A Systematic Review of Greenhouse and Integrated Pest Management Adoption in Tomato Production: Insights from Smallholder Farming Regions

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ABSTRACT

This systematic review examines the literature on the use of greenhouse technology and Integrated Pest Management (IPM) in tomato production. It focuses on the effects on yield and economic returns, as well as the challenges farmers face. Following the PRISMA method, we conducted a thorough search of academic and institutional databases. Studies have shown that combining greenhouse and IPM practices significantly improves yield stability and farm profits by reducing biotic and abiotic stressors. However, farmers still face significant barriers to adoption, such as high upfront costs, limited access to credit and quality inputs, and a lack of technical training. The review also highlights the growing role of ICT-based services in supporting IPM use. This synthesis offers essential insights for policymakers and extension services seeking to promote resilient, sustainable tomato production systems, especially for smallholder farmers. Future research should examine long-term socioeconomic impacts and context-specific adoption models.

Keywords: Greenhouse,Integrated pest management(IPM),Tomato production

INTRODUCTION

Tomatoes are of significant importance in the horticultural subsector, contributing substantially to food security, nutrition, and economic growth, particularly in sub-Saharan Africa (Abdelmawgoud et al., 2021; Chamuah et al., 2024; Hemingway et al., 2022). As a high-value crop, tomatoes offer significant potential to improve the livelihoods of smallholder farmers due to their daily consumption in households worldwide and their capacity to generate higher farm-gate value per unit of land than many staple foods (Johnson et al., 2008; Shortall). However, this potential is challenged by inconsistent production patterns stemming from multiple challenges, including limited water resources, unpredictable climatic conditions, and severe pest infestations (Hassan, 2025). A prominent example is the destructive insect, the fruit fly, which can infest up to 60% of tomatoes, posing a significant threat to both productivity and farmer incomes (Pennington et al., 2021).

In response to these challenges, the adoption of adaptive agricultural technologies has become necessary. Greenhouse cultivation enables year-round production, providing more stable income and supporting a consistent supply chain (Santana et al., 2019). This is reflected in the rapid expansion of the greenhouse vegetable sector; for instance, the greenhouse vegetable industry in the U.S. has grown from approximately 0.5% of retail grocery sales of tomatoes to more than 60% today(Michael et al., 2024). Concurrently, there is a need to implement ecologically sound pest control strategies. Integrated pest management (IPM) provides a comprehensive approach that utilises biological control agents, cultural practices, and strategic pesticide use to manage pests and minimise environmental harm (Kabir & Rainis, 2015). This combination has been identified as a key solution for improving the productivity and sustainability of tomato cultivation.

Despite these benefits, farmers rely on pesticides, and the adoption of integrated pest management practices remains limited (Maureira et al., 2022). Technological adoption is influenced by a complex interplay of factors, including financial constraints, access to training and quality inputs, and farmers' perceptions (Kaliba et al.,

2018; Liu et al., 2018). While individual studies have examined aspects of adoption in tomato production, a comprehensive synthesis of the literature remains lacking. This systematic review aims to address the gap by examining the adoption of greenhouse technologies and IPM in tomato production. By providing this synthesis, the review contributes to the literature on sustainable agricultural innovation and offers evidence-based insights to guide policy, extension services, and future research aimed at enhancing resilient tomato production systems

METHODS

This systematic review was conducted for peer-reviewed journal articles and book chapters published until June 2024. The following databases were used: Scopus, Web of Science Core Collection, and the repositories of the Food and Agriculture Organisation (FAO), the International Food Policy Research Institute (IFPRI), and the World Bank. The search string comprised keywords related to 1)tomato,2)technology (greenhouse or protected cultivation), 3) management (integrated pest management or IPM), using Boolean operators (AND, OR). Grey literature and conference proceedings were excluded to maintain focus. This study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher et al., 2009).

Eligibility Check.

Publications were included if their titles and abstracts met at least one of the specified inclusion criteria.

Inclusion criteria

- Studies that explicitly focused on the adoption, implementation, and impact of greenhouse technologies or Integrated Pest Management (IPM) in tomato production.
- Studies reporting quantitative or qualitative results on outcomes such as yield, economic returns, pest incidence, and sustainability.
- Case studies examining practical implementation, challenges, and success.

Exclusion cretaria

A study was excluded from the review if it met one of the following exclusion criteria

- Studies not available in English
- Previous studies have not focused on tomato production
- Studies with no full-text available

Studies lacking primary data on adoption outcomes or factors.

Study Selection Process

The study selection process followed the PRISMA 2020 guidelines (Page et al., 2021). A total of 428 records were found from databases, with an additional 12 records identified through citation searching. After removing 89 duplicates, 351 records were screened by title and abstract. Then, 336 full-text articles were checked for eligibility, and 311 were excluded for various reasons. Finally, 25 studies met all inclusion criteria and were included in this systematic review. The selection process is summarised in Figure 1.

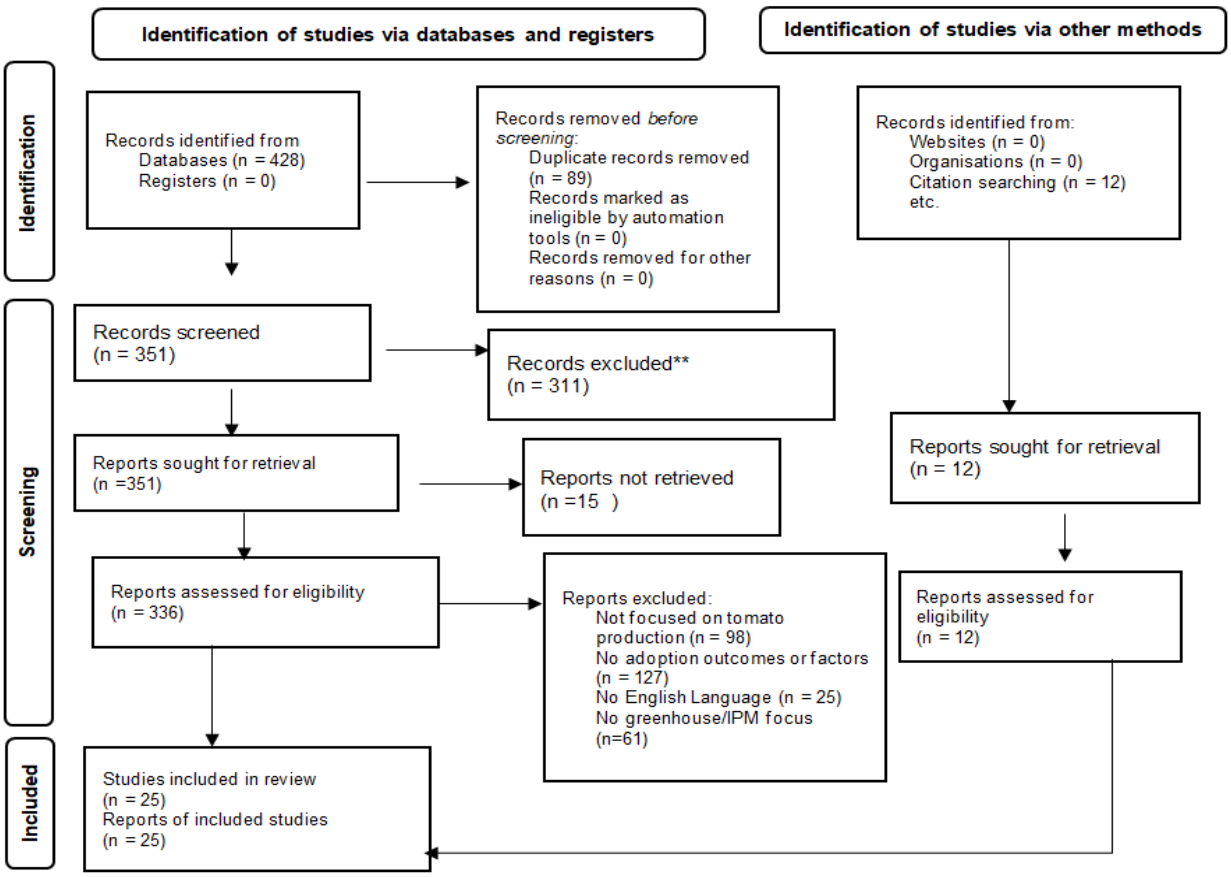

Figure 1:PRISMA flow diagram

RESULTS AND DISCUSSION

This section summarises the important discoveries from multiple research projects on greenhouse tomato cultivation and integrated pest management (IPM). This study covers various areas. It offers perspectives on the challenges and prospects of production, the influence of ICT-based pest information services, the efficiency of different cultivation methods, the uptake of protected farming technologies, and specific IPM approaches. The relevant articles used field trials, surveys, and comparative analysis methods.

Importance of protected farming technologies

A protected culture strategy that offers a fully regulated environment reduces the number of biotic and abiotic stressors. Previous studies have demonstrated that investing more in protected farming is necessary given the rising global food needs; hence, greenhouses are the most effective way to meet protected horticulture goals(Chamuah et al., 2024). Differences in socioeconomic and institutional factors have influenced smallholder tomato farmers' adoption of protected farming technologies, such as greenhouses, in different regions. Most studies use variables such as age, the household head's education (in years), and annual household income to demonstrate the positive relationship between protective farming technologies and credit access. Ramasamy & Ravishankar (2018) highlight that 29.8% of the surveyed households used PFT, indicating the inclusion of campaigns that consider all smallholder farmers' distinct abilities and needs, while allowing farmers to accumulate more human and financial capital. Advanced greenhouse technology systems, including automated climate-controlled irrigation, can improve and promote productivity by replacing inefficient resource use.

Yield outlook

Yield improvement is an important factor in the outcomes of greenhouse technology. In South European tomato production, especially in Spain and Italy, adopting these technologies has led to a 30% increase in yield compared to traditional open-field production (Maureira et al., 2022). The use of greenhouse-controlled

technologies helps maintain year-round tomato production (Ayele et al., 2025; Badu, 2023). Similar results were observed among high-tech greenhouse tomato farmers in Kenya (Otiende et al., 2024). Despite low adoption of greenhouses and IPM in Bangladesh, targeted approaches and training have led to significant improvements among tomato farmers. In different studies(Alam et al., 2016; Van Der Velden et al., 2012), the results of the sample in Figure 2 indicate improved yield across different regions; Kenya showed a 25% improvement, Brazil a 20% increase, Bangladesh 15%, and Spain 50%, regardless of whether the farmers used greenhouse or Integrated Pest Management strategies.

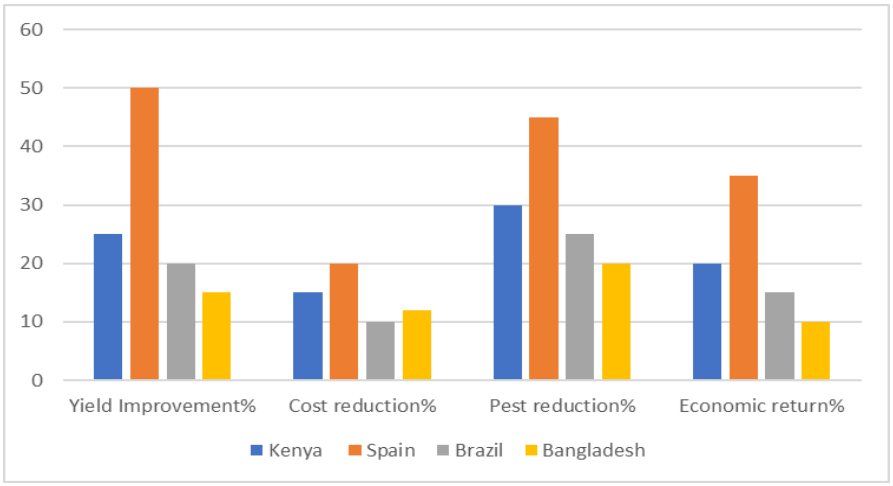

Figure 2: Results of different outcomes for the use of technology.

Economic Importance of Agricultural Technologies.

These cutting-edge agricultural techniques have resulted in significant cost savings, increased profitability, and enhanced market competitiveness. Integrated Pest Management (IPM) plays a key role in reducing reliance on chemical pesticides and lowering associated costs for farmers. (Kabir & Rainis, 2015). Moreover, these practices increase crop yields and optimise farmers' profits. Farmers can achieve continuous production by leveraging climate-controlled greenhouses, which translates into consistent annual profits(Abdelmawgoud et al., 2021). Adopting these technologies increases competitiveness in international markets by ensuring the delivery of high-quality products that command premium prices, giving farmers a distinct advantage in meeting and exceeding stringent export standards (Johnson et al., 2008). Adopting these practices has a greater economic impact because higher yields improve the economic situation of tomato farmers across different regions (Michalis et al., 2023).

Challenges experienced in the adoption of these farming methods.

Greenhouse tomato production offers numerous advantages, such as controlled environmental conditions and reduced pest problems; however, it also presents numerous challenges. Figure 3 shows the diseases and pests encountered by farmers during tomato production.

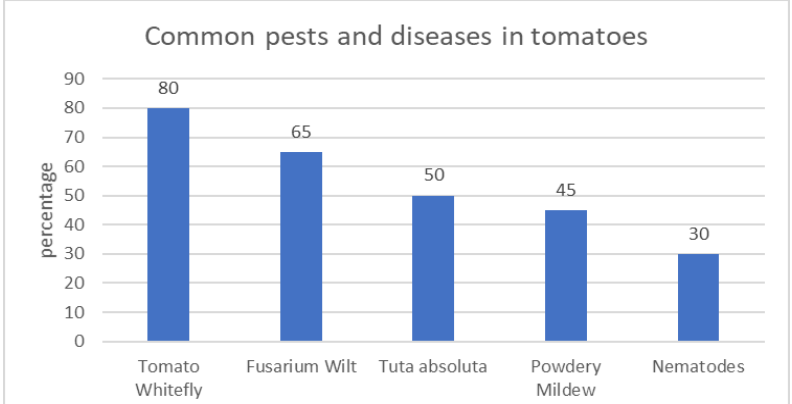

Figure 3: Common pests and diseases in tomatoes

Financial constraints

One of the major challenges is the high greenhouse setup and maintenance costs(Singh et al., 2024), as the initial capital investment for constructing greenhouses, purchasing equipment, and obtaining quality inputs, such as seeds and fertilisers, is substantial. Figure 4 shows that smallholder farmers often lack access to affordable credit, making it difficult for them to invest in greenhouse technology.

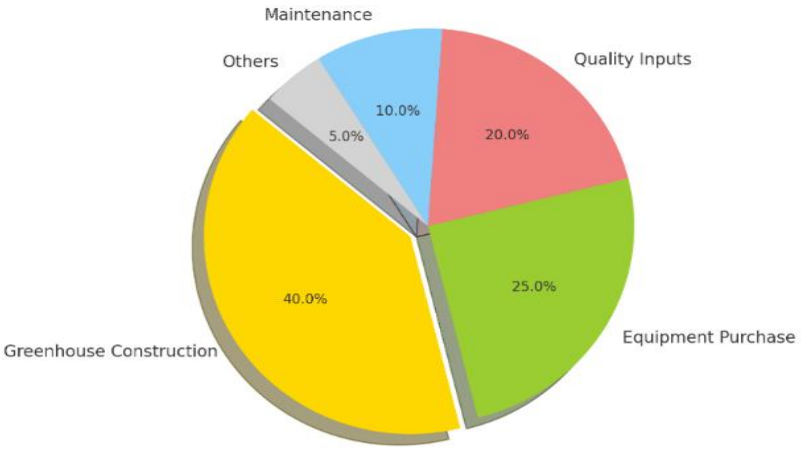

Figure 4: Distribution of production costs in tomato production

One commonly mentioned obstacle is the significant expense of building and maintaining greenhouses. The initial capital investment for building greenhouses, acquiring equipment, and obtaining high-quality inputs, such as seeds and fertilisers, is substantial. For instance, Muriithi et al. (2021) reported that production costs in greenhouse tomato farming are distributed as follows: 40% for greenhouse construction, 25% for equipment purchases, 20% for quality inputs, 10% for maintenance, and 5% for miscellaneous costs. Smallholder farmers face challenges accessing affordable credit, making it difficult to invest in and adopt greenhouse technologies (Dwasi, 2017). Although greenhouse use appears effective, it is still affected by pests. Management practices such as grafting and bio-insecticides are promising but still require resources that are not readily available to all farmers (Awu et al., 2023).

Quality agricultural inputs

The use of quality and certified inputs is important for agricultural production. The correct inputs are necessary for high-quality tomato production. Research has shown that high-quality inputs provide greater output than low-quality inputs. A comparative analysis (Pennington et al., 2021) distinguished the outputs of greenhouse tomato farmers from those of open-field tomato production in Kenya. The results indicated that the output in the greenhouse was 16.1 kg/m2, whereas that in the open field was 2.3 kg/m2. This indicates a distinct difference between the two methods. Farmers who can purchase greenhouse inputs achieve higher yields than open field farmers. Additionally, the availability of relevant inputs for farmers, especially in greenhouse farming, is important at a reasonable price. Therefore, farmers should purchase these inputs to maintain high-quality output.

Adequate farming training for tomato production

Another major problem experienced by most farmers in using greenhouses and IPM practices is the lack of relevant information and training on advanced farming techniques (Sekabira et al., 2022). A study by Chamuah et al. (2024) found that various factors contribute to technical efficiency, including household size, production systems, seed type, fertiliser use, and access to extension services. Additionally, greenhouse Farmers are more technically efficient and have more training regarding quality inputs, with an average of 39.55% compared to open-field farmers. Most smallholder farmers lack sufficient knowledge of modern agricultural practices, hindering their adoption. With more farmer training, the gap will eventually be filled, as more farmers are willing and eager to learn and improve their productivity.

Relevance of ICT-Based Pest Information Services on IPM and Greenhouse

The integration of Information and Communication Technology (ICT) into agriculture has changed traditional farming practices, especially in pest management. Farmers can now use mobile devices to access tools and databases to identify pests that may harm their crops. With ICT-based services, farmers receive real-time alerts and recommendations for pest-control measures. This empowers them to act quickly and effectively in emergencies. For example, SMS alerts and mobile applications can inform farmers about pest outbreaks and provide relevant solutions. This helps farmers avoid losses due to pests and bad weather. Maureira et al. (2022) and Mwenda et al. (2023) discovered that farmers who occasionally use ICT platforms for learning reported greater competence in managing pests more efficiently, greater confidence in their farming, and that the use of mobile phones is very effective and efficient for obtaining pest information, especially for small-scale farmers without access to traditional extension services. More studies have demonstrated that effectively managing pests and ensuring the safety of agricultural produce depend significantly on farmers adopting Integrated Pest Management (IPM) practices and adhering to pre-harvest intervals (PHI) (Angon et al., 2023; Zhou et al., 2024). Research findings indicate that using information and communication technology (ICT) resulted in a 22.8% increase in farmers' utilisation of pest control methods, a 21.2% increase in adopting IPM, and a 61.7% improvement in adherence to PHI. Moreover, those who embraced these practices were more likely to use multiple pest management strategies, including synthetic pesticides, biopesticides, and mechanical controls. This reduced their reliance on any single method and enhanced their overall pest control efficiency.

Policy Implications.

Therefore, in-depth policy frameworks are necessary to encourage the widespread use of advanced greenhouse technology and IPM practices. Policymakers should address farmers' challenges, including training, overcoming financial barriers, and improving market access. The government should offer low-interest loans to start-up greenhouse facilities to support the farmers. Second, extension officers should organise regular workshops and field days to provide continuous training on seed quality and ways to monitor crops to maintain quality and quantity. Third, the government should enhance market access by implementing quality standards that align with the export requirements. Policymakers can foster sustainable, profitable tomato production by addressing financial barriers, improving education and training, expanding market access, and promoting public-private partnerships. These policies have many benefits for farmers, supporting environmental sustainability and food security while also improving their economic situation.

CONCLUSION

This review highlights that integrating greenhouse technology with pest management can significantly improve tomato production and sustainability. The evidence clearly shows benefits such as stable yields, higher farm profits, and reduced environmental impact. However, achieving these benefits depends on overcoming major challenges. These include the high costs of greenhouse setups, limited access to financing and quality supplies, and gaps in technical knowledge and support.

These findings highlight the importance of creating policies that address these challenges holistically. Effective steps include making it easier for farmers to obtain affordable loans, improving training and support services focused on integrated pest management, and building market connections that reward high-quality, sustainably grown tomatoes. Future research should focus on long-term studies to evaluate the sustainability of these systems and on participatory action research to develop adoption models that meet the specific needs of smallholder farmers. By addressing these issues, stakeholders can enhance the effects of these technologies, improve lives, and help achieve broader food security goals.

Ethical consideration

The ethical standards followed in this study were in line with Nanjing Agricultural University's guidelines. All data used in this study were obtained from publicly available sources, ensuring transparency and integrity of the research process. The study adhered to ethical guidelines in the collection, analysis, and reporting of data.

Conflict of Interest

The authors declare no conflicts of interest.

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