Adapting to smart farming: communication media and local knowledge in overcoming technical challenges

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Abstract. Smart farming has great potential for improving agricultural productivity and addressing global food security. However, the adoption of these technologies remains a challenge, particularly for smallholder farmers in developing countries. This study investigates the technical challenges faced by farmers in West Java, Indonesia, in adopting smart farming and explores how communication media and local knowledge facilitate adaptation. Using a qualitative approach, data were collected through in-depth interviews and field observations of seven participants, including farmers who had used smart farming for horticultural crop management, agricultural extension workers, and representatives of smart farming technology vendor companies in Subang Regency, West Bandung Regency, Bogor City, and Sumedang Regency. The study findings revealed that limited infrastructure, extreme climate variation, limited land availability, uneven nutrient distribution, suboptimal sensor performance, component damage, complex tool calibration, and limited technical support are the major technical barriers. Farmers overcome this challenge using communication media to exchange experiences, access information for technical advice, and utilize local knowledge by combining traditional skills with modern technology. This study concludes that communication media and local knowledge are essential drivers of smart-farming adaptation. Stronger technical support, digital literacy programs, and farmer-centered agricultural technology design are crucial to enhance adoption. These findings highlight the need for targeted policies to improve infrastructure, expand training programs, and ensure that smart farming technologies are accessible and practical for smallholder farmers.

1 Introduction

The second goal of the United Nations Sustainable Development Goals (SDGs) is to alleviate hunger by ensuring that future generations have adequate food supplies, which is largely

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contingent on the implementation of sustainable agricultural systems. Studies have shown that the best approaches to achieving sustainability involve employing smart and precision agriculture techniques to address issues related to soil fertility and environmental efficiency [1]. The use of a combination of technologies, including sensors, drones, weather satellites, intelligent software algorithms, and robots, generates data that can be integrated and interpreted in an agricultural context to provide enhanced information to farmers [2]. The development of smart machines and sensors in agriculture has rendered the process data-oriented. The data analytics used in smart farming can help monitor productivity and make more accurate predictions to prevent crop failure [3]. Smart farming offers numerous advantages, including the ability to gather crop data in real-time, accurately assess soil and crops, and allow farmers to monitor conditions remotely. It also involves tracking water and other natural resources, which leads to enhanced livestock and agricultural yields. Conséquent, smart farming is seen as an evolution of precision agriculture, utilizing modern and intelligent techniques to collect information on various farming activities, which are then managed remotely and supported by appropriate real-time farm maintenance solutions. The key accomplishments of smart farming in promoting sustainable agriculture include crop rotation, managing nutrient deficiencies in crops, controlling pests and diseases, recycling, and water collection, all of which contribute to a safer environment [4].

Farmers face several challenges in implementing smart farming, such as high initial cost of technology, lack of expertise and knowledge regarding technology, connectivity and access in rural areas, farm size, and government support [5]. Smart farming technology is still in its infancy, and many barriers must be overcome before it can be widely adopted, such as connectivity and data management issues, high costs, and a lack of knowledge among farmers [6]**.** Barriers to adopting digital farming include farmers' economic constraints and a lack of infrastructure and technological knowledge**.** Adoption factors are related to the perceived benefits of technology, willingness to innovate, and risk-taking [7].

Agriculture continues to be the primary economic sector in Indonesia, with farming and its associated activities serving as the most crucial sources of income and employment for the nation. The advancement of modern agriculture is a key strategy for ensuring national food security, as detailed in the National Medium-Term Development Plan for 2020-2024, which was announced by the Ministry of Agriculture. According to one of the National Long-Term Development Plans for 2024-2045, enhancing sustainable agricultural productivity can be enhanced through the adoption of smart farming technology, sensor technology, weather modification, and other innovations in the agriculture, forestry, plantation, and fisheries sectors.

Digitalization is regarded as the fourth agricultural revolution, characterized by the presence of diverse digital technologies and data applications. The adoption of innovative agricultural technologies has been a key policy focus in developing nations. Despite the clear advantages of numerous new agricultural technologies such as machinery and management practices, farmers often either refrain from adopting them or take considerable time to begin the adoption process and enhance their skills. Although smart farming has the potential to boost productivity, its application is constrained by the technical challenges faced by smallholder farmers.

Technical challenges arise in the technological realm and require specific technical knowledge and skill. These challenges can be distinguished from adaptive ones, which involve profound changes in values, beliefs, and assumptions [8]. The lower adoption rates of smart farming technologies can be attributed to inadequate information, missing knowledge, lack of awareness of the technology, and a lack of perceived practical value [10]. A high level of communication between farmers and digital technology providers is critical for driving the adoption of digital technologies in production. Farmers with better communication levels are more likely to adopt digital technologies in production and optimize their use than those with low communication levels. The role of communication in facilitating the adoption of digital technologies in soybean production and promoting sustainable agricultural development is critical [11]. Acknowledging these barriers, it is essential to understand how farmers adapt smart-farming technologies to address their requirements. This study was conducted in the Western Java region. West Java is an important agricultural area. Observational findings revealed several patterns of smart-farming implementation by farmers in West Java. The results of the IPB and FAO surveys in 2023 indicate that West Java is a province demonstrating progressive implementation of digital agricultural innovations. However, the level of digital maturity in rural areas varies from the pilot stage to the commercial stage. This study aims to investigate the technical challenges faced by farmers in West Java in adopting smart farming technologies and to explore the role of communication media and local knowledge in overcoming these challenges. By examining these dynamics, this study contributes to the expanding discourse on sustainable smart-farming adoption in developing countries.

2 Methods

This study uses a qualitative approach to explore farmers' experiences in implementing smart farming technology in West Java, including the Subang Regency, West Bandung Regency, Bogor City, and Sumedang Regency, from January to July 2024. These farmers have used data-based technologies, such as sensors to monitor soil and environmental conditions, automatic irrigation, and software for data analysis to improve agricultural efficiency, productivity, and sustainability. This system allows farmers to make accurate and efficient decisions to manage their agricultural resources. Farmers obtain smart farming tools from various sources, including self-financing, grants from the government or institutions, and semi-independence in the form of self-financing.

This qualitative approach allows an in-depth analysis of programs, events, activities, processes, or individuals. Primary and secondary data were used in this study. Data were collected through in-depth interviews and field observations to understand the technical challenges, role of communication media, and the integration of local knowledge. This study adopted a case study approach in its research design to explore phenomena, formulate hypotheses, and test the validity of the method. Using this design, this study explored the interactions between technology acceptance, communication media, and local knowledge. Thematic analysis was applied by coding the interview transcripts to identify key themes and to reveal patterns that enrich the understanding of farmers' adaptation strategies. Participants included seven informants, including farmers who had used smart farming for horticultural crop management and agricultural extension workers, and representatives of smart farming technology vendor companies who were selected using the snowball sampling method.

3 Results and discussion

3.1 Technical challenges in smart farming implementation

3.1.1 Limited infrastructure

Smart farming is a significant innovation in the agricultural sector that offers increased efficiency and productivity using modern technologies. However, smart farming often faces obstacles, particularly in West Java. Infrastructure is a major challenge for the implementation of smart farming in rural areas. Agricultural land located far from electricity and water sources makes it difficult to use modern technologies such as automatic irrigation systems or sensors. Limited access to electricity hampers the operation of electrically powered equipment, whereas a lack of adequate water sources hampers the implementation of smart farming techniques. Many farmlands do not have direct access to rivers or other sources of water. This requires farmers to build additional infrastructure, such as irrigation channels, which require significant investment. As stated by one of the farmers :

> *"... the main problems implement smart farming are water, electricity, and internet. Regarding the internet, people don't even want to install electricity, let alone the internet"* (N, Farmer, 55 years old).

Internet connectivity in rural areas of West Java remains uneven. Internet of Things (IoT)-based technologies that require real-time Internet connections are difficult to implement in these areas. For example, sensors that monitor soil moisture or air temperature cannot send data directly to the monitoring platform if the internet connectivity is poor. This results in delays in farmers' decision making. Meanwhile, there are still farmers who buy Internet quotas with limited cellular data. If the Internet quota runs out, the system stops being used.

Consequently, the efficacy of smart farming technologies is undermined, constraining their capacity to enhance agricultural processes. Farmers who depend on real-time data to adjust their irrigation schedules, monitor plant health, or detect pest infestations may encounter disruptions that diminish the precision and timeliness of their interventions. Over time, these connectivity issues may engender frustration and reluctance among farmers to fully embrace IoT-based solutions as the perceived advantages are overshadowed by practical challenges.

Furthermore, dependence on cellular data for Internet access imposes an additional financial burden, particularly for small-scale farmers with limited income. The recurring expense of purchasing data quotas may prove unsustainable, compelling some farmers to prioritize other essential expenditures over the maintenance of their smart farming systems. This digital divide further exacerbates disparities in technology adoption, where only farmers with superior financial resources or access to stable Internet infrastructure can fully exploit advanced agricultural technologies.

Strategic interventions are necessary to address these challenges, such as expanding rural broadband coverage, developing low-bandwidth alternatives for smart farming applications, and providing subsidies or incentives for internet access. Community-based solutions, such as shared internet hubs or operative models for data access, could also enable farmers to collectively benefit from IoT technologies without bearing the full cost individually. Resolving these connectivity issues is crucial for ensuring the effective implementation of smart farming across rural areas in West Java, ultimately enhancing agricultural productivity and sustainability.

Security risks are a serious concern in the implementation of smart farming. The remote location of the land and distance from farmer settlements increase vulnerability to theft of high-tech agricultural equipment. Sensors, surveillance cameras, cables, or automatic control devices installed in open areas can be targets for thieves. This not only harms farmers financially but also disrupts the continuity of the application of smart farming technologies. Consequently, farmers may be reluctant to invest in advanced technologies, which slows the adoption of modern farming practices in rural areas. In some cases, farmers must spend extra money on extra security measures, such as putting up fences or hiring guards, installing CCTV, or even storing equipment at home. The impact of these constraints on the effectiveness of smart farming implementation in West Java is significant. Farmers are unable to utilize this technology optimally; therefore, agricultural productivity does not increase as expected.

Furthermore, the security threats linked to smart farming impact not only individual farmers but also have wider consequences for the entire agricultural industry. Frequent incidents of theft or vandalism can deter stakeholders such as technology providers and policymakers by investing in the growth and advancement of smart farming projects. This lack of trust might result in slower innovation, decreased research funding, and a reluctance to expand technological solutions. Moreover, the requirement for additional security measures imposes financial strain on farmers, especially those operating on a small scale and with limited resources. Instead of channeling funds into enhancing farming methods or increasing production capacity, they are compelled to allocate part of their budget to protect their equipment. This situation creates an imbalance where only well-funded farmers or large agricultural businesses can fully adopt and maintain smart farming technologies, leaving smaller farmers at a disadvantage. In West Java, where agriculture is vital to local economies, these issues impede the anticipated benefits of smart farming. Hesitation to invest in technology due to security concerns slows the shift to modern agricultural practices, hindering farmers from optimizing efficiency, reducing reliance on labor, and boosting yields. To address these challenges, collaboration among farmers, local governments, and technology providers is crucial. Implementing community-based security measures, subsidizing protective infrastructure, and developing theft-resistant technology could help alleviate these issues and foster a more favorable environment for the adoption of smart farming. It is imperative to highlight that [12] explored numerous barriers to the adoption of smart farming with a significant emphasis on security issues. The research also delves into technological hurdles, such as system compatibility and technical complexity, in addition to broader external challenges, such as the lack of institutional support and inadequate infrastructure, which further complicate the implementation process.

3.1.2 Extreme climate variations

Extreme climate variations are a major challenge for farmers. Unpredictable weather changes, such as those occurring during El Niño events, require farmers to adapt quickly. Farmers must consider the environmental conditions when determining appropriate irrigation practices. This uncertainty adds complexity to farm management because, without a clear understanding of the climate, farmers may not be able to take effective action. As one farmer put it:

> *"...The climate conditions are all different, we can't take data from outside and bring it here. There's nothing like Lembang, even if we have sensors, what is the actualization like, so it's difficult"* (D, farmer, 46 years old).

This statement highlights the limitations inherent in utilizing standardized climate data or predictive models developed for other regions, as microclimatic variations significantly impact agricultural outcomes. Despite the availability of sensors and advanced monitoring tools, their practical application remains questionable if the collected data fails to accurately reflect the specific environmental conditions in Lembang. Factors such as altitude, humidity levels, wind patterns, and local weather anomalies are crucial for agricultural decision-making. Consequently, farmers must rely on their experiential knowledge and real-time local observations rather than solely depending on generalized climate models or external recommendations. This insight emphasizes the necessity of context-specific technological solutions in smart farming. Instead of importing external datasets, there is an increasing demand for localized research, adaptive sensor calibration, and site-specific modeling to ensure that smart-farming technologies provide meaningful and actionable insights for farmers. Training programs that integrate traditional farming knowledge with modern technological tools could enhance farmers' trust and willingness to adopt data-driven approaches tailored to their unique agricultural environments.

One of the chili pepper farmers who has traveled abroad revealed that the environmental conditions in Indonesia are very different from those in countries such as the Netherlands or Korea; therefore, cultivation methods cannot always be applied here. He explained that in countries such as the Netherlands, temperature and humidity are regulated by drawing air from the outside into the greenhouse, while in Indonesia, hot temperatures often cause carbon dioxide ($CO2$) levels to decrease. Carbon dioxide ($CO2$) is an important component of plant photosynthesis. He also shared his experiences when discussing with Koreans who developed smart farming in Bogor, where the temperature inside the greenhouse reached 46°C, a condition that is considered extreme. However, chili pepper plants are still able to survive because the $CO2$ levels do not decrease drastically, allowing them to continue to process nutrients properly. According to him, sunlight in Indonesia is a distinct advantage that supports the formation of fruits on chili pepper plants. As he stated:

> "… In other countries, at low altitudes like this, they can engineer the temperature to reach optimal levels without a drop in CO_2, which benefits the plants. There, when the temperature reaches 27°C, plants experience stress. Meanwhile, in our greenhouse in Indonesia, temperatures can reach 46°C—quite extreme, right? But the plants remain unaffected because CO_2 levels don't drop significantly. This allows them to process nutrients efficiently. Plus, the sunlight here is excellent, which contributes to good fruit quality" (D, farmer, 46 years old).

There is a critical need for the development of smart farming technologies that are specifically tailored to Indonesia's unique climatic and ecological conditions, rather than merely replicating those from other countries. Ultimately, this analysis reinforces the notion that successful smart farming in Indonesia requires an integrative approach that combines technological advancements with a comprehensive understanding of local environmental factors. The experiential knowledge of farmers, such as the insights shared by chili pepper farmers, should be incorporated into smart farming strategies to ensure their effectiveness and practicality in real-world agricultural settings. Extreme climate fluctuations threaten agricultural productivity, especially for smallholders in developing countries who are vulnerable to extreme weather events. This affects agricultural production, farmers' livelihoods, local economies, and the food system. Increasing farmers' awareness and knowledge of climate change-related agricultural practices are also critical for effective adaptation [13]. Access to accurate weather forecasts, early warning systems, and climate-smart technologies is essential to support decision-making and risk reduction.

3.1.3 Limited land availability

In Indonesia, the rice field area continues to decline each year, leading to a significant reduction in rice production. This conversion of agricultural land is typically driven by long-term development projects including housing, factories, toll roads, and other public facilities. Consequently, the availability of farmland for rice cultivation is decreasing, which can impact food production and agricultural sustainability. The amount of land available for specific use is a significant issue in smart farming. Many farmers must work on limited land, which requires them to be more innovative in increasing their productivity. According to farmers, renting land can help increase the area of planting and productivity by using a smart farming system. This land limitation forces them to find alternative solutions and adapt to the existing conditions. The use of limited land affected the harvesting and efficiency of the system. It is believed that productivity can increase over larger areas of land. As stated by farmers:

> *"Previously I rented land, the land was still conventional. When the land was taken by the owner, what else could I do? Fortunately, I haven't installed a drip stick system there, if I put it in, the loss will be even greater. Before, the one that was already running had to make a well, which cost 80 million rupiah. And it was only the second year that the land was taken, so what else could I do? I couldn't do anything about it. Using an automated system is much more profitable than a manual one, especially for larger areas. The savings are significant. I have calculated that the cost for a larger scale, such as 2,000 square meters, is much more efficient with an automated system. When the land is taken back, I must think of other solutions" (F, farmer, 37 years old).*

Limited land availability is a significant problem for agricultural development. In densely populated regions, such as Java, many farmers are forced to cultivate crops on restricted land, especially where agricultural land is continuously decreasing due to urban expansion and industrial development. This poses challenges for adopting advanced technologies and optimizing production. Uncertainty in land tenure represents a significant impediment to the adoption of smart-farming practices within the agricultural sector. From an economic and risk management standpoint, this uncertainty deters investment, as technologies such as automatic irrigation are asset-specific and entail high risk without long-term access. Farmers lacking land security are generally reluctant to engage in investments with substantial sunk costs, necessitating mitigation strategies, such as the adoption of flexible technologies or the establishment of more stable land rental agreements. Socially, restricted access to land exacerbates inequality in the adoption of innovation between landowners and tenant farmers. Consequently, policy interventions, including the legal protection of land leases and support for more adaptive technologies, are essential for promoting agricultural sustainability and enhancing farmers' welfare.

3.1.4 Uneven nutrient distribution

The combination of appropriate irrigation and fertilization methods can optimize plant growth and resource-use efficiency [14]. However, in smart farming practices by farmers at the research location, this optimization has not been achieved because of the uneven distribution of nutrients in the fertigation system. Automatic irrigation and fertilization systems often fail to distribute nutrients evenly owing to their sloping contours. One respondent revealed that the AB mix output is not always consistent. The amount released should be the same, for example one liter, but there is often a difference in the amount of AB mix produced. Consequently, the rows of plants above that are closer to the water tank are larger and healthier than those further down the slope. Looking at the sloping contour conditions, the farmer indicated that the system design factors might be the main cause of blockage. The condition of the land slope was never analyzed by the vendor as a risk factor for uneven nutrient flow before installing smart farming devices on the farmers' land. One consequence is the disruption of the balance of nutrients received by plants, which affects growth and crop yields. In addition, this results in wastage or shortage of materials, so resource utilization is less than optimal. As a short-term solution, farmers are addressing the problem of nutrient distribution in irrigation systems by redesigning the pipe network and dividing it into zones based on the activation schedule of the system. As a long-term solution, farmers are planning to create terraces on the land to reduce the slope so that the flow of nutrients can be more evenly distributed throughout the crop area, with future implementation depending on the capital availability.

According to another farmer, the use of drip irrigation equipment initially went smoothly, particularly during the first season. However, over time, problems began to arise, especially those related to blockages in drip-stick components. According to the farmer, the blockage is caused by cracking in the nutrients used, which tends to settle in the emitter due to excessive heat exposure, as revealed:

> *" As for the challenges, since it is a tool, problems are inevitable. For example, during the first season, everything goes smoothly with no issues. However, after the first season, the biggest problem is blockage in the drip sticks due to the nutrients. At first, the nutrients seemed to be 100% fine, but over time, especially in hot weather, they cause the emitters to crack as well" (F, farmer, 37 years old.)*

Another farmer explained that uneven nutrient application causes variation in plant growth. The farmers explained that each part of the land had different characteristics, so nutrient needs also varied. The influence of weather factors, such as sudden rain, further exacerbates this problem by reducing fertilizer use. The lack of accurate data as a reference for farmers regarding crop needs is an additional obstacle, particularly for West Java. Without proper information, farmers have difficulty in determining the appropriate fertilizer dosage.

Other farmers face similar challenges, where the nutrients in their plants are not evenly distributed even though the land is flat. Plants closest to the source of the nutrient reservoir grow larger than those farther from the water source. The emitter water pressure is stronger in the front row close to the water source but becomes smaller in the back row, which causes uneven plant growth. Higher water pressure in the front row causes more water and nutrient flow to be received by the plants in the front. Meanwhile, plants farther from the flow source received less water owing to the reduced pressure along the drip pipe. Farmers found that there was a system that was not installed properly and that the emitter used did not match the length of the channel or the size of the pipe. Instead, they redesigned the irrigation channel piping system based on the activation time.

One farmer experienced similar problems even though he had implemented smart farming technology and found that the drip irrigation system he used did not flow nutrients smoothly because there was sediment at the end of the drip pipe, even though his land had a flat contour. Consequently, the plants lacked nutrients and could not be harvested. The farmer realized that he had been relying so much on machines and automation that he had never checked for sediment blocking the path of nutrients. Farmers teach farming through social media and other people because of their educational backgrounds and work in the health sector. From this failed experience, the farmer concluded that, although technology offers convenience, relying too much on machines without regular checks can be risky. These farmers recognize the importance of human roles in agriculture, where technology needs to be complemented by active supervision and maintenance. This experience confirms that technology cannot completely replace farmers' experience and intuition in managing field problems and shows the need for more adaptive irrigation systems and ongoing training support for farmers to ensure optimal technology functions and support better agricultural outcomes. After identifying the obstacles, farmers regularly flushed the drip lines to reduce blockages. The sediment clogging of emitters is a common problem in drip irrigation. The solution implemented by farmers is regular flushing of drip lines.

3.1.5 Suboptimal sensor performance

Sensors can provide many benefits to agricultural management; however, their performance is affected by various technical, environmental, and economic factors. Constraints related to the performance of sensors in smart-farming systems, which are not yet optimal, include several technical and operational aspects. One of the main problems is inadequate measurement accuracy, where sensors often produce inaccurate data related to important parameters such as soil moisture, temperature, or nutrient levels, which can potentially lead to inappropriate decision-making in agricultural management. One farmer was pessimistic when the soil sensor read different results when plugged into different polybags. Even at different depths, the results were different.

In addition, sensors tend to be unable to adapt to heterogeneous field conditions, such as variations in soil types or local climate change; therefore, the resulting readings are not always representative. Other factors that affect sensor performance include physical damage due to external factors such as extreme weather, dust, or wear, which can reduce the accuracy and reliability of the sensor or cause accidents. As with one informant, the sensor condition was disconnected because it was tripped by a visitor when the farmer opened the land to the public during the mass harvest.

Connectivity issues are also a significant barrier, with signal disruptions or network instability hampering real-time data transmissions. In addition, sensors are limited in terms of power and lifespan, and most use batteries that drain quickly and require regular replacement to maintain their performance. The high cost of installing and maintaining sensors is also a barrier, especially for small-scale farmers who have difficulty accessing technology. The inability of sensors to effectively integrate with other systems adds complexity to data management, which can lead to inconsistencies between different systems.

Most systems in the research location are not fully equipped with sensors that can automatically measure soil moisture and nutrient requirements. This shows that monitoring soil and plant conditions relies on manual observations, which can reduce the efficiency and effectiveness of agricultural management. Furthermore, the installed sensors have not been fully integrated into an automated system that provides commands based on obtained data. This lack of integration has the potential to result in delays in the response to changes in environmental conditions, thereby disrupting the sustainability of plant growth.

In addition, the accuracy of the sensors used is a concern. Current sensors are not completely reliable and require manual verification to ensure that the nutrient data obtained are accurate. This reliance on manual verification can increase the workload and reduce the speed of decision making required in farm management. Finally, there are problems with the recommendations provided by the IoT system. Occasionally, these recommendations do not match the actual needs of the crop, which can lead to ineffective management of nutrients and moisture.

Farmers face significant challenges related to inaccurate and incomplete data from the sensors used in smart farming. Sensors are used only to collect and store data and not to make decisions. This hampers their ability to make informed decisions, which in turn reduces the effectiveness of implemented agricultural technologies. According to farmers, reference data that include relevant and reliable information, such as soil conditions, climate, and specific crop needs, are essential for informed decision-making. Without this data, farmers have difficulty planning agricultural activities, such as determining planting times and fertilizer use, which impacts efficiency and yields. Accurate reference data also plays an important role in optimizing the application of modern agricultural technologies. One informant emphasized that even though sophisticated sensor devices are available, without adequate reference data support, the technology will not function optimally, as he explained:

> *" ... Even though the sensor is as complete, as sophisticated as anything, once it does not have data or reference data, it still cannot be run. For example, here was El Nino recently, we have temperature, humidity, wind speed sensors. When I asked about this condition, what should I do for my practice ? What should I do with the watering?What should it be like, the amount, the volume, everything. No one can answer*" (D, farmer, 46 years old).

Although advanced sensor devices are available, their efficacy in smart farming is contingent on the availability of adequate reference data. Sensors employed for monitoring soil moisture, temperature, and nutrient levels require baseline data to accurately interpret readings. In the absence of proper reference data, the technology may yield inaccurate measurements, potentially leading to erroneous decision-making by farmers. For example, soil moisture sensors require historical data to ascertain the optimal water content of a specific crop in each region. Without such data, the sensor might misinterpret normal variations as problematic, resulting in either unnecessary irrigation or an insufficient water supply. Similarly, climate sensors require localized weather data to provide meaningful insights as environmental conditions differ across regions. Consequently, although sensor technology has the potential to enhance precision farming, its full potential can only be realized if supported by comprehensive and localized reference data. Without this, technology may not function optimally, thereby limiting its utility in enhancing agricultural productivity.

3.1.6 Component damage and complex tool calibration

Smart farming offers huge benefits, but the complexity of setting up and managing these high-tech tools can be time consuming and challenging. This is especially true for systems that handle large amounts of data, or in areas where technical expertise is scarce, as was the case at the research site. Machines and devices used in smart farming can sometimes break down and stop working properly. When this occurs, it can disrupt agricultural work. One farmer panicked when the Central Processor Unit (CPU) kept beeping and the pipes kept flowing water, even though all devices had been turned off. After consulting with the vendor, the sensor dysfunction and electrical problems were observed. It took a long time for the farmer to wait for the technician to arrive, which resulted in nutrient waste because the water continued to flow, as stated by the farmer.

> *"...My IoT device keeps making noises, even though I'm not using anything. The CPU is the one making the noise—it's the greenhouse's brain. No wonder it's wasting nutrients. When I asked the vendor, they said there was an electrical problem and a sensor malfunction, and that a technician would be brought in" (M, farmer, 42 years old).*

The high-tech tools used in smart farming must be carefully calibrated to work properly. Calibration is an important step to ensure that the tool functions according to the desired specifications. However, this process often involves several complicated steps and can be daunting for new users. They may not have sufficient knowledge to perform calibration properly, which can lead to errors in nutrient and water settings. This error not only impacts the efficiency of resource use but also affects the overall health of the plant. According to a technology practitioner who guided farmers in using smart farming, he said:

> *"… Actually, smart farming doesn't have to be controlled via a cellphone. The important thing is having the right measurements. Why ? For example, take a pH meter—it usually becomes inaccurate after about a year. The device has never been calibrated, and secondly, there is no calibration process in place. So, if we check the pH here, it might read 7, while in another spot, it could be 4. Calibration is usually done once every two weeks. There is a solution—the calibration powder costs only 5,000 Rupiah and contains four packets. One packet can be mixed with one liter of water and lasts for six months. It's actually not expensive. The issue is simply understanding how to use the instrument, which is something only agricultural professionals typically know…"* (A, technology consultant, 44 years old).

Although smart farming practices are being increasingly implemented, the uncertainty of the system and difficulties in land maintenance are major challenges to its adoption. Farming systems are highly susceptible to disruptions owing to equipment breakdowns, which can result in reduced crop yields. Equipment reliability is crucial because component failures and complex tool calibrations can destabilize production. Therefore, farmers not only need to understand the technology they use but also have skills in equipment care and maintenance. If not managed properly, this can hinder an increase in agricultural productivity. Unfortunately, many farmers do not realize the importance of this aspect, even though maintenance does not always require a large amount of money economically.

3.1.7 Limited technical support

Technical support plays a crucial role in helping farmers overcome challenges, improve yield, and adapt to changing environments and technologies. Technical support includes guidance from agricultural experts, training programs to improve farmers' skills and knowledge, access to information resources, and collaboration between farmers and agricultural organizations. Overall, technical support improves agricultural efficiency and productivity. However, farmers have been hampered by a lack of timely and adequate technical support. Farmers often face difficulties in troubleshooting and maintaining smart-farming equipment, which hinders their long-term adoption. A lack of access to expert assistance and local resources can hinder the adoption of new technologies and more efficient farming practices. One farmer experienced the challenge of inadequate communication with vendors, resulting in a lack of follow-up and solutions to the problems faced. Farmers find it difficult to obtain appropriate technical guidance to respond to the challenges they face. Farmers found it difficult to reach the vendors. The following quote illustrates this:

> *"…But the vendor said he likes to go out of town, everywhere. I also haven't contacted him for a long time. But in the past, sometimes they would be there, they would often come. Now I don't know because I haven't been in contact for a long time…"* (I, farmer, 46 years old).

A similar incident happened to a farmer *whose* equipment was struck by lightning but was slow to be handled by the government that provided the *equipment* as a grant, so he repaired his equipment himself, as he explained:

> *"…When the device was hit by lightning, I checked it myself, called the service to replace it, but the response was slow. So, I fixed it myself,*

> *some could be done, some components had to be replaced…"* (N, farmer, 55 years old)

This incident highlights the complex challenges faced by farmers who rely on the agricultural equipment provided by the government. Unexpected lightning strikes that damage critical machinery highlight the potential for significant disruptions to farming operations and livelihoods. The farmers' initial responses, including thorough inspections and prompt reporting to relevant government agencies, demonstrate a methodical approach to crisis management. However, a delayed bureaucratic response indicates potential weaknesses in the government support system in the agricultural sector. Farmers' self-improvement initiatives often demonstrate that a level of independence and innovation is required to address agricultural challenges. This situation highlights several key aspects of modern agriculture: reliance on advanced technologies and equipment that increase productivity but also create new vulnerabilities; the critical role of government support in facilitating farm operations; the importance of efficient response systems; the value of farmer-level resilience and innovation in the face of unexpected challenges; and the need for a balance between institutional support and farmer autonomy.

3.2 Communication media as a gateway

Communication media are one of the entry points for farmers to learn about smart farming, especially for those who do not have a formal agricultural background. One informant did not have a formal agricultural background and worked as lecturer. Her initial interest in agriculture was because she saw social media and interacted with other people as she really wanted to be an agricultural entrepreneur:

> *"... I used to watched agriculture technology on YouTube, I also had the chance to see a farmer's here that already uses smart farming. I went there and looked around again, walking with my children every day, I'm actually interested in systems like that, it seems easy, there aren't many employees because one of the problems here is that employees are hard to find…" (I, 47).*

Initially, the farmers had positive perceptions and were enthusiastic about this system. According to farmers, the system would be easy to operate and efficient in the use of labor based on videos seen on social media. Farmers were also able to identify local problems in the form of difficulties in getting employees and saw smart farming as a potential solution. Farmers have reflected on the initiative to adopt modern technology in their agricultural practices. Farmers believe that the system would be easy to operate and labor-efficient, as demonstrated by the videos they observed on social media platforms.

Social media platforms, such as Facebook and YouTube, have become essential tools for farmers to share market information, exchange farming techniques, and engage in socioeconomic interactions. Beyond serving as a knowledge hub, these platforms function as digital diaries where farmers document daily activities, showcase farming practices, and communicate their perspectives to both agricultural and non-agricultural audiences. Their ability to disseminate information in real time allows farmers to stay updated on market trends, weather forecasts, and policies affecting agriculture, thus enabling informed decision-making and risk reduction. Additionally, social media fosters community building by facilitating interactions with experts, peer discussions, and collaborative problem solving, ultimately increasing trust and encouraging knowledge sharing. Social media play a critical role in modernizing and sustaining agricultural practices by reducing uncertainty and promoting the adoption of smart farming technologies.

However, farmers face several technical obstacles when implementing smart farming. Initially, they were still technically guided by vendors, either by visiting or telephone, but when the contract was finished, the vendors became difficult to contact. As a solution, farmers seek information and guidance from various sources. One of them is utilizing social media and platforms, such as YouTube, to learn about modern agricultural techniques and solutions that are appropriate to land conditions. In addition, farmers consulted agricultural extension workers, who provided insight into better agricultural practices. Farmers also discussed with other farmers in their communities via WhatsApp, shared their experiences, and received moral support. Through these steps, farmers attempt to improve their understanding and skills in land management, although technical challenges remain. Communication Media also play an important role in connecting farmers with experts and fellow farmers. Technical challenges usually require informational learning; that is, addressing the challenge of information involving the acquisition of new knowledge or skills. This learning directly affects the behavior and abilities of actors [8]. Discussions about experiences and best practices help to build a better understanding and more effective solutions.

Communication media have played a pivotal role in the development of digital agriculture, facilitating the exchange of information among farmers, researchers, and technology developers. By enabling real-time data sharing and collaboration, communication technologies enhance decision-making processes, improve resource management, and foster innovation in agricultural practices. Consequently, farmers can now access critical insights and tools that will enable them to optimize crop yields, minimize waste, and respond more effectively to changing environmental conditions. This interconnectedness empowers individual farmers and contributes to the overall sustainability and efficiency of the agricultural sector.

Knowledge and information are key elements that drive the adoption of agricultural technology, as discussed in various studies. Communication plays an increasingly significant role in facilitating the adoption of smart-farming technology. The dissemination of agricultural information relies on two main channels, namely, traditional mass media and modern technology, which contribute to conveying knowledge and innovation to farmers. Multidisciplinary analysis structures the role of communication in the adoption of digital technologies in agriculture. The distribution of information from various institutions through different communication channels, including mass media, social media, and interpersonal meetings, has helped many farmers adopt digital technologies involving IoT.

3.3 Contribution of local knowledge

Farmers face various challenges that require them to adapt their methodologies to the local environmental and climatic conditions. These decision-making processes are influenced by diverse and dynamic factors that often go beyond the technological solutions. Familiarity with the local resources and support institutions is crucial. This knowledge empowers farmers to access necessary assistance and increase their preparedness to address potential obstacles. The integration of local knowledge plays a critical role in adapting smart-farming technologies to the specific conditions of West Java. Farmers combine traditional methods and contextual expertise with contemporary tools to design innovative approaches. Through independent experimentation, farmers can identify techniques that best suit their local condition. For example, when automatic irrigation fails, farmers ensure an even distribution of water and nutrients by reusing 220 ml mineral water containers as manual watering meters. This improvised method is valuable owing to its high precision and accessibility. Such practices are spread through informal word-of-mouth networks, with information being passed from one farmer to another. The appeal of this approach lies in its simplicity and efficiency, as the containers are readily available and pre-calibrated to provide the correct amount of water for plant hydration, as the farmers explained:

> *"When my drip irrigation is clogged and the harvest fails, I don't use it anymore while waiting for the technician to repair, I water my tomatoes using a glass of mineral water, manually, each plant is watered with a glass, the measure is right, and the plants are growing well, I know from my employees"* (I, farmer, 44 years old).

The utilization of manual watering techniques using mineral water containers has been recognized as a temporary measure for farmers. However, when applied extensively to numerous plants, this approach requires substantial energy and time. As a result, farmers are seeking alternative solutions to overcome technical obstacles by engineering simplified irrigation systems tailored to landscape topography. In areas characterized by sloping terrain, irrigation infrastructure is adapted based on local geographical expertise. Given the labor-intensive nature of these systems, farmers have devised a valve-regulated method by restructuring the irrigation pipeline network in parallel configurations and implementing strategic watering regimens. This innovative solution emerged from collaborative discussions, shared experiences, and iterative experimentation, enabling farmers to identify pragmatic strategies to address the complexities associated with irrigation system management.

Most smart farming technologies are imported, including greenhouse equipment. One farmer received a grant for a greenhouse that adhered to international standards, which included a layer that functioned as a curtain on the greenhouse roof, thereby obstructing light from reaching the plants. According to farmers in foreign countries, optimal temperatures can be achieved naturally, even when external temperatures reach 50 °C with low humidity. However, in Indonesia, such conditions are difficult to achieve. The installation of automated systems such as actuators or sensors is often ineffective because optimal temperatures rarely occur. For instance, the installation of automatic curtains that should be closed when certain light intensities are reached does not function as intended because these intensities are not achieved. Consequently, plants enclosed by curtains grow smaller than those that receive sufficient sunlight. The solution adopted by farmers involves the addition of lights that are illuminated throughout the night to force continuous plant production. According to the farmer, this solution was derived from logical reasoning and experimentation, and indeed, the experiments conducted resulted in greater plant growth, as farmers explained:

> *".... For example, abroad, the optimum temperature must be reached. Let's say the outside temperature is 50 degrees. In our country, when is the temperature outside 50 degrees ? With low humidity, for example, even if the actuator is installed, it never acts. For example, I installed the curtain above, it should be automated, oh it turns out that with this much heat it closes itself. In fact, it doesn't mean it's overheated, it's underheated. Why did you install it? Because it never reaches the optimum temperature. I added lights, finally that was eliminated, finally the lights are turned on every night, already. I don't know scientifically, what time he stays up at night. The important thing is to put the lights on. They're forced to produce day and night"* (D, farmer, 46 years old).

Although farmers actively seek information from digital resources to remain informed about contemporary farming methodologies and technological advancements, this information may not always correspond to the environmental, cultural, or socioeconomic conditions of their agricultural enterprises. Nevertheless, when farmers possess a robust foundation of localized knowledge and information acquired through practical experience or knowledge from others, they are better equipped to evaluate and adapt these technologies to their unique requirements. This synthesis of global insights and localized understanding enables agricultural professionals to make informed decisions and facilitate the successful integration of technological innovations into their agricultural practices.

In instances where technology demonstrates unreliability or unsuitability for specific requirements, farmers tend to revert to traditional manual methods, relying predominantly on their intuition and extensive practical experience. This dependence on established practices reflects not only their adaptability, but also the limitations of technology in addressing localized challenges such as unpredictable weather patterns, varying soil conditions, and limited access to technical support. Despite these obstacles, the uncertainty surrounding technological development has paradoxically become an adaptive strategy for many farmers. By integrating traditional knowledge with cautious experimentation using new tools, they can navigate various constraints and identify innovative approaches to maintain productivity while minimizing risks. This adaptive approach underscores the importance of developing technologies that are both reliable and tailored to Indonesian farmers' unique needs.

Successful innovation in agriculture requires an inclusive, flexible, collaborative approach. The active participation of farmers as long-term partners is essential so that the resulting technology can be adapted to local needs and contexts. Flexibility in local adaptation is also a key factor, particularly given the diversity in geographical and socioeconomic conditions. In addition, farmers' tacit knowledge, which is intuitive and informal, plays an important role in practical management decision making. This knowledge provided both qualitative and quantitative benefits. For small-scale farmers, especially in resource-constrained environments, non-technological adaptation is often considered more feasible because it relies more on experience than on financial resources or formal education [14, 15].

4 Conclusions and suggestions

4.1 Conclusion

The findings revealed that limited infrastructure, extreme climate variation, restricted land availability, uneven nutrient distribution, suboptimal sensor performance, component failure, complex equipment calibration, and limited technical support constituted the primary technical challenges. This study highlights the significant role of communication media and local knowledge in facilitating farmers' adoption of smart farming technologies in West Java. Despite substantial technical challenges, farmers have exhibited resilience and ingenuity in surmounting them. Both digital and interpersonal communication media provide mechanisms for information acquisition, knowledge dissemination, and problem resolution, whereas local knowledge ensures contextual relevance for smart-farming solutions.

4.2 Suggestions

Farmers encounter diverse technical challenges in the implementation of smart farming technology, with solutions often being adaptive and predicated on the prevailing conditions and experiential knowledge. Despite persistent reservations, technological advancements have considerable potential for enhancing agricultural efficiency and productivity. However, to facilitate widespread adoption, technologies must be engineered to accommodate local conditions and address agricultural practitioners' specific requirements. Farming communities can serve as invaluable resources for disseminating experience and knowledge. The establishment of networks among agricultural practitioners can facilitate mutual support and learning, thereby accelerating the adaptation to novel technologies.

References

1. M. Lampridi, V. Marinoudi, L. Benos, S. Pearson, D.D. Bochtis, P.M. Pardalos, Towards sustainable agriculture: challenges from the transition to the New Digital Era. Oper Res. **185**, (2022). https://doi.org/10.1007/978-3-030-84156-0_1
2. S. van der Burg, M.J. Bogaardt, S. Wolfert, Ethics of smart farming: Current questions and directions for responsible innovation towards the future. NJAS - Wageningen J Life Sci. **90–91**, 100289 (2019). https://doi.org/10.1016/J.NJAS.2019.01.001
3. S. Wolfert, L. Ge, C. Verdouw, M.J. Bogaardt, Big data in smart farming – A review. Agric Syst. **153**, 69–80 (2017). https://doi.org/10.1016/J.AGSY.2017.01.023
4. M. Dhanaraju, P. Chenniappan, K. Ramalingam, S. Pazhanivelan, R. Kaliaperumal.. Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agriculture*. **12**, 10, 1745 (2022). https://doi.org/10.3390/agriculture12101745
5. D.S.N.A. Ahmad, F.A. Fatah, A.R. Saili, J. Saili, N.M. Hamzah, R.C.M. Nor, et al., Exploration of the challenges in adopting smart farming among smallholder farmers: a qualitative study. J Adv Res Appl Sci Eng Technol. **45**, 17–27 (2025). https://doi.org/10.37934/araset.45.1.1727
6. S. Tiwari, B. Bhardwaj, D. Arora, S. Khatri, Challenges and barriers to smart farming adaptation: a technical, economic, and social perspective. In Smart Agritech: Robotics, AI, and Internet of Things (IoT) in agriculture, (Scrivener Publishing LLC, Massachusetts , 2024). https://doi.org/10.1002/9781394302994.ch4
7. T. Dibbern, L.A.S. Romani, S.M.F.S. Massruhá, Main drivers and barriers to the adoption of digital agriculture technologies. Smart Agric Technol. **8**, 100459 (2024). https://doi.org/10.1016/j.atech.2024.100459
8. W. Powell, O. Kusuma-Powell, Overcoming resistance to new ideas. Phi Delta Kappan. **96**, 66–69 (2015). https://doi.org/10.1177/0031721715583967
9. J.H. Chuang, J.H. Wang, Y.C. Liou, Farmers' knowledge, attitude, and adoption of smart agriculture technology in Taiwan. Int J Environ Res Public Health. **17**, 1–8 (2020). https://doi.org/10.3390/ijerph17197236
10. V.J. Das, S. Sharma, A. Kaushik, Views of Irish Farmers on smart farming technologies: An observational study. Agri Engineering. **1**, 164–187 (2019). https://doi.org/10.3390/AGRIENGINEERING1020013
11. J. Colussi, E.L. Morgan, G.D. Schnitkey, A.D. Padula, Communication affects the adoption of digital technologies in soybean production: a survey in Brazil. Agric. **12**, 611 (2022). https://doi.org/10.3390/agriculture12050611
12. M.Y. Madaki, S. Muench, H. Kaechele, M. Bavorova, Climate change knowledge and perception among farming households in Nigeria. Climate. **11**, 115 (2023). https://doi.org/10.3390/cli11060115
13. T. Li, J. Cui, W. Guo, Y. She, P. Li, The influence of organic and inorganic fertilizer applications on nitrogen transformation and yield in greenhouse tomato cultivation with

surface and drip irrigation techniques. Water. **15**, 3546 (2023). https://doi.org/10.3390/w15203546
14. Y.A. Tessema, J. Joerin, A. Patt, Factors affecting smallholder farmers' adaptation to climate change through non-technological adjustments. Environ. Dev. **25**, 33–42 (2018). https://doi.org/10.1016/j.envdev.2017.11.001
15. S.G. von Diest, J. Wright, M.J. Samways, H. Kieft. A call to focus on farmer intuition for improved management decision-making. Outlook Agric. **49**, 278–285 (2020). https://doi.org/10.1177/0030727020956665