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FASOLA (farming solution application): Integrating IoT innovation in vertical farming to support food security and economic sustainability

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ABSTRACT
Background: Food security is a crucial aspect in human survival. The increasing population poses a major challenge for Indonesia to meet food demand and achieve self-sufficiency. To support the economy and sustainable agriculture, it is necessary to increase food productivity through a land-efficient system. Renewable technologies are needed to help farmers optimize the use of limited land for efficient, sustainable, and adaptable agricultural activities in various regions, especially in urban areas. **Methods:** The Fasola application was developed using a prototype design methodology that includes four main stages: user needs analysis, visual design (wireframe and mockup), IoT technology development and integration, and user test-based evaluation and revision. This approach aims to create innovative and user-friendly solutions to support productivity and sustainability of IoT-based vertical farming. **Findings:** Fasola is an IoT-based application that supports vertical farming in urban areas to improve the efficiency and sustainability of food production. Its features allow farmers to monitor the planting environment, manage irrigation and energy, and market their crops digitally. The application increases productivity, reduces operational cost, and strengthens local food security. With the support of education and community approaches, Fasola contributes to environmentally friendly agriculture and the transition to a green economy. **Conclusion:** Fasola (Farming Solution Application) is an appropriate technological innovation in the digital era that supports food security and a sustainable economy. Its features help optimize the use of resources, reduce agricultural waste, and increase production efficiency, allowing farmers to manage the entire farming process in one integrated platform. **Novelty/Originality of this article:** This study introduce an IoT based application innovation that provides practical support for modern agriculture on limited land. This application integrates hydroponic farming and vertical farming through advanced features, offering a sustainable system that can contribute to food security.

KEYWORDS: food security; internet of things; vertical farming.

1. Introduction

Food security constitutes a fundamental pillar for human survival and societal stability. The continuous increase in population presents a critical challenge to Indonesia's ability to ensure adequate food supply. Escalating consumption demands and national aspirations for self-sufficiency necessitate enhanced agricultural productivity. According to Susetya (2024), the reduction of green land essential for food production has become a pressing issue. Between 2005 and 2020, an average of approximately 96,512 hectares of green land disappeared annually due to land-use conversion, predominantly in urban areas where

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agricultural zones have been replaced by industrial and residential developments. The rapid decline in arable land availability signals a growing threat to national food security and agricultural sustainability (Mulyani et al., 2016). Intensified land conversion further exacerbates this problem, compelling Indonesia to urgently seek innovative, land-efficient solutions capable of maximizing agricultural output while supporting sustainable economic development.

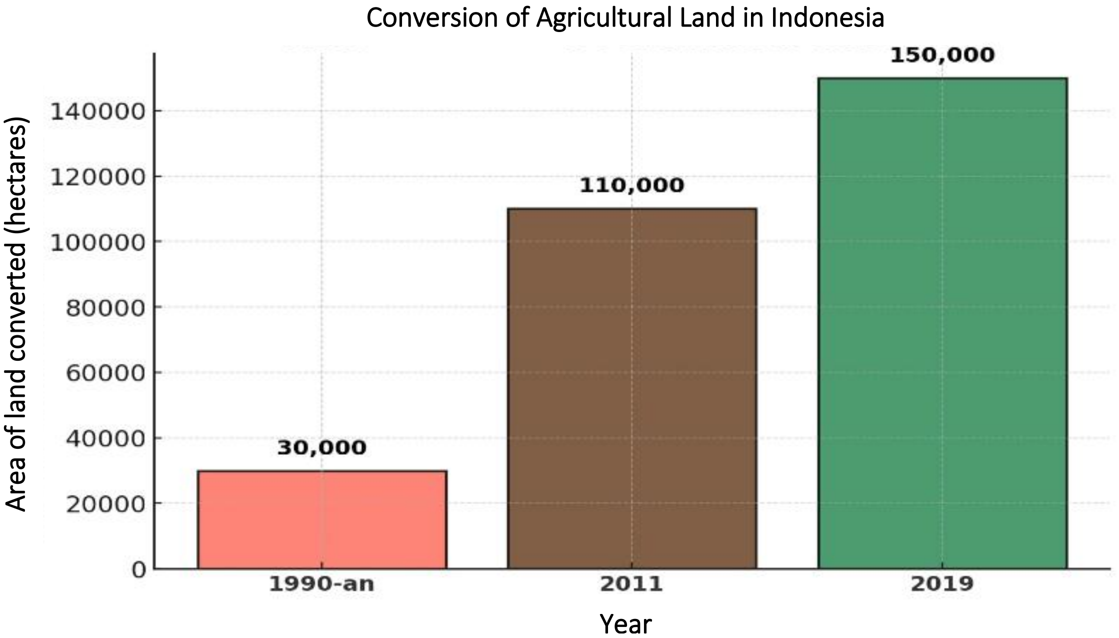


Fig 1. The increasing rate of agricultural land conversion (Kompas, 2019)

The transition from conventional agricultural practices to vertical farming presents an innovative solution to the challenge of diminishing green space in urban environments. This transformation requires intelligent approaches capable of integrating modern technology into urban agricultural systems in a manner that is both practical and economically accessible (Masliani et al., 2024). Fasola (Farming Solution Application) represents a breakthrough in digital innovation designed to support vertical farming operations by enhancing efficiency and oversight, particularly for farmers operating in urban settings. The application addresses core agricultural challenges by offering a suite of intelligent features that contribute to food security and promote long-term economic sustainability. Fasola serves as a digital enabler for modern farming systems, aligning technological advancement with the principles of accessible, resilient, and high-efficiency agriculture.

The implementation of the Fasola (Farming Solution Application) is expected to provide a new avenue for realizing national food security while simultaneously promoting sustainable economic growth. Key features embedded within the Fasola platform include a Monitoring System, Irrigation System, Energy System, Lighting System, Waste System, Nutrition Analysis, Agri-Market, Warning System, Guide Education, and Farmer Communication. These integrated tools are designed to streamline agricultural management and optimize resource use within urban farming environments. Through the adoption of Internet of Things (IoT) technology, Fasola contributes to the modernization of agricultural systems by enabling real-time control and automation. This innovation represents a tangible step toward achieving national food self-sufficiency and fostering the expansion of the digital economy within the agribusiness sector.

In the era of increasingly rapid and revolutionary digital transformation, technological innovation has become the main key and irreplaceable foundation in overcoming the various complex challenges faced by the global agricultural sector, especially in order to increase sustainable productivity, optimal operational efficiency, and holistic environmental sustainability. This challenge is becoming increasingly urgent as the world's population growth is projected to continue to increase, while available agricultural land is increasingly limited due to massive urbanization and unpredictable climate change (Waluyo et al., 2021). This condition demands a new paradigm in the agricultural approach that not only focuses on increasing production quantity, but also on the quality of results, efficient use of resources, and minimal environmental impact. According to Harahap et al., (2024), digital transformation in the agricultural sector, known as Agriculture 4.0 or Smart Farming, offers a comprehensive solution through the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), machine learning, big data analytics, and automation systems that are able to optimize every aspect of the agricultural production process. The development of this technology not only allows for more precise monitoring and control, but also provides predictive and adaptive capabilities that are responsive to changes in environmental conditions and crop needs in real time.

One of the important and revolutionary innovations currently being developed by our team consisting of Georgia, Nadine, and Ilham is the Fasola (Farming Solution Application) application, an Internet of Things (IoT)-based platform that is specifically and comprehensively designed to support the implementation of vertical farming systems in densely populated urban areas. The concept of the Fasola application was born from a deep understanding that vertical farming is a strategic solution to overcome the limitations of agricultural land in urban areas, where this system allows crop production in a tiered structure that can be maximized vertically rather than horizontally. This system aims to maximize the use of limited land through intelligent automatic management and integrated real-time monitoring, so as to significantly increase agricultural yields while ensuring the quality and safety of harvests that meet international standards. The vision of the Fasola application is to create a fully automated, efficient, and sustainable agricultural ecosystem, where every aspect of the agricultural process can be monitored, analyzed, and optimized through IoT technology integrated with artificial intelligence algorithms (Ullah et al., 2023). The platform is designed with a user-centric approach that takes into account the practical needs of modern farmers, from beginners to experienced farmers, with an intuitive interface that still provides full control over all important parameters in the vertical farming system.

The Fasola application developed by our team not only functions as a conventional monitoring and control tool, but also as an innovative and comprehensive solution that combines various advanced technologies to support national food security and provide positive and sustainable contributions to sustainable economic and community development. In a broader context, this application acts as a bridge between modern technology and traditional agricultural practices, enabling a smooth transition from conventional farming systems to more efficient and productive technology-based farming systems. The strategic role of the Fasola application covers several important dimensions: first, as a technology enabler that allows farmers to adopt the vertical farming system without requiring in-depth technical expertise; second, as an optimizer that automatically analyzes and optimizes plant growth conditions based on real-time data and historical patterns; third, as a decision support system that provides data-based recommendations for better decision making in agricultural management; and fourth, as a collaborative platform that enables sharing of knowledge and best practices between farmers in the vertical farming community. Moreover, this application also plays a role in supporting the national food security program by providing agricultural solutions that can be implemented in various geographical and climatological conditions, especially in urban areas which have so far been less than optimal in local food production.

Through the development of complete and sophisticated features that have been carefully designed by the Georgia, Nadine, and Ilham teams, the Fasola application integrates various advanced technology systems such as a precise temperature and humidity monitoring system with high accuracy, light intensity monitoring that can be adjusted to the specific needs of each type of plant, an efficient automatic irrigation system with drip irrigation technology and nutrient film technique (NFT), as well as environmentally friendly and sustainable energy and waste management (Ngoma et al., 2025). The temperature and humidity monitoring system is equipped with IoT sensors that are capable of continuously measuring at configurable time intervals as needed, while the collected data will be analyzed using machine learning algorithms to identify patterns and trends that can affect plant growth. The light intensity monitoring feature not only measures the quantity of light but also the quality of light, including the optimal light spectrum for various phases of plant growth, from the vegetative phase to the generative phase, with the ability to automatically adjust LED grow lights based on the specific needs of the plant and external environmental conditions. The automatic irrigation system integrated into the Fasola application is able to regulate the provision of water and nutrients precisely by considering factors such as crop type, growth phase, weather conditions, and soil moisture levels, so as to optimize the use of water and nutrients while minimizing waste and runoff that can pollute the environment.

The Fasola application developed by our team is expected to provide a significant transformative impact in helping farmers, especially in urban and semi-urban areas, to run vertical farming efficiently, resource-efficiently, and environmentally friendly, while maintaining high productivity and superior crop quality. The application's contribution to sustainable agriculture includes several fundamental aspects: reduced water use compared to conventional farming through integrated recirculating hydroponic and aeroponic systems, reduced pesticide and herbicide use to almost zero percent due to the controlled and sterile environment, increased productivity per unit area compared to traditional horizontal farming, and reduced carbon footprint by eliminating the need for long-distance transportation from the farm to urban consumers. In addition, the implementation of the Fasola application also contributes to the creation of new jobs in the agritech sector, the development of skills and knowledge in the field of modern agricultural technology, and the empowerment of the local economy through more independent and sustainable food production. This article is compiled as a comprehensive effort to introduce and deeply examine the innovative potential of the Fasola application as a concrete and applicable future solution in realizing sustainable, resilient, and adaptive national food security to the development of the times, as well as a real contribution from the Georgia, Nadine, and Ilham teams in encouraging the digital transformation of the Indonesian agricultural sector towards a more advanced and sustainable Agriculture era.

2. Methods

The Fasola (Farming Solution Application) application development method is carried out through a prototype design methodology approach consisting of four main stages that are interrelated and integrated in creating comprehensive and innovative agricultural technology solutions. The first stage is an in-depth analysis phase that involves systematically collecting and analyzing user needs and thoroughly identifying the complex challenges faced in implementing a modern urban vertical farming system, including evaluating relevant technologies, assessing the required infrastructure, and determining the crucial features that need to be included so that the application can provide optimal support for farmers' needs in running their farming operations (Chua et al., 2023). This analysis process not only includes literature research and case studies of similar existing applications, but also involves extensive field surveys, in-depth interviews with key stakeholders including experienced urban farmers, agricultural experts, and vertical farming practitioners, as well as direct observation at various vertical farming locations to understand the daily operational workflow and pain points faced by users. In addition, this analysis stage also includes an evaluation of the latest IoT technology that can be integrated into the system, such as soil moisture sensors, temperature and humidity sensors, pH sensors, nutrient sensors, monitoring cameras, valve control systems, and various other hardware needed to create a fully automated and data-driven agricultural ecosystem. The second stage is the creation of a prototype design which is a creative and technical process that involves creating detailed wireframes and mockups of intuitive user interface displays using professional design tools such as Figma for interactive prototyping and Canva for attractive graphic design elements, resulting in a comprehensive visual depiction of the application that not only includes the layout of key features but also reflects the optimal user experience journey, including easy-to-understand navigation, logical information architecture, and an application logo that reflects a strong brand identity in the field of agricultural technology.

The third stage is the most complex and challenging development process, which includes intensive coding using leading programming technology and systematic integration of IoT technology into the application system so that various key features such as the Monitoring System that can track real-time plant and environmental conditions, Irrigation System that can regulate automatic watering based on sensor data and machine learning algorithms, Energy System that can optimize electricity usage and support integration with renewable energy sources, Lighting System that can control the LED light spectrum according to the plant growth phase, Waste System that can manage organic waste into high-quality compost, and various other features can function comprehensively and interact smoothly according to the initial prototype design that has been made. This development stage also includes the implementation of a scalable and robust system architecture, development that can connect various IoT components, creation of a database that can handle large volumes of sensor data, implementation of artificial intelligence algorithms for predictive analytics and automated decision making, and development of a responsive user interface that can be accessed through various device platforms. During this development stage, comprehensive and continuous internal testing is carried out to ensure that all features run as expected and can be operated in real time under various operational conditions, including unit testing for each code component, integration testing to ensure communication between systems runs well, performance testing to optimize application speed and responsiveness, and security testing to ensure data security and overall system integrity (Erlangga et al., 2025). This development process also involves continuous integration and continuous deployment practices to ensure code quality and accelerate the development cycle, as well as the implementation of monitoring tools that can provide real-time insights into system performance and user behavior patterns (Zharandont, 2015).

The final stage is the evaluation and revision phase which is very critical in ensuring the quality and effectiveness of the Fasola application, which involves extensive user testing with real users in a real environment to obtain valuable and actionable feedback on the reliability of the system under various operational conditions, ease of use from a user experience perspective, the effectiveness of the features in solving existing agricultural problems, and the overall level of user satisfaction with the solution offered. This evaluation process not only involves beta testing with experienced urban farmers and vertical farming practitioners, but also includes usability testing with A/B testing methodology to optimize the interface design, load testing to ensure the system can handle high user volumes, accessibility testing to ensure the application can be used by users with various levels of ability, and compliance evaluating to confirm that the application complies with relevant regulatory and security requirements. Based on the feedback and data obtained from this comprehensive evaluation process, a series of improvements and optimizations were then carried out including bug fixing, performance tuning, user interface refinement, feature enhancement, security strengthening, and scalability improvement to perfect the application design, ensure data security and user privacy are maintained with the implementation of robust encryption protocols and access control, and optimize application performance through code optimization and infrastructure scaling before being widely implemented to farmers and other target users in various geographic locations. The entire prototype design methodology approach is designed with the main objective of creating a technological solution that is not only innovative and cutting-edge but also user-friendly, accessible, and practical that can significantly increase agricultural productivity, support the sustainability of IoT-based vertical farming systems, reduce waste and inefficiency in agricultural operations, and contribute to food security and environmental sustainability in the context of growing urbanization and increasingly complex climate change challenges (William & Nugroho, 2025).

3. Result and Discussion

Digital transformation has significantly reshaped various sectors, including agriculture. The integration of information and communication technologies is emerging as a strategic response to global challenges such as food insecurity and land scarcity. Technological innovation plays a critical role in enhancing the efficiency, productivity, and sustainability of modern farming systems. The adoption of Internet of Things (IoT) and vertical farming offers promising solutions to address resource limitations and rapid urbanization. This study provides a comprehensive analysis of digitalization impacts, the role of IoT, and the innovation of the Fasola application in promoting sustainable agriculture and food security.

3.1 Impact of digitalization

Digitalization refers to the transformation of processes, activities, and information from conventional systems to digital technologies. The advancement of the digital era has brought significant impacts to the agricultural sector in Indonesia, presenting both opportunities and challenges. It enables farmers to utilize smartphones and related technologies to access applications that support agricultural and economic sustainability (Savira et al., 2020). The integration of digital tools such as IoT-based sensors, drone technology, and artificial intelligence has become a new potential to enhance agricultural productivity under various conditions. The emergence of digital platforms, including agricultural e-commerce, allows farmers to market their products directly to consumers, providing them with full profit margins and offering buyers more affordable prices by eliminating intermediaries.

Rapid technological advancement has also resulted in negative consequences, such as the reduction of green land due to infrastructure development, particularly in urban areas as a result of urbanization (Merdekawan & Sari, 2022). This trend threatens the availability of arable land, which could undermine future food security. Excessive digitalization can lead to overreliance on high-end technologies that are not always accessible to smallholder farmers, thus exacerbating inequality. The implementation of automation systems may also reduce the demand for manual labor, potentially increasing unemployment in the agricultural sector. While conventional farming methods are often insufficient to meet the growing food demand, unbalanced digital transformation without inclusive policies may widen the gap between technologically advanced large-scale farms and smallholders who struggle to adapt.

3.2 The role of IoT and vertical farming

Achieving consistent crop yields remains a significant challenge for farmers in conventional agriculture. The development of digital technologies has positioned the Internet of Things (IoT) as an innovative solution to address agricultural challenges by enhancing efficiency, productivity, and sustainability. IoT implementation in sustainable agriculture requires integrated tools, sensors, and modules connected through internet networks (Hakim et al., 2022). Vertical farming productivity can be significantly improved through IoT-based smart monitoring and automation systems. Smart vertical farming minimizes crop failure risks and increases farmers' income by enabling food production in urban areas through hydroponic systems and artificial lighting technologies. One of the key advantages of vertical farming lies in its superior efficiency in water and energy use compared to traditional farming methods. This approach also reduces dependence on large tracts of arable land and supports continuous, year-round food production regardless of seasonal changes.

3.3 Technological innovation in fasola application

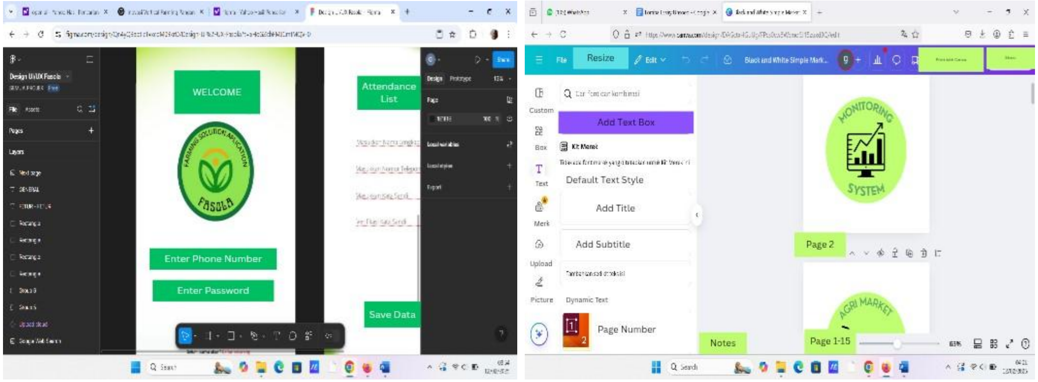
The integration of technology into vertical farming methods presents significant potential for achieving national food self-sufficiency. Digitalization in the agricultural sector has been recognized as a catalyst for technological breakthroughs that optimize agricultural income and economic outcomes (Udova, 2017). Appropriate technological innovation fosters digital transformation in agriculture, supporting both national self-sufficiency and sustainable economic development. The Fasola (Farming Solution Application) was developed to optimize urban vertical farming systems by leveraging the Internet of Things (IoT) to enhance agricultural efficiency. This application aims to increase farming productivity while ensuring that harvest quality remains optimal and healthy. A full-featured system was specifically designed to support farmers in overcoming challenges associated with implementing vertical farming techniques. Key features of the Fasola application include.

Monitoring system: ensures optimal environmental conditions for plant growth by monitoring temperature, humidity, CO_2 levels, and light intensity within the vertical farming area. Irrigation system: regulates water distribution efficiently based on the specific needs of each plant, minimizing water waste and maintaining proper hydration. Energy system: monitors and optimizes energy usage, including lighting and water systems, to reduce operational costs and improve overall energy efficiency. Lighting system: controls the intensity and duration of artificial lighting according to plant requirements, supporting effective photosynthesis and growth, particularly in indoor farming environments. Waste system: promotes sustainability by recycling agricultural waste such as plant residues and used water, contributing to environmental conservation.

Nutrition analysis: manages the accurate delivery of nutrients to each plant, ensuring optimal growth and improving overall crop quality. Agri-market: provides a platform for farmers to market their produce directly to consumers and purchase agricultural inputs without intermediaries. Warning system: delivers alerts in the event of equipment malfunction, declining water quality, or pest detection, thereby reducing the risk of crop failure and financial loss. Guide education: supports novice farmers by offering guidance on plant care, system management tutorials, and troubleshooting resources for common farming challenges. Farmer communication: facilitates peer-to-peer communication among farmers, enabling knowledge sharing and collaborative problem-solving within the vertical farming community.

Technological applications must undergo a structured development process to ensure functional effectiveness and user accessibility. Design prototyping plays a crucial role in translating conceptual ideas into tangible, testable models. Fasola's development began with a detailed assessment of user needs, agricultural challenges, and appropriate digital technologies. A user-centered approach was adopted to create an interface that is both intuitive and aligned with the operational realities of urban farming. The following section outlines the sequential stages in the development of the Fasola application prototype.

Analyze stigma: the initial development of the Fasola (Farming Solution Application) was based on an analysis of user requirements, urban agriculture challenges, and the technological components suitable for integration into the platform. Agriculture remains a key pillar of the national economy; however, population growth and the reduction of arable land have become driving factors behind the creation of Fasola. The application was designed to be intuitive, functional, and accessible to users with varying levels of technological literacy. Essential tools used in the prototyping process included. Figma: utilized to design and structure the UI/UX of the Android-based application interface. Canva: employed to create the application's logo and iconography for its core features. Prototype design creation: the initial stage focused on developing wireframes and mockups that represented the interface layout and feature structure of the Fasola application. The visual framework included schematic representations of each functional component within the app (Fig. 2).



(a) (b)

Fig 2. (a) Creating prototype design; (b) Designing feature logo

Prototype evaluation: evaluation of the early design emphasized the need for visual refinement, including graphical elements and ornamental enhancements to improve user appeal and interface aesthetics. Prototype implementation and development: the refined prototype was further developed into a functional application, integrating actual code and IoT (Internet of Things) technology. The system was engineered to perform reliably in accordance with the design specifications. Access to the Fasola application is structured as follows: users are required to register by providing their name, phone number, and a secure password. Once verified, users gain access to all application features, including the Monitoring System, Irrigation System, Energy System, Lighting System, Waste System, Nutrition Analysis, Agri-Market, Warning System, Guide Education, and Farmer Communication.

3.4 Impact of fasola to many aspects

Fasola (Farming Solution Application) is an IoT-based agricultural solution designed with advanced features to support the management of vertical farming systems. The application offers a combination of strengths and limitations, though its overall functionality remains highly attractive to users. Fasola enables real-time monitoring and control, allowing farmers to manage vertical farming operations with improved precision and responsiveness. The integration of sensors, such as Electrical Conductivity (EC) meters and pH meters, enhances the performance of the application's monitoring and automation systems. Automated irrigation and nutrient analysis features aim to minimize water waste and optimize labor efficiency during crop cultivation.

The inclusion of waste recycling and energy-saving systems distinguishes Fasola from other agricultural applications, offering operational cost reduction alongside environmental benefits. A user-friendly interface was intentionally developed to facilitate communication among farmers across different regions. The platform also supports interaction with consumers, enabling farmers to sell their harvests more efficiently through direct digital channels. The use of the Fasola application, which is built on smart technology, has demonstrated a significant positive impact on farmers. Several key benefits have been identified as follows:

3.4.1 Enhancing farmer productivity

Environmental monitoring systems embedded in the Fasola application allow farmers to consistently regulate critical growth parameters, including humidity, temperature, and nutrient levels. Real-time data acquisition supports timely interventions, reducing the risk of stress or suboptimal conditions for crops (Song et al., 2023). Farmers gain the ability to control growing environments with greater precision, resulting in healthier plants and more reliable yields. The application's automation reduces the necessity for constant manual oversight. These enhancements directly contribute to improved productivity with reduced physical labor.

Increased agricultural productivity does not require the expansion of land, which is critical given the shrinking availability of farmland in urban and peri-urban regions. Vertical farming systems supported by Fasola promote intensive crop production within compact, controlled spaces. This allows for year-round harvesting without being affected by seasonal changes or climate variability. Consistency in crop output ensures food availability, thereby strengthening the resilience of local food systems. Farmers benefit not only from quantity but also from improved crop quality and uniformity.

The application encourages data-driven farming, which shifts traditional practices toward more precise and optimized methods (Eze et al., 2025). Predictive analytics derived from environmental trends assist farmers in forecasting yield potential and adjusting inputs accordingly. Better decision-making leads to resource optimization and minimal waste generation. Productivity is therefore not only measured in output volume but also in the efficiency of operations. This transition supports long-term agricultural viability and professionalization of farming practices.

3.4.2 Reducing resource use and operational costs

Fasola significantly improves resource efficiency by optimizing irrigation and fertilization through IoT-based automation. Water and fertilizer are distributed in controlled amounts tailored to the needs of each crop, minimizing both excess use and resource scarcity. Smart irrigation systems reduce energy consumption and contribute to sustainability by avoiding overwatering. The platform promotes ecological farming practices without sacrificing yield. These improvements help conserve critical agricultural inputs while maintaining high production standards (Pratama & Mandela, 2024).

The built-in Energy System manages and monitors the energy consumption of lighting and other electrical components in the vertical farming setup. Farmers can maintain stable power usage, which is especially important in energy-intensive indoor systems. Load balancing and real-time monitoring allow for timely interventions that reduce energy waste. Cost reductions are achieved through efficient usage, translating into higher profit margins for farmers. Financial savings are especially impactful for small-scale operations operating under budget constraints (Abdelkader et al., 2023).

Operational efficiency leads to more sustainable farming enterprises. With lower input requirements and optimized energy consumption, the cost of running a vertical farming unit is considerably decreased. These savings enhance the financial viability of urban farming and encourage broader adoption. Farmers can reinvest saved capital into business development or system upgrades. Fasola thus supports both economic sustainability and technological advancement in agriculture (Shahab et al., 2024).

3.4.3 Expanding market access

Fasola connects vertical farming practitioners to wider markets by providing direct access to buyers through its integrated Agri-Market feature. Farmers can showcase their products, set prices, and negotiate sales independently without relying on intermediaries. This disintermediation ensures higher income for producers and better pricing transparency for consumers (Chikuni & Kilima, 2019). Transactions are conducted securely through a trusted digital platform that builds confidence among users. The marketplace interface supports a streamlined supply chain tailored to small and medium-scale farmers.

The application also facilitates communication between producers and consumers, allowing for responsive customer service and product customization. Buyers can provide feedback directly to farmers, helping them align production with consumer preferences. Community forums and chat features encourage collaboration and exchange of insights among farmer users. Sharing knowledge enhances innovation and encourages collaborative problem-solving. These social features strengthen networks and foster an inclusive digital farming ecosystem.

Access to broader markets encourages farmers to improve product quality and scale up operations. Vertical farmers can differentiate themselves through niche products such as organic or specialty crops. Fasola helps reduce geographic barriers, enabling urban farmers to reach regional or even national markets. Greater exposure improves competitiveness and encourages entrepreneurial growth in the agricultural sector. This transformation from isolated production to market-oriented farming increases resilience and economic empowerment.

3.4.4 Strengthening sustainability and food security

Vertical farming systems supported by Fasola promote environmentally sustainable practices by reducing dependency on harmful agrochemicals and inefficient resource use. Nutrient delivery is carefully calibrated, and water recycling is implemented to limit waste. These systems significantly reduce the ecological footprint of food production compared to conventional farming. Controlled environments allow for hydroponic cultivation, eliminating the need for soil and reducing contamination risks. Sustainable farming is no longer a concept but an achievable standard enabled by smart technologies (Verma et al., 2024).

Fasola encourages the adoption of hydroponic techniques that produce high-quality crops without synthetic pesticides or fertilizers. The reduction in chemical use ensures that produce is safer for consumption and better for the environment. Nutritional value and shelf life of crops are improved under consistent growing conditions. Health-conscious consumers increasingly prefer food that is clean, fresh, and responsibly grown. Fasola responds to this demand while supporting public health and ecological integrity (Kharel et al., 2023).

Contributing to national food security, Fasola enables continuous production throughout the year, independent of seasonal and climatic constraints. Urban food systems become more self-reliant and less vulnerable to supply disruptions. Communities benefit from locally grown food that reduces transportation costs and carbon emissions. Strategic use of vertical farming in densely populated areas can significantly mitigate food shortages. Fasola aligns technological innovation with the global agenda for sustainable food systems and resilient agriculture (Chowdhury et al., 2023).

3.5 Comparative efficiency: Conventional farming vs fasola-integrated vertical farming

The integration of digital technologies into urban farming systems not only enhances productivity but also transforms resource efficiency. Table 1 provides a comparative analysis between conventional agriculture and Fasola-supported vertical farming systems, reflecting the significant gains in land, water, and operational efficiency.

Table 1. Comparative analysis of agricultural efficiency

Indicator	Conventional Agriculture	Vertical Farming with Fasola
Land Requirement	1000 m^2per ton of produce	100 m^2 per ton of produce
Daily Water Usage	300 liters	30–50 liters (up to 80% reduction)
Harvest Cycles per Year	3–5 cycles	10–12 cycles
Pesticide Use	High	Minimal (due to controlled environment)
Operational Cost	High (manual labor, agrochemicals)	Lower (automation and IoT optimization)
Climate Resilience	Low	High (indoor controlled systems)
Monitoring and Control	Manual	Real-time IoT-based automation
Agricultural Waste Generation	High	Low (via recycling systems)

Market Accessibility	Limited (via middlemen)	Direct-to-consumer via app integration

(Pamungkas, 2023)

These results highlight the significant enhancements in performance enabled by Fasola. The app enhances input-output ratios while enabling farmers to increase their yield with minimal environmental impact. In this scenario, Fasola serves as a scalable model for digital agriculture that can aid in achieving food security objectives while promoting economic inclusivity and ecological sustainability.

3.6 Implementation challenges and strategic measures

The execution of Fasola faces numerous significant obstacles, even with its potential advantages. The primary issue is the low level of digital literacy found among smallholder farmers, especially those who lack knowledge of smart farming technologies. This digital divide limits the efficient use of the application's features. Extensive educational programs like capacity-building workshops, hands-on training sessions, and ongoing mentoring initiatives are essential to facilitate user adoption.

The unequal spread of digital infrastructure, particularly in rural and peri-urban zones, hinders the operation of Internet of Things (IoT)-based systems that depend significantly on reliable internet access. To address this, it is essential to form public-private partnerships that guarantee fair and inclusive access to communication networks in agricultural areas. Financial limitations also create an obstacle, as not every farmer has the necessary startup capital for vertical farming systems that incorporate smart technology. Consequently, scalable financing approaches—like government grants, corporate social responsibility (CSR) initiatives, and cooperative microfinance are crucial for facilitating the extensive adoption of Fasola across various farming communities.

In addition, cultural resistance and traditional farming mindsets pose intangible yet critical barriers to Fasola's widespread adoption. Many farmers, particularly in older generations, exhibit reluctance to shift from long-standing manual practices to automated and technology-driven systems. Such resistance frequently stems from distrust in digital tools, anxiety over potential technological failures, and worries about diminished autonomy in making decisions. Overcoming this challenge requires not only technical interventions but also a human-centered approach that respects local knowledge while gradually introducing innovation. Integrating community leaders, farmer cooperatives, and agricultural extension agents as facilitators of change can foster trust, promote participatory learning, and accelerate behavioral shifts towards digital agricultural transformation.

Sustaining long-term engagement with the Fasola system requires continuous technical support and iterative platform development tailored to user feedback. A dynamic feedback mechanism should be established within the application to capture user challenges, preferences, and system performance. Direct input from farmers ensures that subsequent updates address real-world usability concerns and adapt to diverse agricultural contexts. Inclusion of multilingual interfaces and locally relevant content can further enhance accessibility and cultural compatibility. A responsive and adaptive system design increases user retention, strengthens trust, and promotes deeper integration of digital technologies in everyday farming routines.

3.7 Fasola's contribution to a green economy transition

The Fasola application aligns with the broader agenda of green economic development by optimizing resource utilization and promoting environmentally responsible practices. Through efficient water management, integrated waste recycling systems, and energy monitoring features, Fasola contributes to the reduction of agricultural carbon emissions and mitigates environmental degradation. Urban-based vertical farming systems supported by Fasola enable localized food production, which reduces the dependency on long-distance transportation and thereby lowers the agricultural sector's carbon footprint. Furthermore, the hydroponic methods adopted reduce chemical usage, resulting in safer food outputs and minimal soil contamination. These characteristics position Fasola as a catalyst for digital-green synergy within agribusiness, facilitating a more sustainable and resilient food system.

Fasola promotes circular economy principles by enabling the reutilization of agricultural by-products and minimizing resource wastage. The integrated waste management system allows farmers to recycle excess nutrients and organic residues, contributing to closed-loop production cycles. This approach enhances environmental efficiency while reducing input costs, resulting in improved farm profitability. Precision agriculture practices are supported through real-time data analytics, enabling targeted interventions that conserve resources. Innovations embedded in Fasola strengthen the shift toward regenerative agriculture focused on long-term ecosystem health.

Fasola embeds sustainability education directly within its interface to cultivate environmental awareness among farmers. Features such as Guide Education provide tutorials and best practices related to a green farming, energy conservation, and input efficiency. Knowledge shared through these modules encourages adoption of low-impact agricultural methods aligned with climate-resilient goals. Users are empowered to make informed decisions that integrate productivity with ecological responsibility. The application functions not only as a technological tool but also as a catalyst for embedding sustainability within the ethos of modern agriculture.

4. Conclusion

Fasola (Farming Solution Application) represents a significant technological innovation in the agricultural sector, particularly in addressing the challenges of food security, limited land, and environmental sustainability in urban areas. By integrating IoT-based features such as smart monitoring, automated irrigation, energy optimization, and waste recycling systems, Fasola enables farmers to manage vertical farming operations more efficiently and precisely. The application's user-friendly interface, education support, and integrated agri-market platform empower farmers to enhance productivity, reduce operational costs, expand market access, and adopt eco-friendly farming practices. These innovations collectively strengthen the local food system and contribute to the broader goal of a green, inclusive economy .

Despite its many advantages, the implementation of Fasola also faces several barriers, including low digital literacy among smallholder farmers, limited internet infrastructure in rural areas, and cultural resistance to digital technologies. To overcome these obstacles, the application must be supported by inclusive strategies such as education and training programs, infrastructure expansion, financial support mechanism, and community-based approaches. Continuous platform development and responsiveness to user feedback will ensure that Fasola remains relevant and adaptive across diverse agricultural contexts. Ultimately, Fasola has the potential to become scalable model for smart, sustainable agriculture that not only improves livelihoods but also drives ecological transformation.

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