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Automated Vertical Farming System in Urban Areas: An Urban Farming Solution for Future Food Security

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ABSTRACT
Population growth in urban areas has resulted in a decrease in agricultural land and an increased dependence on food from outside the region. This poses a risk to the city's food security. This study aims to analyze the effect of implementing automation-based vertical farming systems on improving the food security of urban communities. The research was conducted using a quantitative descriptive approach with a survey of 100 respondents from urban farming households in Jakarta. Data were collected through questionnaires and analyzed using simple linear regression to measure the relationship between the use of automation technology (X) and food security levels (Y). The results of the study show that *automatic vertical farming systems* have a positive and significant influence on household food security, especially in the aspects of food supply availability and sustainability. These findings strengthen the argument that technology-based urban farming is the future solution for large cities in maintaining food security sustainably. Therefore, the integration of technology in the *urban agricultural system* needs to be expanded and supported through public policies.

INTRODUCTION

In recent decades, the world has faced serious challenges in ensuring global food security. The United Nations, through the FAO (Food and Agriculture Organization), projects that by 2050, the global population will exceed 9 billion people, which means food production must increase by 70% to meet these needs (FAO, 2017). Rapid urbanization is one of the main factors driving shifts in food consumption and distribution patterns. Data from the World Bank (2020) show that more than 56% of the world's population now lives in urban areas. In Indonesia itself, based on BPS data (2023), around 58% of the population lives in urban areas, and this figure continues to rise every year. Population growth and massive land conversion pose major challenges for food security, especially in urban areas with limited space for conventional agriculture.

The problem of food security in urban areas is not only caused by the lack of agricultural land but also by vulnerability to long and inefficient food distribution chains. Cities' dependence on food supplies from outside regions makes urban food systems vulnerable to disruptions such as natural disasters, climate crises, and global economic shocks (Andersson Djurfeldt, 2015; Factura et al., 2022; Long et al., 2018). In addition, the increasing demand for fresh and healthy food amid space constraints has driven the need for innovation in adaptive and sustainable urban food production. These factors highlight the urgent need to find agricultural solutions that are not only efficient in space use but also integrated with technologies capable of increasing productivity.

One of the emerging solutions to this challenge is vertical farming. This system allows the vertical production of plants in multi-storey structures, significantly saving space. Furthermore, the application of automation technologies, such as humidity sensors, automated irrigation systems, and artificial light control based on the Internet of Things (IoT), enables more efficient, precise, and sustainable agricultural management (Benke & Tomkins, 2017; Engler & Krarti, 2021; Goodman & Minner, 2019; Kumar et al., 2023; Roberts et al., 2020). However, other challenges arise concerning urban communities' understanding of the benefits and effectiveness of these automated vertical farming systems, as well as their long-term contributions to food security.

The main variables in this study are automation-based vertical farming systems (variable X) and urban household food security (variable Y). Automated vertical farming systems refer to the use of technology in multi-storey agricultural structures to maximize crop yields, while food security refers to conditions where households have sufficient, stable, and nutritious access to food at all times (USAID, 2021). This research focuses on how the integration of technology in urban farming contributes to the dimensions of food security, namely food availability, accessibility, utilization, and stability. In the Indonesian context, research of this kind remains relatively limited, especially in mapping the relationship between modern technology-based agricultural systems and their impact on urban communities' food security.

The novelty of this study lies in its empirical approach, which examines the relationship between the use of automated vertical farming systems and the level of food security in urban areas. Unlike previous studies that focused primarily on the effectiveness of technology in boosting crop productivity (Al-Kodmany, 2018, 2024; Maltseva et al., 2018; Oliva et al., 2019), this study measures the actual contribution of the system to the socio-economic dimension of the community, particularly in meeting daily food needs. In addition, this study attempts to map urban communities' perceptions and readiness to adopt automation-based agricultural technology as part of their lifestyle and survival strategies in facing future food security dynamics.

The urgency of this research is amplified by various threats to the sustainability of urban food systems amid climate change, global pandemics, and geopolitical crises disrupting global supply chains. The COVID-19 pandemic serves as a concrete example of how disruptions to the food logistics system can cause uncertainty and scarcity in supply in large cities (Laborde et al., 2020). Meanwhile, climate change has further impaired the productivity of conventional agriculture due to irregular growing seasons, floods, and prolonged droughts. Hence, there is a pressing need to diversify food sources and develop high-technology-based local food production systems as strategic steps toward sustainable food security.

Based on this background, this study aims to analyze the influence of automation-based vertical farming systems on the food security of urban communities by taking case studies of urban farming households in the DKI Jakarta area. The study also seeks to identify the extent to which people understand the benefits of modern agricultural systems, as well as the factors determining the success of their adoption in Indonesia's urban context. This analysis is expected to contribute to the development of technology-based urban agriculture policies and models in the future.

The benefits of this research are divided into two categories: theoretical and practical. Theoretically, this research is expected to enrich the literature on the relationship between agricultural technology and food security within the framework of urbanization and digital transformation. The findings may also serve as a reference for future researchers interested in investigating similar issues at different scales or in other regions. Practically, this study provides relevant information for government agencies, agritech business actors, and the public regarding the potential of automated vertical farming systems as an adaptive strategy to address food crises and land constraints in large cities. The results can also serve as a foundation for developing technology-based urban farming education and training programs at the community level.

RESEARCH METHOD

This study was designed to explore the relationship between the implementation of automation-based vertical farming systems and community food security in urban areas. To achieve this, research strategies were systematically formulated to map the field reality and draw relevant conclusions.

A descriptive qualitative approach was used to provide an in-depth, comprehensive description of the phenomenon without intervening in the object of study. This approach captured the contextual and social aspects of agricultural technology use within the dynamic urban environment. It was appropriate for exploring the perceptions, experiences, and motivations of urban communities adopting automated vertical farming systems as part of their food security strategies.

The research was conducted in the DKI Jakarta area, representing urban zones characterized by high population density, limited land, and complex food distribution systems. Jakarta was selected due to its diverse urban farming practices developed at individual, community, and institutional levels. Research activities took place between January and April 2025, encompassing planning, field observation, data collection, validation, and report preparation. This period was sufficient to observe vertical farming practices in a consistent and sustainable manner.

The study population consisted of urban farming households in DKI Jakarta actively using automation-based vertical farming systems, both on a small scale (home) and in communities. From this population, 100 respondents were selected through purposive sampling. The sampling criteria were:

1. Households operating automated vertical farming systems for a minimum of six months
2. Use of technology components such as automated irrigation, humidity sensors, or IoT modules
3. Permanent residence in the DKI Jakarta area
4. Willingness to participate in interviews and complete research instruments

This sample was chosen to ensure valid, relevant data aligned with the research focus and to reflect the diversity of practices and perceptions within Jakarta's urban farming community.

The primary instruments included interview guidelines, observation sheets, and questionnaires, developed based on relevant literature on vertical agriculture and food security (FAO, 2021; Al-Chalabi, 2015). These instruments addressed technology use, production outcomes, cost savings, and impacts on household food consumption. A pilot study with 10 respondents was conducted to test the clarity and suitability of the instruments before full implementation.

RESULTS AND DISCUSSION

This study aims to examine the influence of automation-based vertical farming systems on household food security in urban areas, with a case study on 100 urban farming households in DKI Jakarta. The main focus of this study is to understand the extent to which the application of automation technology in vertical agriculture can increase the availability, accessibility, utilization, and stability of food for families in urban environments that have limited space. Data was obtained through surveys, in-depth interviews, field observations, and visual documentation of the vertical gardens owned by the respondents. The two main variables studied were automation-based vertical farming systems (variable X) and food security (variable Y).

Respondent profiles show that 60% of participants are male and 40% female, with the dominant age being between 30 to 45 years. The majority of respondents (70%) have a minimum undergraduate educational background, and most work in the formal sector, such as private and professional employees. All respondents are domiciled in the DKI Jakarta area and have been running a vertical farming system for at least six months. The automation technologies used in their gardening practices include automated irrigation systems, automatic LED planting lights, and Internet of Things (IoT)-based soil moisture sensors. As many as 78% of respondents have implemented at least one automation technology in their urban farming activities, while the rest use manual or semi-automated systems.

One of the key findings of the study is that the use of automation technology has proven to be very helpful in the management of vertical gardens. As many as 87% of respondents stated that automation makes farming activities more efficient and regular, especially in terms of watering and lighting. Automatic irrigation systems are the most widely used technology, followed by LED planting lights with automatic timers, and soil moisture sensors connected to mobile apps. With automation, respondents find it more helpful to manage their farming time, especially since most of them work full-time outside the home.

Food security is measured based on indicators from FAO which include food availability, accessibility, utilization, and stability. The results showed that 94% of respondents were able to provide part of their daily vegetable needs from their vertical garden. In addition, 83% admitted to experiencing a reduction in weekly vegetable spending by 25-40%. As many as 79% stated that they felt safer about the food supply during the pandemic and market distribution disruptions, while 65% managed their own crops and rated the quality as fresher and healthier than market products. These findings confirm that automated vertical farming systems are not only technically efficient, but also capable of making a real contribution to the dimension of household food security in large cities.

Data analysis showed a positive correlation between the level of automation use and the household food security index score. Respondents with a fully automated system (n=46) had an average food security score of 82.4 out of 100, while the semi-automated group (n=32) recorded an average of 74.7 and the manual group (n=22) recorded an average of 66.1. This difference in score shows that the higher the intensity of the use of technology in vertical agriculture, the greater its contribution to meeting daily food needs. Automation technology simplifies the farming process, speeds up harvest time, and provides consistency in crop yields, thereby strengthening the dimension of food availability and access.

Furthermore, this study reveals the perception and motivation of users in adopting an automated vertical farming system. As many as 86% of respondents cited the desire to live a healthy life and consume pesticide-free products as the main motivation. This is followed by the need to save household expenses (72%), awareness of the global food crisis (63%), and interest in agricultural technology (42%). Some respondents stated that their interest in urban farming emerged during the COVID-19 pandemic, when food supply was disrupted and the price of staples increased dramatically. In these conditions, they began to look for alternatives to independent food production, and vertical farming became a practical solution that could be implemented at home with limited land.

However, there are a number of obstacles faced by respondents in applying automation technology. The main obstacle is the limited upfront cost for the purchase of automation tools, which was mentioned by 65% of respondents. In addition, some respondents have difficulty understanding how automated devices work due to a lack of technological literacy, especially in the older generation. Technical issues such as device malfunctions, sensor errors, or unresponsive apps are also common, although most can be addressed through urban farming communities or online guides. Support from the government or related institutions is still minimal, especially in terms of training and counseling on urban agricultural technology.

The study also noted that there are various good practices that can be replicated on a wider scale. Some of them are the use of analog timers as simple automatic irrigation solutions, the use of used goods for vertical structures, to the formation of online communities that actively share information on how to grow auto-crops. In fact, some respondents work with local agritech startups that provide application-based installation, education, and remote monitoring services. The community is an important force in maintaining the motivation and success of technology-based urban farming practices. Respondents who were members of the community showed higher levels of success and consistency than those who worked individually.

From the social and economic aspects, this study also found that the practice of automatic vertical farming has a positive impact that goes beyond the technical aspect. As many as 73% of respondents stated that farming activities strengthen relationships between family members, especially children who are involved in caring for plants. A small percentage (17%) have even sold their crops to neighbors or through online platforms, albeit on a microscale. This activity not only fosters an entrepreneurial spirit but also increases collective awareness of the importance of local food production and an environmentally friendly lifestyle. Some respondents also use kitchen waste to make compost used in vertical gardens, thus supporting circular economy principles at the household level.

Overall, the results of this study confirm that automation-based vertical farming systems have great potential in strengthening food security in urban environments. Automation technology provides efficiency and consistency of production, allows the use of tight space to be productive, and reduces household dependence on external food supplies. These findings also suggest that with the right approach, public education, and supportive policy interventions, these systems can be adopted more widely as an adaptive strategy to the global food crisis and climate change. Although there are still obstacles in technical and economic aspects, the innovative spirit of the community and community support are strong capital in expanding the application of urban farming technology in a sustainable manner.

Discussion

The main problem behind this study is the declining ability of large cities to provide food independently due to limited land and dependence on out-of-region supplies. Rapid urbanization has led to many agricultural areas being converted into residential and commercial areas. This exacerbates local food security, especially in the context of households living in densely populated cities. In this context, the research is focused on finding strategic solutions in the form of automation-based vertical farming systems as an innovative approach that can simultaneously answer the challenges of food availability and land efficiency.

Data obtained from 100 urban farming households in DKI Jakarta shows that vertical farming systems with automation are able to make a real contribution to the dimension of food security. Of the four main dimensions of food security measured—i.e., availability, accessibility, utilization, and stability—all showed reinforcement when vertical farming technologies were applied consistently. As many as 94% of respondents were able to produce some of their daily vegetable needs independently, and 83% stated that their spending on vegetable shopping has decreased significantly. This shows a direct improvement in the aspect of family food availability and accessibility, which was previously highly dependent on market supply.

The main causes of food security problems in urban areas so far are the limited physical space for farming, lack of public awareness of the potential for independent food production, and the non-optimal role of technology in encouraging the efficiency and productivity of urban agriculture. Many households do not realize that narrow spaces such as balconies, exterior walls, or roofs can be used for vertical farming. With the use of automation technologies such as automated irrigation systems and IoT-based humidity sensors, the planting process has become simpler and can be carried out by anyone, including those with no agricultural background. This is in line with the findings of Al-Kodmany (2018) who stated that the success of technology-based urban farming is greatly influenced by the level of adoption of appropriate technology and its ease of use at the household level.

In relation to solutions, the automated vertical farming system approach has proven to be able to answer most of these obstacles. Technology allows the farming process to be carried out efficiently, time-saving, and does not require special skills. Some respondents even mentioned that the use of a simple timer and an inexpensive sensor module is enough to manage a vertical garden well.

In addition, this system allows for a more regular and planned harvest, thus strengthening the dimension of household food stability. With the availability of vegetables every week from their own garden, families not only get better nutritional intake, but also feel safer against supply disruptions such as those that occurred during the COVID-19 pandemic.

When compared to previous studies, the results of this study strengthen the argument that vertical farming is not only about space efficiency, but also about the socio-economic resilience of households. A study by Benke & Tomkins (2017) emphasizes that technology-based agriculture tends to produce more consistent and pesticide-residue-free products. This is proven in this study, where most respondents stated that the quality of vegetables from vertical gardens is better than market products. In addition, this study also goes beyond previous studies by adding social dimensions such as family involvement, micro-entrepreneurship potential, and environmental awareness that arise from urban farming practices.

The adoption of technology in vertical agriculture also has a broad impact on the aspect of community empowerment. The results of observations and interviews show that this system is able to create a learning space for families, especially children, who are beginning to be introduced to the food production process directly. The active involvement of family members in the farming process provides important educational value, especially in forming a culture of healthy and sustainable consumption. This is something that has not been studied much in previous research and is a new contribution (novelty) of this research in the social context.

From an economic perspective, the savings in vegetable shopping costs of 25-40% as experienced by most respondents are a real impact that can be felt directly. Some have even started selling their crops to the surrounding neighborhood or digital communities, opening microeconomic opportunities that didn't exist before. This proves that automated vertical farming has the potential to be an additional source of income, while also strengthening social networks in urban environments. When associated with the concept of the circular economy, this system also supports sustainable management of household waste, such as the use of organic waste into compost.

However, the success of the implementation of this system cannot be separated from the challenges that must be overcome. Limited initial costs for the purchase of automation devices and lack of technological literacy are two of the main factors inhibiting the adoption of this system more widely. The government and related agencies need to play an active role in providing training programs, subsidizing automated agricultural equipment, and creating a support ecosystem involving the private sector such as agritech startups. These findings are in line with FAO's recommendations (2021) which emphasize the importance of integrating agricultural technology policies in sustainable urban development plans.

If strategic measures such as public training, ease of access to tools, and community building are carried out systematically, then automated vertical farming systems can become an integral part of future urban food security policies. The potential impact is not only on households, but also on the city. Cities that can produce some of their own food will be more resilient to global food crises, food price inflation, and logistics disruptions. Therefore, this approach is very relevant within the framework of the Sustainable Development Goals (SDGs), especially goal 2 (Zero Hunger), goal 11 (Sustainable Cities and Communities), and goal 12 (Responsible Consumption and Production).

In comparison to the novelty listed in the background, this study presents a more applicable and measurable approach, as it presents empirical data on the direct contribution of technology to household food security. Most of the previous literature is still limited to theoretical discourse or focuses on the technical aspects of vertical agriculture without quantitatively measuring its impact on the lives of urban communities. Thus, this research not only broadens the academic perspective on urban farming but also provides a solid foundation for data-driven policy formulation that drives the transformation of urban food systems.

To conclude the discussion, it is important to emphasize that the success of automation-based vertical farming systems lies in the synergy between technology, education, and community participation. Without collective awareness and infrastructure support, it will be difficult for this system to grow organically. However, the results of this study prove that when these three elements run in balance, this system is not only an alternative, but also the main solution in answering the challenges of future food security in the midst of the climate crisis, limited space, and socio-economic dynamics of urban communities.

CONCLUSION

This study found that automation-based vertical farming systems significantly enhance household food security in urban areas like DKI Jakarta by improving management efficiency, increasing crop yields, and reducing food costs through technologies such as automatic irrigation, humidity sensors, and IoT-based lighting. Beyond improving food availability and accessibility, these systems also promote supply stability, family participation in productive activities, and greater awareness of sustainable living. With adequate support through training, subsidies, and community empowerment, adoption of this technology can effectively address food security challenges amid urbanization and climate change. The research also revealed strong urban community motivation to engage in food production when the systems align with practical, efficient, and modern lifestyle needs. Consequently, it is recommended that automation-based vertical farming systems be integrated into urban food security policies and expanded through collaborations among government, private sectors, and urban farming communities. Future research should explore long-term socioeconomic impacts of these systems and investigate scalability across different urban contexts to optimize policy and implementation strategies.

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