixed-methods approach was employed. This includes purposive and stratified sampling methods to ensure a diverse and representative sample of stakeholders within the tomato and onion supply chains in the Coimbatore District. The study sample comprises 350 to 400 farmers selected based on various factors such as farm size, technology adoption levels, and geographical location. Additionally, 5 to 10 digital agri-tech startups, including prominent players like WayCool and emerging startups, are included to provide insights into different digital solutions. Surveys are conducted with 50 to 75 supply chain stakeholders, including intermediaries, wholesalers, and retailers, to offer a comprehensive view of supply chain dynamics. Consumer perceptions are explored through surveys of 100-150 individuals who are engaged with vegetable supply chains influenced by agri-tech startups, focusing on price sensitivity and perceived value. Furthermore, 10 to 15 interviews with agricultural experts, economists, and policymakers are conducted to gain broader economic perspectives and assess the feasibility of scaling these technologies. This comprehensive sample size of 515 to 650 participants ensures robust data for statistical analysis and generalizable findings.

Data collection for this study involved a blend of quantitative and qualitative methods to thoroughly assess the impact of digital agri-tech on the vegetable supply chain in Coimbatore District. Surveys were administered to farmers to collect detailed information on agricultural practices, associated costs, crop yields, income levels, and the extent of digital technology adoption. These surveys aimed to capture a broad spectrum of data, ensuring a comprehensive understanding of how digital technologies influence farming operations. Field visits were conducted to observe and analyze the supply chain processes at various stages, including farms, WayCool facilities, and local markets. These visits provided practical insights into

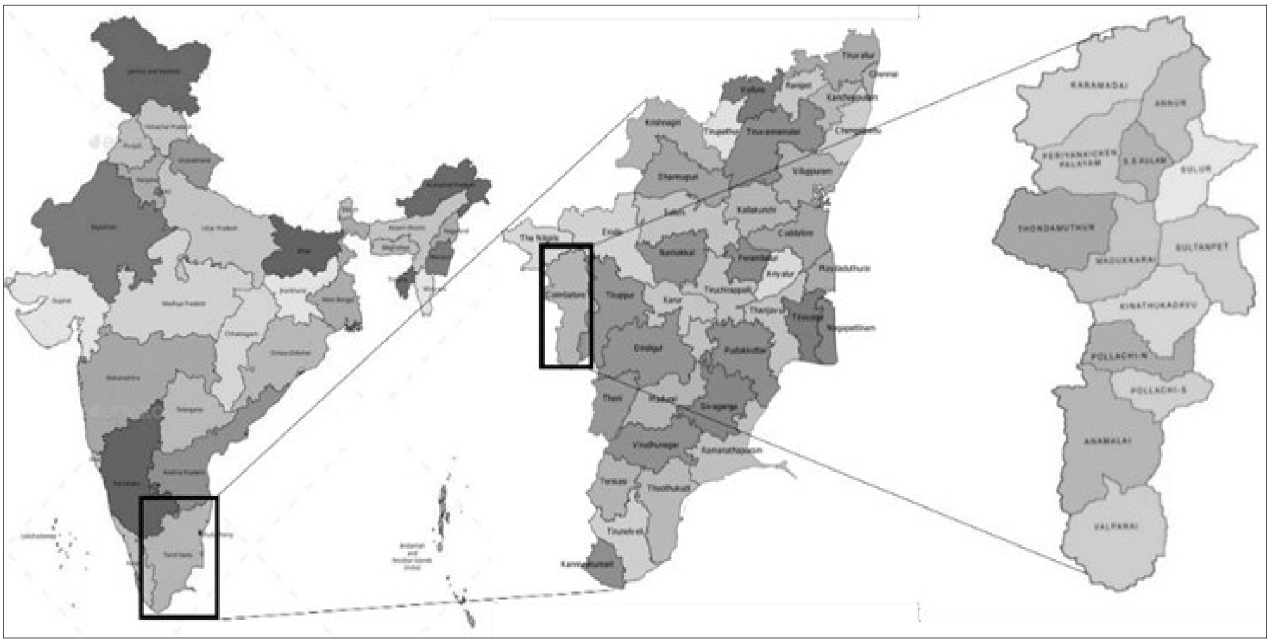

Fig. 3. Geographical map of Coimbatore district.

the real-world application of digital technologies and their impact on supply chain efficiency. Semi-structured interviews with key stakeholders, including intermediaries, wholesalers, and retailers, were carried out to gain qualitative insights into the role of digital agri-tech solutions in the supply chain. These interviews helped in understanding stakeholder perspectives and the broader implications of technology adoption.

To measure the effectiveness of digital agri-tech, several key metrics were analyzed, including Price Spread, which highlights the disparity between consumer prices and net prices received by producers, and Marketing Efficiency, evaluated using the Acharya Method to assess resource utilization in marketing. Additionally, a Cost-Benefit Analysis (CBA) was performed to compare the investment costs in digital technologies with the benefits derived, such as cost savings and productivity improvements, utilizing the Benefit-Cost Ratio (BC Ratio). Agricultural productivity metrics, such as Yield per Acre (YPAC), Labor Productivity (LP), and Resource Utilization (RU), were also examined to assess the impact on crop output and efficiency. Financial performance was evaluated through metrics like Return on Investment (ROI) and Profit Margin. Supply chain operations were scrutinized using metrics including Order Fulfilment Rate (OFR), Warehouse Utilization Rate (WUR), Stockouts, Overstock, Inventory Turnover Ratio (ITR), and Lead Time to understand the operational effectiveness of digital interventions. Logistic regression analysis was applied to identify key predictors influencing the success of digital agri-tech initiatives, while Propensity Score Matching (PSM) was used to mitigate selection bias and ensure a fair comparison between digital and traditional farming practices, thereby enhancing the validity and reliability of the study's findings.

Results

This study elucidates the transformative impact of Agri-tech practices on vegetable supply chains in Coimbatore, emphasizing key aspects such as pricing efficiency, marketing efficiency, financial performance, productivity, supply chain dynamics, and the determinants of Agri-tech adoption.

Table 1 shows the comparative price analysis reveals a distinct advantage for Agri-tech farmers over their traditional counterparts. Specifically, Agri-tech farmers achieved a selling price of ₹2835.4/- per quintal for onions, which surpasses the ₹2621.3/- attained by traditional farmers. Moreover, the wholesaler purchase price for Agri-tech onions reached ₹3015.6/- per quintal, compared to ₹2851.3/- for traditional onions. This pricing advantage extends to consumers, with Agri-tech onions retailing at ₹4900/- per quintal, in contrast to ₹4650/- for traditional onions. Table 2 shows similar pattern emerges in the tomato market, where Agri-tech farmers sold their product at ₹1503/- per quintal, significantly higher than the ₹1200/- received by traditional farmers. Additionally, Agri-tech tomatoes provided wholesalers with a higher margin of 56.25%, compared to 54.76% for traditional tomatoes. These findings affirm the superior pricing structure inherent in Agri-tech practices, benefitting both farmers and consumers.

In terms of marketing efficiency, Agri-tech practices further demonstrate their efficacy. The marketing efficiency for Agri-tech farmers stood at 95% for onions and 91% for tomatoes,

Table 1. Comparative analysis: traditional vs. agri-tech value chains for onion and tomato

Stage	Onion		Tomato	
	Traditional	Agri-tech	Traditional	Agri-tech
Producer's Sale Price (₹/Qtl)	2621.3	2835.4	1200	1503
Marketing Cost (₹/Qtl)	230	180	160	100
Wholesaler's Purchase Price (₹/Qtl)	2851.3	3015.6	1332	1604
Wholesaler's Margin (₹/Qtl)	860.4	1634.4	690	900
Wholesaler's Margin (%)	23.18%	35.14%	54.76%	56.25%
Wholesaler's Sale Price (₹/Qtl)	3711.7	-	2022	-
Retailer's Purchase Price (₹/Qtl)	3711.7	-	2022	-
Retailer's Margin (₹/Qtl)	1188.3	-	500	-
Retailer's Margin (%)	24.25%	-	23.81%	-
Consumer Purchase Price (₹/Qtl)	4900	4650	2646	2400

₹: Indian rupees

b. qtl: quintal

c. Margin (%): the percentage margin calculated as (sale price - purchase price) / sale price × 100

d. Wholesaler's margin: the difference between the wholesaler's purchase price and the selling price.

e. Retailer's margin: the difference between the retailer's purchase price and the selling price.

Table 2. Comparing traditional and agri-tech farming economics for onions and tomatoes

Crop	Farmer Type	Net Price (₹)	Marketing Cost (₹)	Marketing Margin (₹)	Marketing Efficiency Index
Onion	Traditional	1921	380	2048.3	0.79
	Agri-tech	2247.57	250	1634	1.19
Tomato	Traditional	870	750	1025	0.49
	Agri-tech	1200	360	900	0.95

Crop: type of agricultural product (onion or tomato).

Farmer type: the category of farming method (traditional or agri-tech).

Net price (₹): the selling price per unit after deductions.

Marketing cost (₹): the total expenses incurred in the marketing process.

Marketing margin (₹): the difference between net price and marketing cost.

Marketing efficiency index: a measure of the effectiveness of marketing strategies markedly higher than the traditional methods, which recorded indices of 79% and 49% respectively. This translates into reduced marketing costs and enhanced net returns, with Agri-tech methods yielding a net price of ₹2247.57/- for onions versus ₹1921/- for traditional methods. For tomatoes, the net price for Agri-tech farmers was ₹1200/- compared to ₹870/- for those employing traditional practices. These findings emphasize Agri-tech's capacity to lower costs and improve profitability, thereby enhancing overall market efficiency.

Table 3 illustrates financial performance reveals further advantages associated with Agri-tech practices. The Benefit-Cost Ratio (BC Ratio) for onions cultivated under Agri-tech methods was 1.65, leading to a net profit of ₹83594.80/- from an investment of ₹132700/- In comparison, traditional methods yielded a BC Ratio of 1.17, resulting in a net profit of ₹40421/- Similarly, for tomatoes, Agri-tech methods produced a BC Ratio of 1.47 and a net profit of ₹72963/- whereas traditional methods achieved a BC Ratio of 1.14 and a profit of ₹28563.80/- These results highlight the economic benefits associated with Agri-tech practices, which are characterized by higher profitability and improved cost efficiency.

Table 4 illustrates productivity analysis further corroborates the advantages of Agri-tech methods over traditional practices. In onion cultivation, Agri-tech methods resulted in a yield of 2.51 tonnes per acre, in contrast to 1.91 tonnes per acre for traditional farming. Labor productivity was also significantly higher among Agri-tech farmers, who generated ₹2600.71/- per hour compared to ₹1382.50/- for traditional farmers. For tomatoes, the yield from Agri-tech methods was 7.63 tonnes per acre, with labor productivity recorded at ₹461.82/- per hour, while traditional practices yielded only 4.58 tonnes per acre and achieved a labor productivity of ₹233.61/- per hour. These results clearly illustrate the effectiveness of Agri-tech in optimizing productivity and enhancing labor utilization.

Table 5 provides comprehensive financial analysis further substantiates the benefits of Agri-tech practices. The Return on Investment (ROI) for onions under Agri-tech methods was ₹0.67/- resulting in a net profit of ₹83594.8/- from an investment of ₹132700/- In contrast, traditional farming methods exhibited an ROI of ₹0.44/- yielding a net profit of ₹40421/- For tomatoes, Agri-tech methods achieved an ROI of ₹0.63/- and a net profit of ₹72963/- while traditional methods displayed an ROI of ₹0.55/- and a profit of ₹28563.8/- These findings indicate that Agri-tech

Table 3. Economic analysis: agri-tech vs traditional farming for onion and tomato

Crop	Farmer Type	Total Benefits (₹)/Ql	Total Costs (₹)/Ql	BC Ratio
Onion	Agri-tech	₹ 80,595	₹ 30,313	1.65
	Traditional	₹ 75,421	₹ 41,000	1.17
Tomato	Agri-tech	₹ 48,489	₹ 19,562	1.47
	Traditional	₹ 42,363	₹ 20,775	1.14

bc ratio: benefit-cost ratio, a measure of the economic return on investment, calculated as total benefits divided by total costs.

₹: Indian rupees, the official currency of India.

ql: quantity per liter, indicating the yield measured in liters for comparison purposes.

Table 4. Comparative analysis: yield and productivity in agri-tech vs. traditional farming

Parameter	Onion		Tomato	
	Traditional	Agri-tech	Traditional	Agri-tech
Yield per Acre (Tonnes)	2.51	1.91	7.63	4.58
Labor Productivity (₹/hr)	2600.71	1382.50	461.82	233.61
Resource Utilization	11.99	9.12	9.76	5.32

Yield per acre: total agricultural output per acre in tonnes.
Labor productivity: monetary value of output produced per hour of labor.
Resource utilization: efficiency in utilizing available resources, measured in appropriate units.

Table 5. Financial performance: agri-tech vs. traditional farming in onion and tomato

Parameter	Onion		Tomato	
	Traditional	Agri-tech	Traditional	Agri-tech
Return on Investment (ROI)	0.67	0.44	0.63	0.55
Net Profit (₹)	83,594.8	40,421	72,963	28,563.8
Total Investment (₹)	1,32,700	97,121	1,15,636	51,761.19
Average Increase in Net Profit over Traditional (₹)	88,173.67	-	1,42,471.2	-
Average Increase in Gross Revenue (Per Ac) (₹)	85,579	-	1,39,874.8	-
Difference in Profit Margin (%)	12.1	-	31.4377	-
Cost Saving (₹)	2,594.67	-	2,596.433	-

Roi - return on investment: a measure of the profitability of an investment, calculated as the net profit divided by the total investment.
net profit - the total earnings after all expenses have been deducted from revenues, represented in Indian rupees (₹).
total investment - the overall capital outlay for the agricultural activities, represented in Indian rupees (₹).
average increase in net profit over traditional - the average difference in net profit between agri-tech and traditional farming methods.
average increase in gross revenue (per ac) - the average increase in gross revenue per acre, comparing agri-tech with traditional farming.
difference in profit margin - the percentage difference in profit margins between agri-tech and traditional farming methods.
cost saving - the reduction in expenses incurred, represented in Indian rupees (₹).

practices not only provide superior financial returns but also enhance cost efficiency, which is essential for sustainable agricultural development.

Table 6 provides supply chain performance further highlights the operational advantages of Agri-tech companies compared to traditional wholesalers. Fig. 4 illustrates that agri-tech firms achieved an Order Fulfilment Rate (OFR) of 96%, significantly surpassing the 76.67% reported by traditional wholesalers. The Warehouse Utilization Rate (WUR) for Agri-tech companies was 84%, compared to just 53.8% for traditional wholesalers. Additionally, Agri-tech companies demonstrated shorter Lead Times, averaging 20 days compared to 26 days for traditional methods, and experienced minimal stockout rates of 1%, as opposed to 8% for traditional wholesalers. These operational efficiencies showcase the effectiveness of Agri-tech practices in managing supply chains, ultimately resulting in improved responsiveness and reliability in the market.

Table 7 and 8 provides multinomial logistic regression analysis identified key demographic factors influencing Agri-tech adoption. From the illustration of Fig. 5, the analysis indicated that older and more educated farmers were more likely to adopt Agri-tech solutions for onion cultivation, whereas younger farmers with larger landholdings exhibited higher adoption rates for tomatoes. Table 9 and 10 provides propensity score matching analysis which confirmed that middle-aged farmers, individuals with larger landholdings, and literate farmers are more inclined to embrace Agri-tech solutions, with training and landholding size identified as significant predictors of adoption.

Discussion

The findings of this study provide substantial evidence that Agri-tech startups are transforming vegetable supply chains in Coimbatore. By enhancing pricing structures, marketing strategies, financial performance, productivity, and overall supply chain management, these startups are reshaping the agricultural landscape in ways that benefit both producers and consumers. The data indicate a significant shift toward modern agricultural practices, suggesting a promising future for Agri-tech in the region. These insights emphasize the importance of sustained investment in Agri-tech innovations to bolster

Table 6. Comparison of supply chain metrics: agri-tech vs. traditional wholesalers

Metrics	Agri-tech Company	Traditional Wholesalers
Order Fulfilment Rate (OFR)	96%	76.67%
Warehouse Utilization Rate (WUR)	84%	53.8%
Lead Time (days)	20	26
Stockouts (%)	1%	8%
Overstock (%)	10%	25%
Inventory Turnover Ratio (ITR)	4	2.4

order fulfilment rate (ofr): percentage of customer orders completed on time.

warehouse utilization rate (wur): percentage of warehouse space being utilized.

lead time: time taken from order placement to order delivery (measured in days).

stockouts: percentage of time products are unavailable for sale.

overstock: percentage of inventory exceeding demand.

inventory turnover ratio (itr): ratio indicating how many times inventory is sold and replaced over a period.

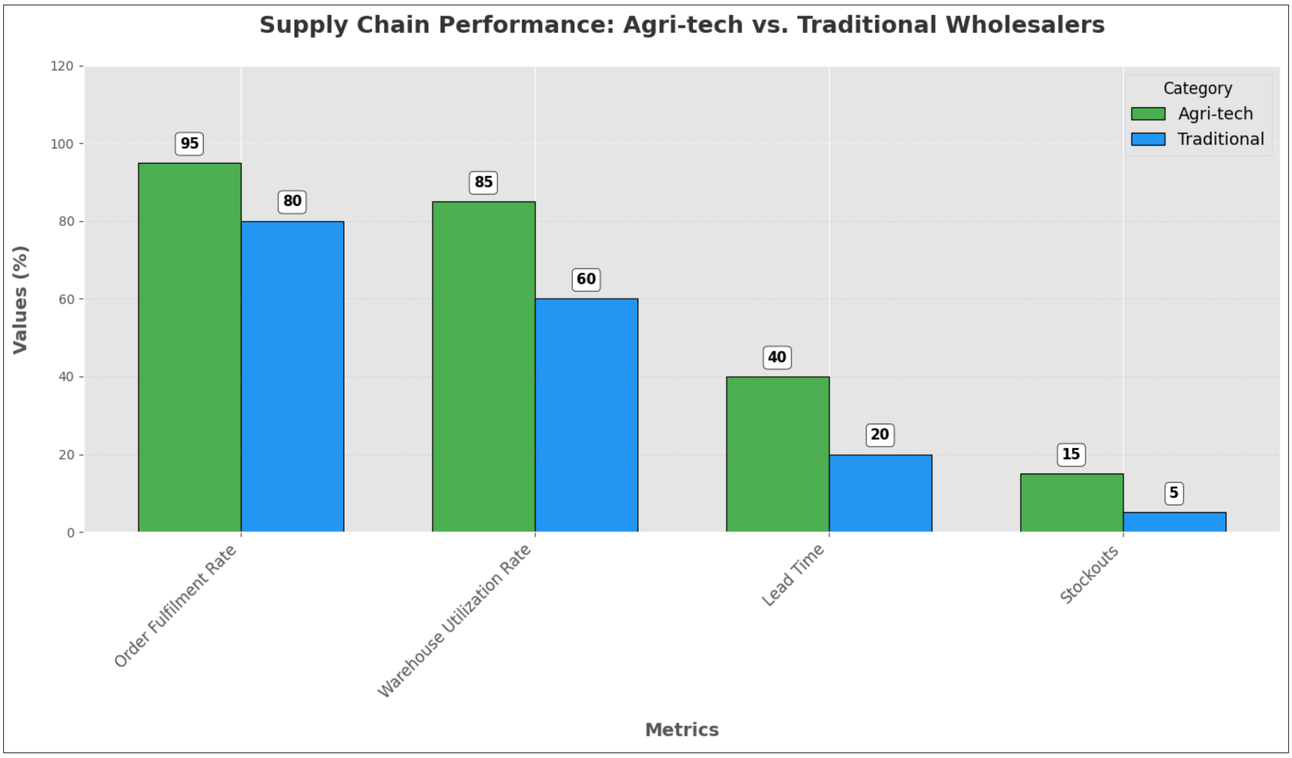

Fig. 4. Supply chain performance: agri-tech vs. traditional wholesalers.

Table 7. Agri-tech adoption in onion farming: multinomial regression factors

Summary Statistics	Value
Estimator: Multinomial Logistic Regression	
Number of Observations	400
Likelihood Ratio Chi-Square (LR chi2(7))	22.34
p-value	0.0042
Log Likelihood	-28.57321
Pseudo R-squared	0.3562

Variable	Coefficient (Coef.)	Standard Error (Std. Err.)	z-value	p-value	90% Confidence Interval [Lower Bound, Upper Bound]
gender	-0.88751	0.634	-1.40	0.045	[-0.355, 2.131]
age	0.0212	0.027	0.78	0.039	[-0.0321, 0.074]
landholding	-0.1648	0.207	-0.79	0.028	[-0.2423, 0.572]
years of experience	0.0410	0.031	1.32	0.188	[-0.1023, 0.020]
adaptation	0.3012	0.585	0.51	0.607	[-1.448, 0.846]
attended training	-0.383	0.634	-0.60	0.546	[-1.626, 0.860]
educational attainment	-0.158	0.274	-0.58	0.021	[-0.380, 0.696]
_cons	-1.978	2.191	-0.90	0.366	[-6.273, 2.315]

coef.: coefficient – indicates the effect of the variable on the likelihood of agri-tech adoption.

std. err.: standard error - a measure of the variability of the coefficient estimate.

z-value: the z-statistic, used to determine the significance of the variable in the regression model.

p-value: the probability value indicating the statistical significance of the variable (significant at $p < 0.05$).

90% confidence interval: the range in which the true coefficient is expected to lie with 90% confidence.

Table 8. Agri-tech adoption in tomato farming: multinomial regression factors

Summary Statistics	Value
Estimator: Multinomial Logistic Regression	
Number of Observations	400
Likelihood Ratio Chi-Square (LR chi2(7))	15.04
p-value	0.0023
Log Likelihood	-25.17321
Pseudo R-squared	0.2461

Variable	Coefficient (Coef.)	Standard Error (Std. Err.)	z-value	p-value	90% Confidence Interval [Lower Bound, Upper Bound]
gender	0.5005	0.494	1.01	0.411	[1.355, 3.745]
age	-0.0502	0.172	-0.29	0.034	[0.032, 0.068]
landholding	0.3248	0.157	2.07	0.040	[0.242, 0.407]
years of experience	-0.0210	0.021	-0.99	0.699	[-0.523, 0.010]
adaptation	0.1512	0.385	0.39	0.699	[-0.648, 0.346]
attended training	0.2430	0.434	0.56	0.023	[-0.770, 0.284]
educational attainment	0.2580	0.224	1.15	0.125	[-0.080, 0.435]
_cons	0.0508	1.091	0.05	0.645	[-1.784, 2.786]

coef.: coefficient – indicates the effect of the variable on the likelihood of agri-tech adoption.

std. err.: standard error – a measure of the variability of the coefficient estimate.

z-value: the z-statistic, used to determine the significance of the variable in the regression model.

p-value: the probability value indicating the statistical significance of the variable (significant at $p < 0.05$).

90% confidence interval: the range in which the true coefficient is expected to lie with 90% confidence.

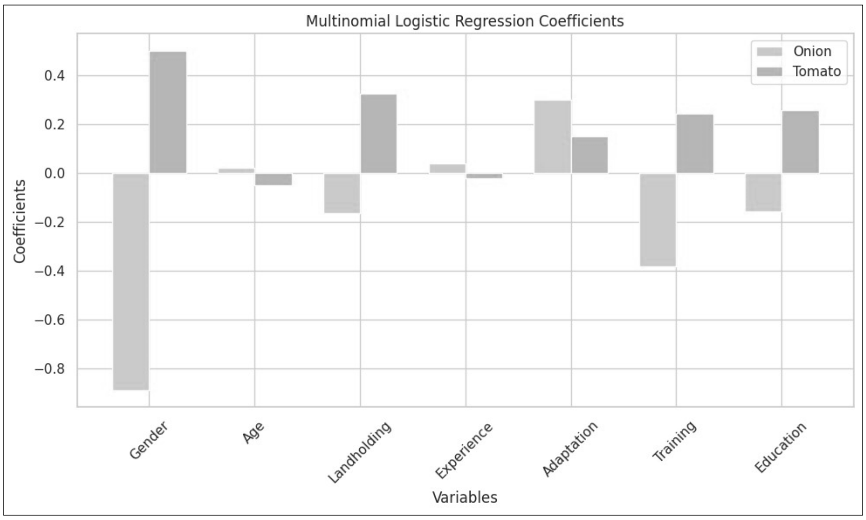

Fig. 5. Multinomial logistic regression: coefficient comparison for onion and tomato.

Table 9. Propensity score matching of agri-tech adoption in onion farming

Summary Statistics	Value
Estimator: Propensity-Score Matching	
Outcome Model: Matching	
Treatment Model: Logit	
Number of Observations	400
Matches Requested	8
Minimum Number of Matches	8
Maximum Number of Matches	400

Variable	ATE Coefficient	AI Robust Std. Err.	z-value	p-value	95% Confidence Interval [Lower Bound, Upper Bound]
mage (Adults vs Old Age)	2.243	1.050	2.15	0.036	(-0.580, 1.415)
mgender (Male vs Female)	0.987	0.432	2.28	0.047	(0.134, 1.840)
mtarea (Large farm vs Small farm)	1.756	0.789	2.00	0.023	(0.043, 3.469)
myearexp (High experience vs Low experience)	0.531	0.287	1.85	0.093	(-1.092, 0.030)
mtnautech (Adoption vs Non-adoption)	-0.274	0.193	-1.42	0.155	(-0.652, 0.104)
mtrainpro (Attended vs Not-attended)	0.652	0.312	2.09	0.082	(0.040, 1.264)
medu (Literate vs Illiterate)	0.821	0.401	2.05	0.055	(0.035, 1.607)
mlocality (Urban vs Rural)	0.189	0.112	1.69	0.272	(-0.409, 0.031)

ATE: Average Treatment Effect; Std. Err.: Standard Error; z-value: Z-statistic; p-value: Probability value; mage: Age category (Adults vs. Old Age); mgender: Gender category (Male vs. Female); mtarea: Farm size category (Large farm vs. Small farm); myearexp: Years of experience category (High experience vs. Low experience); mtnautech: Adoption of technology (Adoption vs. Non-adoption); mtrainpro: Training participation (Attended vs. Not-attended); medu: Education level (Literate vs. Illiterate); mlocality: Locality type (Urban vs. Rural).

Table 10. Propensity score matching of agri-tech adoption in onion farming

Summary Statistics	Value
Estimator: Propensity-Score Matching	
Outcome Model: Matching	
Treatment Model: Logit	
Number of Observations	400
Matches Requested	8
Minimum Number of Matches	8
Maximum Number of Matches	400

Variable	ATE Coefficient	AI Robust Std. Err.	z-value	p-value	95% Confidence Interval [Lower Bound, Upper Bound]
mage (Adults vs Old Age)	1.932	0.987	1.86	0.076	(-0.320, 4.180)
mgender (Male vs Female)	1.204	0.589	2.05	0.045	(0.102, 2.306)
mtarea (Large farm vs Small farm)	1.632	0.821	2.00	0.097	(0.032, 3.232)
myearexp (High experience vs Low experience)	0.421	0.287	1.47	0.142	(-0.981, 0.139)
mtnautech (Adoption vs Non-adoption)	-0.354	0.193	-1.84	0.367	(-0.734, 0.026)
mtrainpro (Attended vs Not-attended)	-0.721	0.312	-2.31	0.421	(0.110, 1.332)
medu (Literate vs Illiterate)	0.942	0.401	2.05	0.041	(0.158, 1.726)
mlocality (Urban vs Rural)	0.214	0.112	1.91	0.127	(-0.434, 0.006)

ATE: Average Treatment Effect; Std. Err.: Standard Error; z-value: Z-statistic; p-value: Probability value; mage: Age category (Adults vs. Old Age); mgender: Gender category (Male vs. Female); mtarea: Farm size category (Large farm vs. Small farm); myearexp: Years of experience category (High experience vs. Low experience); mtnautech: Adoption of technology (Adoption vs. Non-adoption); mtrainpro: Training participation (Attended vs. Not-attended); medu: Education level (Literate vs. Illiterate); mlocality: Locality type (Urban vs. Rural).

agricultural productivity and sustainability in Coimbatore and beyond.

The analysis reveals several advantages associated with adopting Agri-tech practices compared to traditional agricultural methods. These advantages encompass improved pricing efficiency, enhanced marketing effectiveness, stronger financial outcomes, and increased productivity. Agri-tech firms demonstrate notable improvements in supply chain performance, illustrating the transformative impact of digital agriculture on conventional farming practices. The efficiency of supply chains is crucial for the success of agricultural operations, particularly in an increasingly competitive marketplace.

Furthermore, the study identifies demographic factors and landholding sizes as critical determinants influencing Agri-tech adoption. Recognizing these factors is essential, as targeted interventions could significantly enhance both agricultural sustainability and profitability, especially in Coimbatore District. However, the advancement of digital Agri-tech is met with various challenges. Traditional farmers often display reluctance to embrace new technologies due to unfamiliarity, perceived complexity, and high initial costs. In the context of Coimbatore District, additional obstacles such as inadequate rural internet connectivity and concerns over data privacy and cybersecurity exacerbate the situation.

Despite these challenges, there are considerable growth opportunities driven by innovations in sensor technology, the Internet of Things (IoT), and artificial intelligence (AI). Raising awareness among farmers and consumers regarding the benefits of digital Agri-tech can foster a more supportive market environment. The substantial investments in India's Agri-tech sector from 2017 to 2023, including leading startups such as Tropical Animal Genetics, DeHaat, and Ninjacart, accent the potential for continued growth within this sector. To optimize supply chain management in the vegetable sector, digital Agri-tech startups must develop user-friendly interfaces that facilitate the adoption of technology among traditional farmers. Additionally, comprehensive training programs are vital to equip farmers with the necessary skills to effectively utilize new tools. Collaborating with telecommunications providers to enhance rural internet infrastructure is essential to improve access to digital platforms. Moreover, government support plays a pivotal role in advancing Agri-tech initiatives. Implementing subsidies, tax incentives, and grants can stimulate investment in digital solutions. Furthermore, establishing regulatory frameworks that address data privacy and cybersecurity concerns is necessary to foster trust and encourage participation in digital agricultural initiatives.

Expanding rural broadband access and promoting digital literacy will enable wider adoption of Agri-tech solutions, ultimately supporting sustainable agricultural development. This study highlights the significant role of Agri-tech startups in revolutionizing vegetable supply chains in Coimbatore. By achieving improvements in agricultural practices, yield, and overall supply chain efficiency, these startups are redefining traditional frameworks. While challenges persist, the integration of technology into agriculture presents a promising pathway for enhancing productivity and economic viability. The future of agriculture in Coimbatore is closely linked to advancements in Agri-tech, representing a critical step toward modernizing the industry and ensuring food security in the region.

Conclusion

The study reveals that digital agricultural technologies offer significant advantages over traditional methods, notably in pricing, marketing efficiency, financial performance, and productivity. Key factors influencing adoption include demographic characteristics and landholding sizes, indicating that targeted interventions could enhance agricultural sustainability and profitability. Despite these benefits, several challenges hinder widespread adoption. These include farmer resistance due to unfamiliarity and perceived complexity, high initial costs, inadequate rural internet connectivity, and concerns over data privacy and cybersecurity. Nevertheless, the potential for growth in the agri-tech sector remains robust, driven by advancements in sensor technology, the Internet of Things (IoT), and artificial intelligence (AI). To address these challenges, startups must develop user-friendly technologies and provide training for traditional farmers. Additionally, collaboration with telecom providers to improve rural internet infrastructure and government support through subsidies and regulatory frameworks are essential. Enhancing rural broadband and promoting digital literacy will facilitate broader adoption, thereby supporting sustainable agricultural development and transforming vegetable supply chains in Coimbatore.

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Authors' contributions

SN conceptualized the research, carried out the primary data collection and drafted the manuscript. KN supervised the research, provided guidance on methodology, and reviewed the manuscript. VA contributed to the data analysis and interpretation of results. MK assisted in designing the field study and participated in reviewing the manuscript. SK contributed to the statistical analysis and supported the development of the discussion section. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of Interest: The authors declare that they have no competing interests related to this research.

Ethical Issues: None. The study adhered to all ethical guidelines, with informed consent obtained from participants, and no animals or endangered species were involved in the research process. The study’s data collection and analysis were conducted in accordance with ethical standards, ensuring confidentiality and respect for all participants.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used OpenAI's ChatGPT to improve the language and readability of the manuscript. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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