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# The Role of Digital Agricultural Extension for Achieving Development in Farmers' Groups, Maros Regency, Indonesia

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**Research Article**

**Keywords:** Digital Agricultural Extension, Farmer Groups development, access to digital extension, barriers and challenges, PLS-SEM

**Posted Date:** June 23rd, 2026

**DOI:** https://doi.org/10.21203/rs.3.rs-9737509/v1

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**Additional Declarations:** No competing interests reported.

# Abstract

The development of farmer groups in Maros Regency is influenced by the role of the Agricultural Extension Center in disseminating scientific knowledge, agricultural innovations, and digital extension services to farmers. This study investigates the contribution of digital agricultural extension to farmer group development and identifies factors affecting its effectiveness. A quantitative research approach was employed using structured questionnaires distributed to 100 respondents, comprising rice farmers and agricultural extension agents from eight subdistricts in Maros Regency. Data were analyzed using Partial Least Squares–Structural Equation Modelling (PLS-SEM) to examine the relationships among digital agricultural extension, access to digital extension, use of digital extension tools, perceived barriers and challenges, and farmer group development.The results indicate that digital agricultural extension does not have a statistically significant direct effect on farmer group development. Instead, its influence occurs indirectly through mediating factors related to barriers and challenges, including limited digital literacy, inadequate internet connectivity, and institutional constraints. Access to digital extension emerged as a key enabling factor, showing a significant positive effect on farmer group development while simultaneously reducing perceived barriers. Although the use of digital extension tools did not directly enhance group development, it increased awareness of existing challenges, reflecting an ongoing transition toward digital adoption among farmers. The study concludes that the effectiveness of digital agricultural extension depends not only on technology deployment but also on equitable access, farmer capacity building, and strong institutional support. Strengthening these factors can enhance sustainable farmer group development and contribute to achieving SDG 1 (No Poverty) and SDG 9 (Industry, Innovation and Infrastructure) through improved farmer capacity, information access, and rural development.


# 1. Introduction

Indonesia’s agricultural sector is central to food security and rural livelihoods, with government programs consistently emphasizing food sovereignty and farmer welfare. Agricultural extension (AE) plays a critical role in this strategy by strengthening farmers’ management and technical capacities, thereby improving productivity, reducing losses, and facilitating technology adoption. (1). At the national level, extension contributes to food system resilience, while at the farm level, it directly enhances farmer performance and welfare. AE has been institutionalized through the National Agricultural Extension System (AES) under Law No. 16/2006, aligned with the Agricultural Revitalisation Programme (ARP) 2025, which targets productivity growth in 14 strategic commodities (2).

Recent studies suggest that access to digital extension greatly boosts technology adoption and income among smallholder farmers (3). Digital services such as mobile phones, social media, and web-based platforms are increasingly incorporated into extension services, enabling broader information access and connecting farmers with markets and financial services (4). However, uneven digital literacy among extension agents and rural communities continues to limit inclusivity (5).

Digital agricultural extension is rapidly emerging as a crucial catalyst for sustainable agricultural development. By significantly enhancing farmers’ access to vital knowledge, innovations, and market information, digital extension serves as a powerful tool for fostering food security, alleviating poverty, and strengthening climate resilience. These essential outcomes not only benefit communities but also align perfectly with the United

Nations Sustainable Development Goals (SDGs), particularly in advancing SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 8 (Decent Work and Economic Growth), Investing in digital extension is key to a prosperous future for all.

Extension Extension services are also critical for adapting to climate change. Pluralistic extension models that combine government agencies, private providers and community groups have been linked to improved smallholder resilience and greater responsiveness to farmer (6). Localized, participatory approaches notably Farmer Field Schools and Climate Field Schools have been shown to increase farmer knowledge, trust and adoption of climate-smart practices, and to help farmers use climate forecasts in planning (7). Strengthening Indonesia’s extension system by integrating proven participatory methods with emerging digital tools and climate-resilient strategies will therefore be vital to meet national agricultural goals and improve farmer welfare (8).

In developing countries like Indonesia, increasing the productivity of small-scale farming is essential for economic growth and reducing poverty. However, farmers' groups often face several challenges, including unpredictable weather, subsidies, market risks, and restricted access to financial services, technology, and informations. Low productivity and little market participation are the results of these limitations. Therefore, overcoming the primary obstacles to smallholder farmers' access to markets and knowledge is a crucial policy concern for fostering rural development and reducing poverty (9).

In many developing nations, public support for spreading knowledge and fostering innovation among smallholder farmers largely relies on agricultural extension services (10). Traditionally, extension agents have either worked with specific "model farmers" who are then expected to serve as information multipliers or have attempted to directly educate farmers about optimal practices (11). However, the efficacy of conventional extension methods has been constrained, either due to limited funding and thus low outreach or because the information is not adequately adapted to farmers' needs. Although there is little empirical evidence of actual effects, the creation and application of new digital extension strategies that build on information and communication technologies (ICTs) like mobile phones and internet platforms could potentially improve the situation (12).

The role of agricultural extension agents is crucial in enhancing farmers’ awareness and knowledge, which ultimately helps develop farmers' groups (13). Law No. 16 of 2006, concerning the Agricultural, Fisheries, and Forestry Extension System, was enacted after the Reformation era and significantly changed the organizational and functional aspects of extension services in Indonesia, making the delivery of these services more complex (14). Research on policy implementation has shown that when extension agents have high capacity, meaning they effectively understand and apply science and technology for sustainable resource management, extension outcomes tend to improve (15). Farmers have evaluated the performance of extension agents during crises, such as the COVID-19 pandemic, identifying deficiencies in several areas, including personal, social, managerial, and professional skills (16). In the digital age, extension workers need to adapt to rapidly changing technologies; studies suggest providing better ICT training and increasing internet usage to strengthen extension performance (17, 18) .

The ability of extension workers to communicate and disseminate agricultural development initiatives, innovations, and the most recent agricultural knowledge to farmers so that these can be implemented

successfully demonstrates their function as agricultural communicators. Additionally, extension agents help farmers make decisions, expedite the flow of information, and offer solutions to their difficulties (19). Through these functions, agricultural extension activities can motivate farmers to become more advanced, broaden their perspectives, and become increasingly market-oriented (20). Because of this, agricultural extension workers must constantly advance their knowledge and abilities by becoming proficient in the most recent agricultural advancements and information.

Extension workers can now readily access a variety of information through both offline and online communication medium because to the quick growth of information and communication technology (ICT) (4). The use of digital information is accessible to everyone, including extension workers. They constantly need innovations from various technologies, and one of the most accessible media today is the internet, which is facilitated through cyber extensions. Studies have shown that applying information technology via computers or mobile phones within cyber extension systems can speed up community learning processes and enhance knowledge sharing among farmers (21).

However, in the digital age, one of the main challenges in agricultural extension is how workers can produce information that is innovative, up-to-date with agricultural technological advances, and practical for sustainable farming. Extension workers often encounter barriers due to limited access to knowledge or innovations needed by farmers and other related (22). This issue has become more urgent since the government, through Law No. 16 of 2006 concerning the Agricultural, Fisheries, and Forestry Extension System, requires that Extension Centers provide and disseminate information about technology, production facilities, financing, and markets (23). The Indonesian law requires extension centres to provide continuous learning opportunities for government and private extension personnel. In order to increase the efficacy of extension services in the digital age, extension workers must create and deliver extension messages that make use of both conventional and contemporary media. This has made the use of digital media an essential communication strategy.

The Agricultural Extension System (AES) continues to face challenges amid digital transformation and climate uncertainty. Despite Law No. 16/2006 strengthening institutional structures, extension performance remains uneven, particularly for farmer groups in remote areas (14). Digital extensions, such as cyber extensions, mobile apps, and social media, create new opportunities for wider outreach (3), but disparities in digital literacy limit their effectiveness (24). Moreover, conventional top-down models limit farmer participation and the adoption of innovation (25). Hence, the key issue is how AES can effectively integrate digital technology, participatory approaches, and capacity building to enhance farmer learning, innovation adoption, and resilience.

This research aims to examine the role of digital agricultural extension in promoting sustainable farmer group development and supporting the achievement of relevant Sustainable Development Goals (SDGs) in Maros Regency, South Sulawesi, Indonesia.

## 2. Literature Review

The literature review in this study serves to systematically collect, analyze, and validate relevant theories and empirical findings from prior research related to the topic under investigation. The conceptual underpinnings

of this synthesized body of knowledge inform and direct the development of the research design and methodology (26).

## 2.1 The Role of Digital Agricultural Extension in Supporting Farmer Groups

Through information exchange and capacity building, agricultural extension has long been essential to raising farmers' production, knowledge, and abilities. Extension programs have historically relied on in-person contacts, demonstration plots, and written materials. But with the advent of new, quicker, easier, and more interesting ways to convey information, the digital revolution has altered the agricultural scene. Digital agricultural extension offers significant chances to improve farmers' decision-making and aid in the growth of farmer groups through cellphones, mobile apps, social media, and online training (27, 28)

Maros Regency aims to achieve strong food security and dependable human resources for extension. Therefore, the effectiveness of agricultural extension workers is essential, as they help farmers achieve agricultural growth. Overall, there are signs that agricultural extension in Indonesia is still not operating at its best (29). Several factors contribute to Indonesia's agricultural extension workers' subpar performance, including: 1. Disparities in the importance and role of agricultural extension between the central and regional governments, as well as between the executive and the legislature; 2. Limited funding for agricultural extension activities from regional governments and information scarcity; 3. Limited and weak administrative capacities of agricultural extension workers, as extension workers are less active in visiting farmers' groups (30).

Numerous studies indicate that digital technologies can significantly lower communication costs, which in turn reduces transaction expenses, enhances the efficiency of digital agricultural counseling, and fosters economic growth and poverty alleviation (31). The Agricultural Extension Center in Maros particularly emphasizes the role of mobile phones in developing farmer groups. For instance, research has demonstrated that mobile phone usage can boost sales, decrease purchase prices, improve access to information for small farmers, and ultimately increase farm productivity and income (32). Additionally, some studies have explored the impact of social media on various aspects of small farmers' lives, noting positive effects on nutrition, gender equality (33), employment opportunities outside of farming, and immigration. While most of these studies treat media as a basic communication tool, they collectively suggest that mobile phones can be highly beneficial for farmer groups (9).

### 2.1.1 Farmers’ Perceptions of Digital Agricultural Extension

Farmers’ perceptions play a central role in the adoption of digital agricultural innovations. Farmers are more inclined to use digital platforms in their decision-making processes when they are seen as reliable, useful, and user-friendly (34). Studies show that visually engaging and well-organized communication in digital outreach improves understanding and builds trust (13). However, skepticism persists regarding the accuracy and local relevance of online agricultural information, especially among farmers accustomed to interpersonal and field-based learning (16). Recent research highlights that such doubts often stem from limited digital literacy, a lack of contextual adaptation, and low transparency in digital systems (35, 36, 37). To address these challenges,

scholars increasingly advocate for hybrid extension models that blend digital tools with traditional, face-to-face interaction to strengthen credibility and improve technology adoption (38).

The development of the agricultural sector in Maros Regency plays a vital role in driving regional economic growth by increasing production and farmers' income (39). Efforts to enhance rice production in Maros Regency are closely linked to the collaborative roles of farmers' groups, which act as key stakeholders in agricultural development. Farmers' groups, as stakeholder organizations, consist of individuals or collectives who hold an interest in, or are affected by, agricultural development programs. Their involvement can have either a positive or negative influence on the performance and sustainability of the farming sector (40).

Stakeholder collaboration represents a form of cooperation and social interaction in which farmers' groups actively participate in policy formulation and implementation, contributing to behavioral and institutional changes necessary for achieving collective agricultural goals (41, 42). Farmers' groups may operate at multiple societal levels, ranging from international and national institutions to regional, household, and intra-household structures, thereby creating a multi-layered network of influence.

According to (43) propose that stakeholder mapping involves three main stages: (1) identifying the role of each stakeholder group, (2) determining their interests and influence in decision-making, and (3) analyzing the relationships among them. Communication and negotiation are critical in building consensus and mutual understanding. The interest influence matrix (44) further provides a useful framework for categorizing stakeholders into four groups Key Players, Context Setters, Subjects, and Crowd, thereby helping policymakers and practitioners design participatory and equitable agricultural development strategies.

## 2.1.2 Access to Digital Agricultural Extension

Access to digital tools is a fundamental prerequisite for enabling farmers to benefit from modern agricultural extension systems. Previous studies indicate that smartphone ownership and reliable internet connectivity significantly influence farmers' participation in digital learning platforms and information exchange networks (24). In Indonesia, the Ministry of Agriculture has prioritized digital transformation in its extension services through initiatives such as Cyber Extension and Simluhtan, which aim to strengthen communication between farmers and extension officers (45, 22).

However, despite these efforts, significant challenges persist. Disparities in digital infrastructure, limited digital literacy among farmers, and uneven access to affordable internet servicesparticularly in remote rural areas, continue to hinder the effective implementation of digital extension programs (46). Moreover, there remains a lack of empirical evidence on how these digital platforms impact farmers' decision-making, productivity, and income outcomes, highlighting the need for further research on the inclusivity and effectiveness of Indonesia's digital agricultural extension systems.

## 2.1.3 Utilization of extension tools to Support Agricultural Extension Activities

In Maros Regency, digital and social media are beginning to play a visible yet still inconsistent role in agricultural extension. Local studies and institutional reports indicate that extension officers and some farmer groups use WhatsApp, Facebook, and YouTube to share technical advice, short training videos, meeting

notices, and market or weather information. Meanwhile, official channels (e.g., the Kabupaten Maros YouTube and Facebook accounts) are also utilized for broader informational outreach (47).

Research specific to Maros indicates that these platforms are employed alongside traditional face-to-face methods rather than as wholesale replacements; many village extension activities still rely on meetings at the BPP (Balai Penyuluhan Pertanian) or at farmer group leaders' homes, with social media functioning largely to reinforce or follow up on in-person training (48).

Despite the potential for rapid, low-cost dissemination, studies in Maros identify clear constraints that limit the reach and impact of social-media-based extension: inconsistent internet connectivity, limited smartphone ownership/use among some farmer segments, relatively low levels of digital pedagogy among extension staff, and a tendency for digital channels to be used sporadically (for announcements or occasional videos) rather than as sustained, interactive advisory systems (49).

Where digital tools are used more systematically e.g., organized WhatsApp groups or locally produced short videos evidence from evaluations in the regency shows they can speed problem-solving (quick pest/weed queries), improve information sharing about markets and inputs, and help weaker producers access peer support; however, measurable changes in adoption and productivity depend on complementary supports (training in digital skills, reliable infrastructure, and incentives for regular use (34).

### 2.1.4 Barrier and Challenges

Although digital agricultural extension holds great promise, its implementation faces several key barriers. Technological Barriers: Limited internet connectivity, high data costs, and inadequate access to smartphones remain persistent challenges in rural areas, especially in Maros, restricting farmers' participation in digital platforms (46, (5). Human-Capacity Constraints: Many farmers and extension agents have low digital literacy, making it difficult to utilise online learning tools effectively (16, 34) Extension staff also lack consistent training in digital pedagogy (49).

Institutional Challenges: Weak coordination among agencies and limited budgets hinder the sustainability of digital extension programs (29, 22). Socio-Cultural Barriers: Farmers often trust interpersonal communication more than online advice, and gender disparities further limit women's participation (13, 33).

In summary, these challenges indicate that digital agricultural extension in Indonesia requires stronger infrastructure, inclusive training, and supportive policy frameworks to ensure equitable access and long-term effectiveness.

## 2.2 Digital Agricultural Extension and Sustainable Development

Digital agricultural extension has emerged as an important mechanism for advancing sustainable rural development by improving farmers' access to agricultural knowledge, climate information, market intelligence, and innovative farming practices (37, 50) Furthermore, digital extension contributes to the achievement of SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), and SDG 9 (Industry, Innovation and Infrastructure) through enhanced productivity, income generation, innovation adoption, and

rural connectivity (51).The effectiveness of these benefits depends on equitable access to technology, digital literacy, and institutional support mechanisms (52).

Recent research suggests that the sustainability benefits of digital agricultural extension depend not only on the availability of technology but also on farmers' digital literacy, affordability of digital services, institutional support, and the capacity of farmer groups to collectively utilize digital innovations (53). Effective digital extension systems therefore require supportive policies, investments in rural connectivity, and participatory approaches that ensure equitable access to digital resources. Consequently, digital agricultural extension should be viewed not merely as a technological innovation but also as a social and institutional innovation capable of fostering inclusive agricultural transformation, strengthening rural resilience, and advancing the achievement of multiple SDGs simultaneously (37, 54).

# 3. Conceptual Framework

This study conceptualizes digital agricultural extension as a key driver of farmer group development in Maros Regency, drawing on the Diffusion of Innovation Theory (Rogers, 2003) and the Digital Empowerment Framework. It asserts that farmers' perception of digital extension (X1) is fundamental in cultivating trust, confidence, and the propensity to consistently embrace digital innovations. At the same time, access to digital extension (X2) provides the necessary infrastructure, like smartphones, internet connectivity, and digital platforms, that enable farmers to obtain information and engage with extension services. Furthermore, the use of digital tools (X3) reflects the extent to which farmers actively participate in digital learning, communication, and knowledge exchange. Together, these factors are expected to enhance farmer group development (Y2), as manifested in improved productivity, strengthened collaboration, expanded market access, and more effective knowledge sharing. However, the framework also recognizes the role of barriers and challenges (Y1), including limited digital literacy, poor connectivity, and insufficient training, which may weaken or mediate these relationships. Importantly, such barriers not only constrain outcomes but may also stimulate collective learning and adaptive responses within farmer groups. Therefore, the model suggests that the effect of digital extension on farmer group development is largely indirect and conditioned by both enabling factors and contextual constraints, rather than driven by technology adoption alone.

# 4. Research methods

This study adopted a quantitative research design employing structured questionnaires to collect data from a targeted group of agricultural extension agents and rice farmer groups. The sample was randomly selected to ensure unbiased representation and statistical reliability. This methodological approach enabled the collection of comprehensive data that reflects the diverse perspectives and experiences of farmers regarding the role of digital agricultural extension in enhancing agricultural development within Maros Regency.

# 4.1 Study Location

This study was carried out in Maros Regency, South Sulawesi, Indonesia, a region renowned for its rich agricultural potential. The site was selected due to its well-established agricultural framework, supported by both public and private extension services, as well as dynamic farmer groups that play a pivotal role in enhancing local production. To ensure a focused and meaningful investigation, the research centered on the

key interactions between farmers and the services provided by the Maros Agricultural Extension Center. The study specifically targeted rice cultivation, as rice is the primary staple crop cultivated by the majority of farmer groups in the area. Consequently, Maros District serves as an ideal focal point for this research at the provincial level, underscoring its significance in promoting agricultural development and empowering local farmers.

# 4.2 Data collection

The study was carried out during three months, from September to December 2025, using a quantitative research approach. To guarantee that every member of the population had an equal chance of being chosen, a straightforward random sampling procedure was used. Th groups Members of the Gaboktan, Wanita Tani, and Taruna Tani made up the research population. distributed across eight sub-districts in Maros Regency. In total, the population consisted of 726 individuals, including 700 rice farmers and 26 agricultural extension agents.

Cochran's sample size estimation formula was used to get the minimal necessary sample size:

$$n = \frac{Z^2 pq}{(e)^2} \qquad (1)$$

where $n$ stands for the necessary number of samples, $Z$ for the value from the normal distribution that corresponds to a 95% confidence interval, which is 1.64, and $p$ and $q$ for the 50% probabilities of correct and incorrect outcomes, respectively. $e$ signifies the sampling error rate, which is set at 10%. The number of samples collected for this study was as follows:

$$n = \frac{Z^2 pq}{(e)^2} \quad \frac{(1,96)2\ (0,5)(0,5)}{(0.10)^2} = 96.04 \qquad (2)$$

The Cochran formula indicated that a minimum of 96 respondents were required for this investigation. Considering the study's design, available resources, and anticipated response rate, a final sample of 100 participants was selected, consisting of 86 farmers and 14 agricultural extension workers. All participants provided complete and valid responses, yielding a 100% response rate.

# 4.3 Data analysis

The data analysis in this study employed both descriptive and inferential statistical methods to elucidate the elements affecting the function of digital agricultural extension (DAE) in the advancement of farmer groups. Descriptive statistics, including frequency distributions, percentages, means, and standard deviations, were generated using IBM SPSS Statistics version 26 to summarise respondents' demographic features and important variables.

Partial Least Squares–Structural Equation Modelling (PLS-SEM) was utilised to examine the proposed correlations between constructs, employing SmartPLS version 4, (55). The PLS-SEM methodology was chosen for its appropriateness in predictive modelling and its capacity to examine intricate interactions among latent variables with very small sample sizes (56). The assessment of the measurement (outer) model and the structural (inner) model included the two primary phases of the investigation.

The assessment of the measuring indicators' validity and reliability includes indicator reliability (loading values > 0.70) and internal consistency reliability (Cronbach's alpha and composite reliability > 0.70), and convergent validity (average variance extracted [AVE] > 0.50). Discriminant validity was tested using the Fornell-Larcker criterion and cross-loading values to confirm that each construct was empirically distinct. The structural coefficient model evaluated the causal links between constructs by analysing route coefficients, coefficients of determination ($R^2$), predictive relevance ($Q^2$), and effect sizes ($f^2$).

Quantitative data from structured questionnaires were measured using a five-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree). These ordinal data were treated as interval data to allow for parametric statistical analyses. Median, mean, and standard deviation values were computed for each variable to identify central tendencies and variability among respondents.

The results from both descriptive and inferential analyses were triangulated to interpret the role of DAE in enhancing the development of farmer groups, focusing on dimensions such as access to digital extension, utilisation of social media, perception of digital tools, and the moderating influence of infrastructural barriers.

**Ethical Considerations**

This study was conducted in accordance with relevant guidelines and regulations for social science research. The research involved voluntary participation of farmer groups and extension workers through questionnaire surveys and did not involve medical interventions, human biological samples, or sensitive personal data. Therefore, formal ethical approval was not required under the institutional regulations applicable to this study. Before data collection, all participants were informed about the purpose of the research, and informed consent was obtained from all respondents. Participation was voluntary, and respondents were assured that their identities would remain anonymous and that all information would be treated confidentially and used solely for academic research

# 4.4 Operationalization of Variables

The operationalization of variables converts the conceptual framework into measurable constructs for empirical analysis. All latent variables were derived from established literature and measured using multiple indicators adapted to the study context, assessed on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). The detailed definitions, indicators, and sources are presented in Table.

. Table 1. The operational definitions of variables used in this study, along with their indicators.

| Variable | Operational Definition | Indicators / Questionnaire Items | Measurement | References |
|---|---|---|---|---|
| DAE: Perception toward Digital Agricultural Extension (X1) | Measured by perceived efficiency, clarity, decision-support capacity, and trustworthiness of digital extension services. | 1. Digital extension more efficient than traditional<br>2. Easy to understand content<br>3. Helps make better farming decisions<br>4. Trust in digital sources | 1. Strongly Disagree; 2. Disagree; 3. Neutral; 4. Agree; 5. Strongly Agree | Haryati et al. (2024); Cahyono & Agunga (2016); Villano et al. (2024) |
| ADE: Access to Digital Agricultural Extension (X2) | Measured by ownership of devices, internet use frequency, and ease of accessing digital agricultural platforms. | 5. Access to a smartphone or digital device<br>6. Regular use of the internet for agricultural info<br>7. Receiving info via WhatsApp, YouTube, etc.<br>8. Ease of accessing digital extension services | 1. Strongly Disagree; 2. Disagree; 3. Neutral; 4. Agree; 5. Strongly Agree | Amrullah et al. (2023); Suswadi & Irawan (2023); Rahman & Chen (2022) |
| Use of Digital Extension tools (X3) | Measured by engagement in online training, digital communication, and application of digital information in farming. | 9. Receiving pest/fertilizer info digitally<br>10. Watching online agricultural videos<br>11. Using digital tools to communicate with extension officers<br>12. Applying farming practices learned digitally | 1. Strongly Disagree; 2. Disagree; 3. Neutral; 4. Agree; 5. Strongly Agree | Izmi et al. (2021); Mariyono et al. (2018); Sugihono et al. (2024) |
| BAC: Barriers and Challenges (Y1) | Measured by perception of skills, internet access, and literacy barriers. | 13. Difficulty using digital technology<br>14. Poor internet connectivity | 1. Strongly Disagree; 2. Disagree; 3. Neutral; 4. Agree; 5. Strongly Agree | Sugihono et al. (2024); Krishnayana et al. (2019); FAO (2022) |
| Scale: Likert 1–5 | | | | |

| Variable | Operational Definition | Indicators / Questionnaire Items | Measurement | References |
|---|---|---|---|---|
| | | 15. Need for training to use digital tools<br><br>16. Language or literacy barriers | | |
| DFG: Farmer Group Development (Y2) | Measured by perceived benefits of digital extension in productivity, cooperation, market access, and knowledge sharing. | 17. Increases group productivity<br><br>18. Improves teamwork through digital communication<br><br>19. Enhances market access via digital platforms<br><br>20. Improves training and knowledge-sharing effectiveness | 1. Strongly Disagree; 2. Disagree; 3. Neutral; 4. Agree; 5. Strongly Agree | Ngadi et al. (2023); Antriyandarti et al. (2024); World Bank (2021) |
| Scale: Likert 1–5 | | | | |

## 5. Results and discussion

A total of 100 valid responses were analysed, comprising 86 farmers and 14 agricultural extension agents across eight sub-districts in Maros Regency. Males between the ages of 30 and 50 made up the bulk of responders (82%), representing the most active farming demographic in the region. Approximately 78% owned smartphones, and 65% reported regular internet access via mobile data services. These characteristics indicate a relatively high potential for digital engagement, supporting the relevance of digital agricultural extension (DAE) initiatives in rural settings.

# 5.1 Farmers' characteristics

Figure 2 presents the socio-demographic characteristics of the respondents. The sample is predominantly male (82%), reflecting the persistent gender imbalance in agriculture in Maros Regency, where men continue to dominate farm ownership and decision-making due to greater access to land, capital, and institutional support services (52, 53). This pattern is consistent with national evidence from the 2023 Agricultural Census (ST2023), indicating that gender disparities remain deeply rooted in the agricultural sector, particularly in rice fields.

The age distribution reveals an aging farmer population, with 70% of respondents aged 40 years or older and nearly half (45%) exceeding 51 years. Younger farmers (≤ 40 years) account for only 30% of the sample, confirming limited generational renewal in Maros Regency. This demographic structure has important

implications for technology adoption, as older farmers tend to exhibit higher risk aversion and slower uptake of digital innovations. Educational attainment among respondents is relatively low, with 73% having completed only elementary or junior secondary education. Only 8% possess higher education qualifications. Previous studies have shown that limited formal education constrains farmers' ability to effectively utilize digital extension platforms and data-driven advisory services, whereas higher education enhances information processing capacity and innovation adoption (54, 55). Most of farmer groups operate small-scale farms, with 73% cultivating less than 1.02 ha, and more than half (54%) reporting farming experience of 1–10 years.

Given their influence on information access, learning ability, and risk preferences, farmer group characteristics were included as control variables in the PLS-SEM analysis to isolate the direct effects of digital agricultural extension on farmers' group development outcomes. Collectively, these characteristics provide essential contextual grounding for the measurement and structural models and align closely with regional policy priorities in Maros Regency, where initiatives such as the strengthening of Balai Penyuluhan Pertanian (BPP), Kostratani programs, and the digitalization of extension services are explicitly designed to address ageing farmer populations, low educational attainment, and the predominance of smallholder farming systems.

# 5.2 Measurement Model Assessment

The measurement (outer) model was evaluated to assess the reliability and validity of all latent constructs, including Perception toward Digital Agricultural Extension ($X_1$), Access to Digital Agricultural Extension ($X_2$), Use of Digital Extension Tools ($X_3$), Barriers and Challenges ($Y_1$), and Development of Farmer Group ($Y_2$).

The measurement model evaluation using Partial Least Squares-Structural Equation Modelling (PLS-SEM), which evaluates indicator reliability, internal consistency reliability, and convergent validity for all latent constructs, is shown in Table 2. With outer loading values over the suggested cutoff of 0.70, all indicators load positively and significantly on their corresponding constructs, indicating sufficient indicator reliability and appropriateness for additional study (61). The Perception of Digital Extension ($X_1$) construct shows satisfactory reliability, with outer loadings ranging from 0.708 to 0.806. Higher loadings for trust in digital information sources and improved decision-making highlight the importance of information credibility and decision support in shaping farmers' perceptions of digital extension services in Maros. Access to Digital Extension ($X_2$) exhibits moderate to strong reliability (0.722–0.880), with access to digital devices emerging as the most dominant dimension of digital extension access.

While the Use of Digital Extension tools ($X_3$) construct demonstrates strong and consistent indicator reliability (0.776–0.846), indicating coherent measurement of farmers' engagement with digital tools, communication, and training activities. The Barriers and Challenges ($Y_1$) construct is measured by four indicators with outer loading values ranging from 0.704 to 0.758, meeting the minimum criteria for indicator reliability. The lowest loading ($Y_{1.2}$ = 0.704) suggests that certain barriers, such as internet connectivity and literacy constraints, explain a moderate proportion of variance but remain theoretically meaningful. Higher loading values, particularly for difficulty in using digital technology ($Y_{1.1}$ = 0.758), indicate that technological complexity is a major obstacle faced by farmers in Maros. Overall, the loading pattern suggests that although barriers are multidimensional and heterogeneous. The Barriers and Challenges (BAC) $Y_1$ construct is adequately and reliably measured. The Development of Farmer Group ($Y_2$) construct demonstrates strong outer loading values

ranging from 0.731 to 0.843, indicating satisfactory to high indicator reliability. The highest loading $Y_{2.1}$ = 0.843) emphasizes increased farmer productivity as a key outcome of farmer group development, while other indicators reflect improved collaboration, enhanced market access, and more effective training and knowledge sharing through digital platforms (56).

Internal consistency reliability was examined using Cronbach's Alpha and composite reliability (CR). With Cronbach's Alpha values ranging from 0.708 to 0.842 and CR values from 0.819 to 0.894, all constructions exhibit satisfactory reliability, above the suggested threshold of 0.70. Average Variance Extracted (AVE) was used to assess convergent validity; values ranged from 0.532 to 0.678, all of which were higher than the minimum requirement of 0.50. These findings show that the constructs effectively convey the underlying ideas. The measuring model is appropriate for structural model analysis and hypothesis testing since it shows adequate reliability and convergent validity overall.

Table 2
Factor loadings, reliability, and convergent validity results of the measurement model using SmartPLS

| Variable | Indicator | Loading | Cronbach's Alpha | CR | AVE |
|---|---|---|---|---|---|
| Perception of Digital Extension Services (DAE) | DAE1. efficiency of digital counseling vs. traditional | 0.716 | 0.752 | 0.842 | 0.572 |
| | DAE2. Ease of understanding digital Agri-content | 0.708 | | | |
| | DAE3. Better decision-making due to digital | 0.793 | | | |
| | DAE4. Trust in digital information sources | 0.806 | | | |
| Access to Digital Extension (ADE) | ADE1. Access to information via digital tools | 0.722 | 0.794 | 0.866 | 0.618 |
| | ADE2. Access to digital devices | 0.880 | | | |
| | ADE3. Regular internet use for information | 0.751 | | | |
| | ADE4. Ease of accessing digital counseling | 0.784 | | | |
| Use of Digital Extension (USM) | USM1. Use of digital for pest/guidance | 0.776 | 0.842 | 0.894 | 0.678 |
| | USM2. Frequency of watching online training | 0.846 | | | |
| | USM3. Use of digital tools for communication | 0.834 | | | |
| | USM4. Use the application of farming practices | 0.837 | | | |
| Barriers and Challenges (BAC) | BAC1. Difficulty in using digital technology | 0.758 | 0.708 | 0.819 | 0.532 |
| | BAC2. Poor internet connection as a barrier | 0.704 | | | |
| | BAC3. Need for training in digital tools | 0.734 | | | |
| | BAC4. Language and literacy barriers | 0.719 | | | |
| Development of Farmer Group (DFG) | DFG1. Increased productivity of farmers | 0.843 | 0.791 | 0.864 | 0.614 |
| | DFG2. Better collaboration via digital | 0.731 | | | |

CR: Composite Reliability; AVE: Average Variance Extracted

| Variable | Indicator | Loading | Cronbach's Alpha | CR | AVE |
|---|---|---|---|---|---|
| | DFG3. Easier market access using digital tools | 0.742 | | | |
| | DFG4. More effective training and sharing | 0.814 | | | |
| CR: Composite Reliability; AVE: Average Variance Extracted | | | | | |

# 5.3 Structural Model Path Coefficients:

Table 3 shows the results of the structural model evaluation examining the direct relationships among digital agricultural extension, access to digital extension, use of digital tools, barriers and challenges, and farmer group development in Maros Regency. Before hypothesis testing, collinearity diagnostics confirmed that multicollinearity was not present, indicating that the estimated path coefficients are robust and reliable.

The results indicate that Digital Agricultural Extension ($X_1$) does not exert a statistically significant direct effect on Farmer Group Development (DFG) $Y_2$ ($\beta = 0.196$; $p = 0.083$). Although the coefficient is positive, the relationship does not meet the conventional significance threshold ($p < 0.05$). This finding suggests that the mere provision of digital agricultural extension services is insufficient, on its own, to directly improve collective outcomes at the farmer group level. In line with the Diffusion of Innovation Theory, the introduction of an innovation does not automatically lead to adoption or organizational change unless users possess adequate capacity, resources, and supportive conditions to internalize and apply the innovation.

The result is consistent with research on digital transformation in agricultural extension in Indonesia, which indicates that technology adoption often remains at the informational level and fails to produce group-level effects unless it is accompanied by strengthening social capital, facilitation mechanisms, and learning processes (4).

In contrast, perception of digital agricultural extension (DAE) $X_1$ has a positive and significant effect on Barriers and Challenges (BAC) $Y_1$ ($\beta = 0.355$; $p = 0.005$). This result indicates that greater exposure to digital extension services is associated with increased awareness of constraints, such as limited digital skills, unstable internet connectivity, and the need for additional training. Rather than immediately reducing obstacles, digital extension initiatives may initially make farmers more conscious of the challenges they face when transitioning from conventional to digital advisory systems. This pattern is consistent with early stages of innovation diffusion, where complexity and compatibility issues become more salient during initial exposure. The positive and significant relationship agrees with findings from Indonesia and neigh boring Southeast Asian countries, indicating that early exposure to digital extension services often increases farmers' awareness of constraints rather than immediately alleviating them. (57, 58) in their study of digitalization in Indonesian agricultural supply chains, report that digital initiatives frequently reveal infrastructural weaknesses, limited digital literacy, and coordination gaps during initial implementation stages.

Importantly, Barriers and Challenges (BAC) have a strong and statistically significant effect on Farmer Group Development (DFG) $Y_2$ ($\beta = 0.398$; $p < 0.001$), and the model explains a substantial proportion of variance in DFG ($R^2 = 0.521$). The positive direction of this relationship suggests that the identification and management

of barriers play a constructive role in strengthening farmer groups. When constraints are recognized collectively, farmer groups may respond by improving coordination, seeking institutional support, and enhancing internal learning processes, which ultimately contribute to organizational development.

This result highlights that barriers do not merely hinder development but can also act as catalysts for collective problem-solving and institutional strengthening when adequately addressed. Several studies point out that when constraints are collectively identified, such as limited connectivity, skills gaps, or institutional fragmentation, farmer groups often respond by strengthening internal coordination, seeking external partnerships, and enhancing collective learning (4). A systematic review of digital extension programs for farmer groups in Maros Regency further confirms that addressing barriers explicitly can transform challenges into opportunities for organizational learning and institutional strengthening, particularly when farmer groups act as collective problem-solving units (37).

Furthermore, Access to Digital Extension (ADE) $X_2$ demonstrates a positive and significant direct effect on Farmer Group Development ($\beta = 0.228$; $p = 0.012$). This result confirms that access to smartphones, internet connectivity, and digital platforms is a fundamental enabling factor for improving productivity, collaboration, and knowledge sharing within farmer groups. From a diffusion perspective, access reduces the relative complexity of digital innovations and enhances their observability and trialability, thereby facilitating adoption at the group level.

At the same time, ADE ($X_2$) has a significant negative effect on Barriers and Challenges ($\beta = -0.211$; $p = 0.035$), indicating that improved access helps mitigate perceived constraints. Adequate infrastructure and connectivity reduce technological and informational barriers, enabling farmers to engage more confidently with digital extension services. This dual role of access directly promoting development while indirectly reducing barriers underscores its strategic importance in digital agricultural policy interventions.

The results further reveal that the use of digital extension tools ($X_3$) does not have a statistically significant direct effect on Farmer Group Development ($\beta = 0.138$; $p = 0.136$). This suggests that the frequency or intensity of digital tool usage alone is insufficient to generate tangible group-level development outcomes. Without adequate access, institutional support, and reduced barriers, digital usage may remain superficial and fail to translate into sustained behavioural or organizational change. Research across Southeast Asia indicates that increased frequency of digital tool usage often exposes limitations related to digital literacy, content relevance, and infrastructural reliability, particularly in rural contexts (62). As farmers engage more intensively with digital platforms, shortcomings become more visible, reinforcing the role of barriers as a mediating mechanism rather than a simple obstacle. This explains why digital usage alone may remain superficial and fail to drive sustained organizational change without complementary investments in access, capacity-building, and institutional support.

However, the use of tools (X3) has a positive and significant effect on Barriers and Challenges ($\beta = 0.378$; $p = 0.003$), indicating that increased use of digital tools more clearly exposes farmers to existing infrastructural, skill-related, and institutional limitations. As farmers engage more actively with digital platforms, shortcomings in connectivity, digital literacy, and content relevance become more apparent. This finding further supports the role of BAC as a mediating mechanism through which uses of digital extension influence farmer group development indirectly rather than directly.

The results demonstrate that Barriers and Challenges occupy a central mediating position in the digital agricultural extension framework. Digital extension, access, and use influence farmer group development primarily through their effects on perceived and actual constraints. These findings emphasize that digital agricultural extension strategies should not focus solely on technology deployment or usage metrics but must be accompanied by targeted capacity building, infrastructure development, and institutional support. By addressing barriers explicitly, digital innovations can be transformed from sources of frustration into drivers of collective learning, resilience, and the development of sustainable farmer groups.

Table 3
Structural model results, hypothesis testing, and indirect effects among study variables

| **Hypothesized Relationship** | **Std. Beta** | **Path Coefficient(β)** | **$R^2$** | **P-value** | **Description** | **Indirect Effects** | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | **Path** | **p-value** | **Description** |
| $X_1 \rightarrow Y_2$ | 0.113 | 0.196 | 0.282 | 0.083 | Insignificant | $X_1 \rightarrow Y1 \rightarrow Y_2$ | 0.043 | Significant |
| $X_1 \rightarrow Y_1$ | 0.127 | 0.355 | | 0.005 | Significant | $X_2 \rightarrow Y1 \rightarrow Y_2$ | 0.065 | Insignificant |
| $X2 \rightarrow Y_2$ | 0.100 | 0.228 | | 0.012 | Significant | $X_3 \rightarrow Y1 \rightarrow Y_2$ | 0.006 | Significant |
| $X2 \rightarrow Y_1$ | 0,090 | -0.211 | | 0.035 | Significant | | | |
| $X_3 \rightarrow Y_2$ | 0.093 | 0.138 | | 0.136 | Insignificant | | | |
| $X_3 \rightarrow Y_1$ | 0.127 | 0.378 | | 0.003 | Significant | | | |
| $Y_1 \rightarrow Y_2$ | 0.100 | 0.398 | 0.521 | 0.000 | Significant | | | |

$X_1$: Digital Agricultural Extension; $X_2$: Access to Digital Extension; $X_3$: Use of Digital Extension $Y_1$: Barriers and Challenges; and $Y_2$: Development of Farmer Group.

The analysis of indirect effects in Table 3 provides deeper insight into the mechanisms through which digital agricultural extension variables influence Farmer Group Development (DFG) $Y_2$. The mediation analysis confirms that Barriers and Challenges (BAC) $Y_1$ constitute a pivotal transmission mechanism linking digital agricultural extension variables to Farmer Group Development. Although Digital Agricultural Extension ($X_1$) does not exhibit a statistically significant direct effect on $Y_2$ (DFG), the indirect pathway via $Y_1$ (BAC) is significant, indicating full mediation. This suggests that digital extension initiatives influence farmer group

development primarily by increasing farmers' awareness of infrastructural, skill-related, and institutional constraints, which subsequently prompt collective learning, coordination, and adaptive responses at the group level. A similar mediation pattern is seen in the use of digital extension tools ($X_3$). While there is no direct effect on $Y_2$ (DFG), there is a significant indirect effect through BAC. This suggests that intensive digital engagement reveals underlying limitations that prompt organizational adjustments, rather than leading to immediate performance improvements.

In contrast, Access to Digital Extension ($X_2$) has a significant direct impact on $Y_2$ (DFG), while its indirect effect through $Y_1$ (BAC) (Barriers to Access and Connectivity) is not significant. This result suggests that access to digital extension primarily plays a direct enabling role. These findings show that digital agricultural extension primarily influences farmer group development in Maros Regency through indirect, process-oriented pathways. This highlights the importance of addressing contextual barriers to transform digital initiatives into sustainable collective outcomesThis result suggests that ADE primarily plays a direct enabling role. Overall, these findings show that digital agricultural extension primarily influences farmer group development in Maros Regency through indirect, process-oriented pathways. This highlights the importance of addressing contextual barriers to transform digital initiatives into sustainable collective outcomes

## 5.4 Assessment of Model Explanatory Power and Predictive Capability

The coefficient of determination (R2) was used to evaluate the explanatory capacity of the structural model. The R2 value for Farmer Group Development Y2 (DFG) is 0.521, meaning that digital agricultural extension, access to digital extension, use of digital extension, and the obstacles and difficulties related to these factors account for about 52.1% of the variance in farmer group development. This indicates in accordance with accepted norms.

The Stone–Geisser $Q^2$ value, which was derived using blindfolding methods, was used to assess predictive significance. The endogenous construct's Q2 value was higher than zero, indicating that the model's predictive significance is sufficient. These results demonstrate that the proposed model not only explains a substantial proportion of variance but also has meaningful predictive capability in the context of farmer group development.

## 6. Discussion

This study examined the role of digital agricultural extension in achieving development among farmer groups in Maros Regency, Indonesia, by analyzing the direct and indirect relationships among digital agricultural extension, access to digital extension, use of digital extension tools, barriers and challenges, and farmer group development. Using PLS-SEM modelling, our results provide nuanced insights into how digital extension contributes to collective agricultural outcomes, highlighting the importance of contextual and process-oriented mechanisms rather than purely technological determinants.

Our key finding is that digital agricultural extension in Maros Regency does not have a statistically significant direct effect on farmer group development. Although the estimated path coefficient is positive, the relationship

does not reach conventional significance criteria. This result suggests that the mere availability of digital extension services, such as online information, digital advisories, or virtual communication channels, is insufficient to automatically translate into improved group-level outcomes. This finding aligns with previous studies in Indonesia and other developing-country contexts, which show that digital extension initiatives often remain at the level of information dissemination and fail to generate organizational or productivity gains without complementary support mechanisms (4, 9) .

From a theoretical perspective, this result is consistent with the Diffusion of Innovation Theory, which posits that exposure to innovation alone does not guarantee adoption or impact. Innovations must be perceived as compatible with users' capacities, resources, and institutional environments. In Maros Regency, many farmer groups operate in settings characterized by uneven digital literacy, limited infrastructure, and strong reliance on interpersonal learning. Under such conditions, digital extension may raise awareness but not immediately induce behavioural or organizational change.

This study's key contribution is the identification of barriers and challenges (BAC) as a critical mechanism linking digital extension variables to farmer group development in Maros Regency. These results highlight access to smartphones, internet connectivity, and digital platforms as foundational prerequisites for digital inclusion and organizational development. From a diffusion perspective, access reduces the perceived complexity and cost of innovation while increasing trialability and observability, which are key determinants of adoption. This indicates that more exposure to and involvement in digital extension increases farmers' awareness of challenges like poor internet access, limited digital skills, language obstacles, and the need for additional training.

These findings corroborate prior studies in Indonesia showing that farmers with stable digital access are more likely to engage in information exchange, peer learning, and market-oriented behaviour (3, 54). In the study area, where 78% of respondents own smartphones, 65% regular internet use serves as a structural enabler that supports communication, coordination, and knowledge sharing within farmer groups, resulting in collective benefits. Explain why access exerts a direct effect on group development outcomes, even when digital extension usage itself does not.

Importantly, Access to digital Extension $X_2$ also has a significant negative effect on Barriers and Challenges $Y_1$ (BAC), indicating that improved access helps mitigate constraints related to connectivity and information availability. This dual role directly enhances development while indirectly reducing barriers to access as a strategic leverage point for policy intervention. Similar patterns have been reported in studies from India and Southeast Asia, where investments in rural connectivity significantly enhanced the effectiveness of extension services and farmer organizations (54, 37).

The study also finds that the Use of Digital Tools ($X_3$) does not have a significant direct effect on Farmer Group Development, but it has a strong and positive effect on Barriers and Challenges. This indicates that increased engagement with digital tools tends to expose, rather than immediately resolve, existing limitations such as low digital literacy, unreliable connectivity, and insufficient institutional support.

This result aligns with evidence from global reviews of digital extension initiatives, which show that early-stage digital adoption often reveals infrastructural and capacity gaps (62). As farmers in Maros increasingly use

WhatsApp groups, online videos, and digital communication with extension agents, shortcomings in content relevance, technical skills, and internet stability become more apparent. Therefore, the use of digital tools alone may remain superficial and fail to produce collective gains unless these constraints are addressed.

Rather than interpreting this finding as a failure of digital tools, it should be understood as a transitional dynamic within digital transformation processes. According (63) Digital engagement frequently serves as a diagnostic tool, highlighting systemic flaws and encouraging institutional learning. In this way, increased digital use contributes to development indirectly by highlighting the areas that most urgently require policy support and capacity building.

A central contribution of this study is the identification of Barriers and Challenges (BAC) as a significant mediator linking digital agricultural extension variables to Farmer Group Development. BAC has a strong and positive effect on DFG, and mediation analysis confirms that both perception of digital extension ($Y_1$) and the use of digital extension tools ($X_3$) influence farmer group development indirectly through $Y_1$ (BAC). At first glance, the positive relationship between barriers and development may appear counterintuitive. However, this finding suggests that farmer groups can be strengthened by collectively identifying and managing constraints, which encourages coordination, problem-solving, and engagement with external stakeholders. When farmer groups recognize common barriers, such as poor connectivity or limited skills, they may seek training, advocate for better infrastructure, or reorganize internal roles to meet digital demands.

This interpretation is supported by studies on collective action and institutional learning in agricultural systems. (7) found that farmer groups that actively reflected on constraints during Farmer Field Schools demonstrated stronger organizational capacity and resilience. Similarly, (37) argue that addressing digital barriers explicitly can transform challenges into opportunities for learning and innovation, particularly when farmer organizations function as social learning platforms. In Maros Regency, where extension services are embedded within farmer groups, identifying barriers may encourage closer collaboration between farmers and extension agents, thereby increasing group adaptive capacity. This explains why, when managed collectively, BAC acts as a catalyst for development rather than an impediment to progress.

Overall, the results demonstrate that digital agricultural extension can contribute to sustainable rural development by strengthening farmers' access to information, improving institutional learning, and enhancing adaptive capacity. These outcomes support the achievement of SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), and SDG 9 (Industry, Innovation and Infrastructure). Furthermore, improved digital access can enhance resilience to climate and market-related risks, contributing to SDG 13 (Climate Action).

# 6.1 Implications for digital extension policy and practice

The findings suggest that the effectiveness of digital agricultural extension depends not merely on technology adoption but on the integration of digital tools with access provision, capacity building, and institutional support. Policies focused solely on introducing digital platforms may have limited impact if underlying barriers are not addressed.

For Maros Regency and similar rural contexts, three priorities emerge: (1) expanding equitable access to digital infrastructure to improve farmer participation and reduce barriers; (2) strengthening digital literacy among farmers and extension agents to translate technology use into meaningful learning and organizational development; and (3) incorporating mechanisms to identify and address barriers that hinder digital engagement and collective action.

These findings contribute to a process-oriented understanding of digital innovation in agricultural extension, emphasizing that sustainable farmer group development is achieved through supportive systems rather than technology alone.

The study also demonstrates the relevance of digital agricultural extension to the Sustainable Development Goals (SDGs). By improving access to agricultural knowledge and innovations, digital extension supports SDG 2 (Zero Hunger) and sustainable food production. The importance of digital infrastructure aligns with SDG 9 (Industry, Innovation and Infrastructure), while enhanced digital literacy and farmer participation contribute to SDG 8 (Decent Work and Economic Growth) through stronger human capital and rural economic opportunities. Digital agricultural extension can serve as a key enabler of sustainable rural development when supported by inclusive policies, adequate infrastructure, and continuous capacity-building initiatives.

# 7. Conclusion and Recommendations

This research examined the role of digital agricultural extension in promoting farmer group development in Maros Regency, Indonesia, using a PLS-SEM approach.

The findings indicate that digital agricultural extension does not have a significant direct effect on farmer group development. Instead, its influence operates mainly through indirect, process-oriented pathways shaped by access conditions and contextual constraints. This implies that digital technologies alone are insufficient to achieve collective development goals in the absence of adequate infrastructure, skills, and institutional support.

Access to digital extension proved to be a key enabler, greatly supporting farmer group growth while reducing perceived obstacles. This highlights the importance of digital infrastructure and connectivity in enhancing communication, coordination, and knowledge sharing among farmer groups. However, the use of digital extension tools did not directly boost group development; instead, it increased farmers' awareness of existing challenges like limited digital literacy and unreliable internet access.

Importantly, barriers and challenges played a significant mediating role. Instead of impeding progress, the collective identification of constraints aided farmer group development by encouraging coordination, learning, and adaptive responses. Overall, the study concludes that digital agricultural extension benefits farmer groups primarily through indirect mechanisms that improve access, collective learning, and institutional capacity, rather than direct technological effects.

We recommend that, policymakers should prioritize increasing equitable access to digital infrastructure, such as affordable internet services and digital devices, because access benefits farmer groups in both direct and indirect ways. Digital extension initiatives should be accompanied by continuous capacity-building programs for farmers and extension agents, focusing on digital literacy and the practical application of digital

information. Extension systems should adopt hybrid models that integrate digital platforms with face-to-face interaction to improve trust, inclusivity, and contextual relevance. Barriers and challenges should be explicitly addressed using participatory extension approaches that encourage farmer groups to identify and manage constraints together. Future research should use longitudinal and comparative designs to better capture the dynamic effects of digital agricultural extension.

**Limitations of the Study**

There are a number of limitations to this study. First, the cross-sectional design makes it more difficult to track the long-term and changing impacts of digital agricultural extension on farmer group development. Second, the sample was limited to rice farmer groups and extension agents in Maros Regency, which may affect how well the results apply to other regions or agricultural settings. Third, relying on self-reported data may introduce response bias when measuring digital access, usage, and perceived impacts. Finally, barriers were considered as a single construct and not broken down into infrastructural, institutional, and socio-cultural factors. Future research should use longitudinal and mixed-methods approaches with larger, more diverse samples to overcome these limitations.

## Declarations

# Conflict of Interest:

None

**Clinical trial number**

not applicable.

# Ethical Statement

The study complied with applicable social science research guidelines. Ethical approval was not required because the research involved voluntary questionnaire-based participation without medical interventions or sensitive personal data. Informed consent was obtained from all participants before data collection.

# Funding:

This study did not receive any financial support from any organization or agency.

# Author Contribution

Authorship contribution statement: " H.N.B.A: Writing original draft preparation, writing- review & editing, Validation, Supervision, Resources, Methodology, Conceptualization. M.H.J: Supervision, Methodology, Visualization, writing-review & editing, Validation. E B. D: review & editing, Validation, Methodology, Resources.

M.S: Supervision, Methodology, Conceptualization, review & editing, Validation. D.M. O: Writing – review & editing, software. A.J.B: Writing – review & editing, software. Y. A: review & editing, software. All authors have read and agreed to the published version of the manuscript".

# Data Availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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## Figures

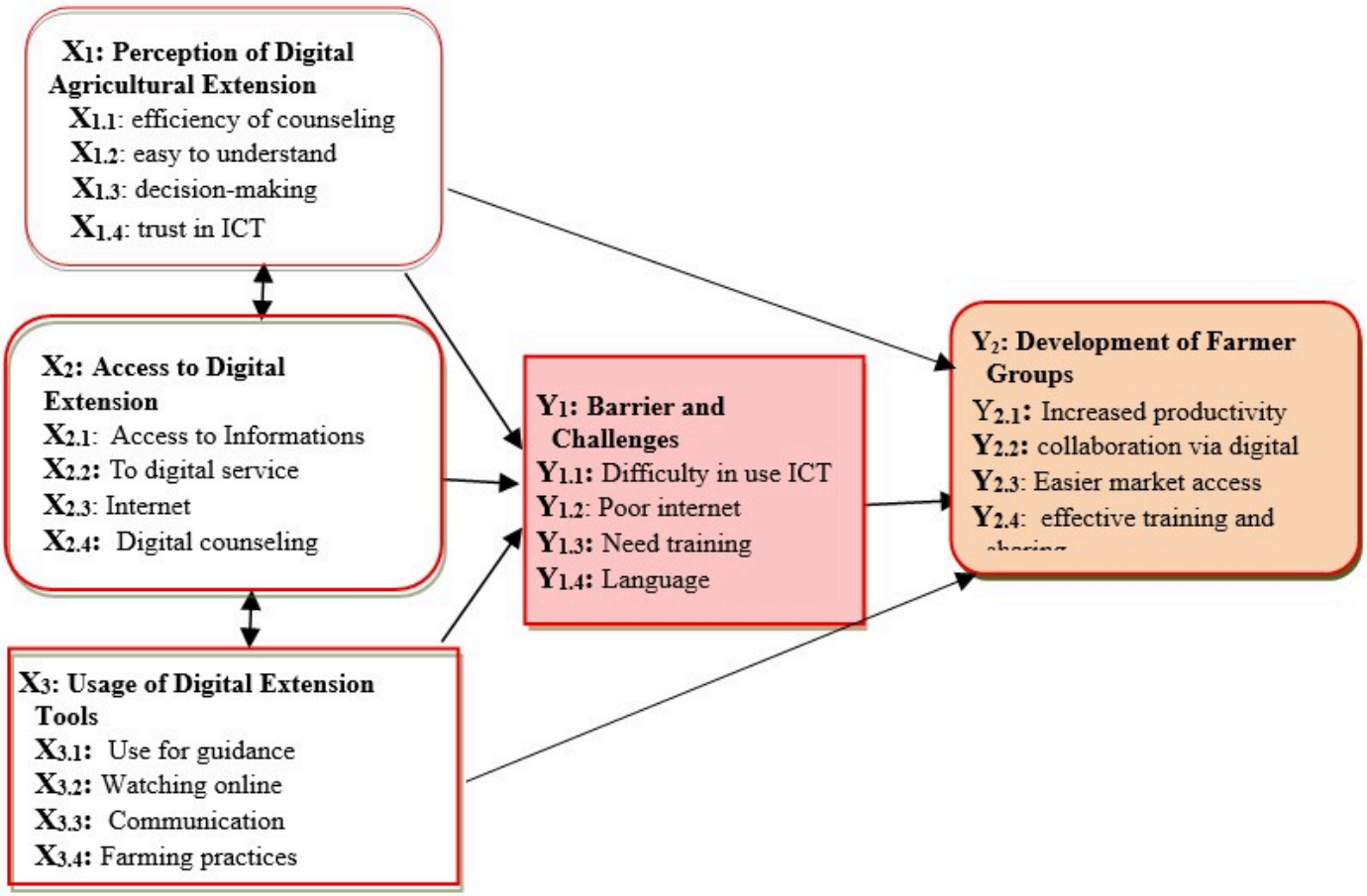



**Figure 1**

Conceptual Framework Model

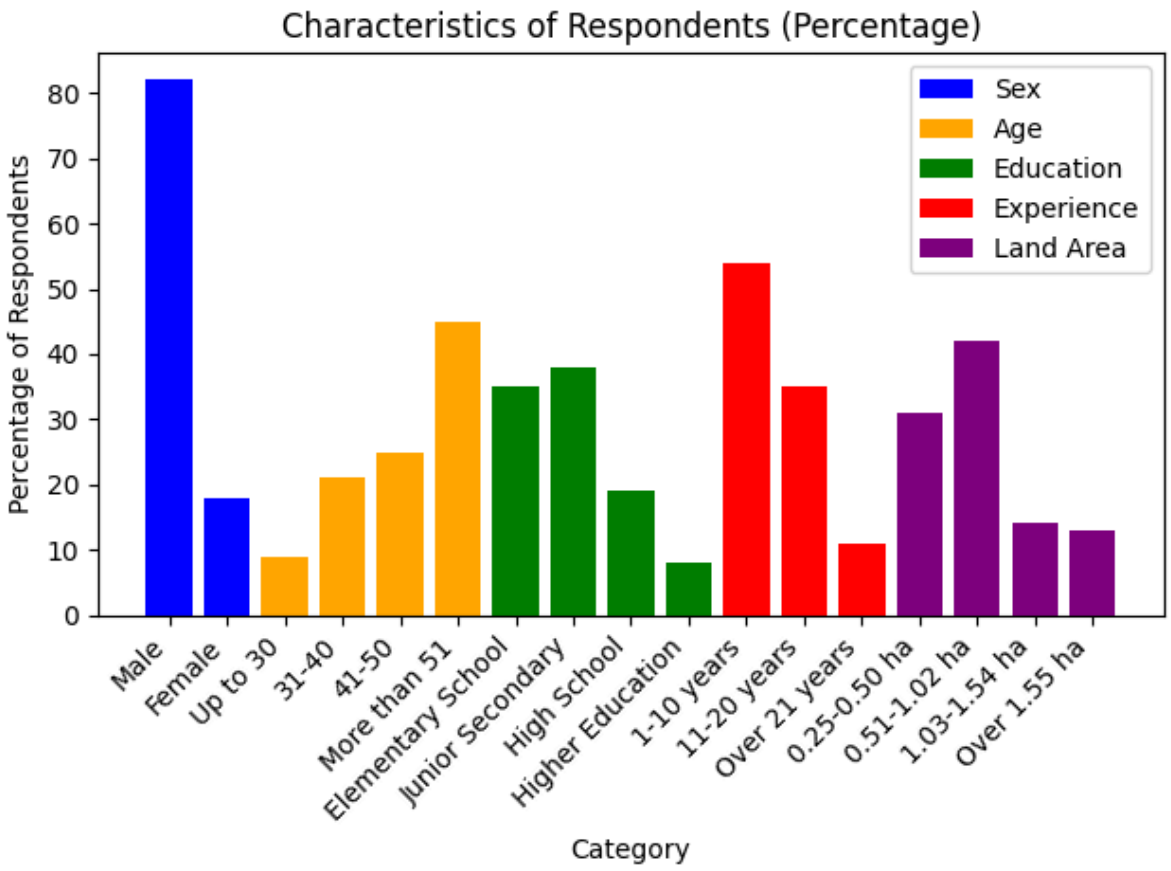



**Figure 2**

Characteristics of the respondents

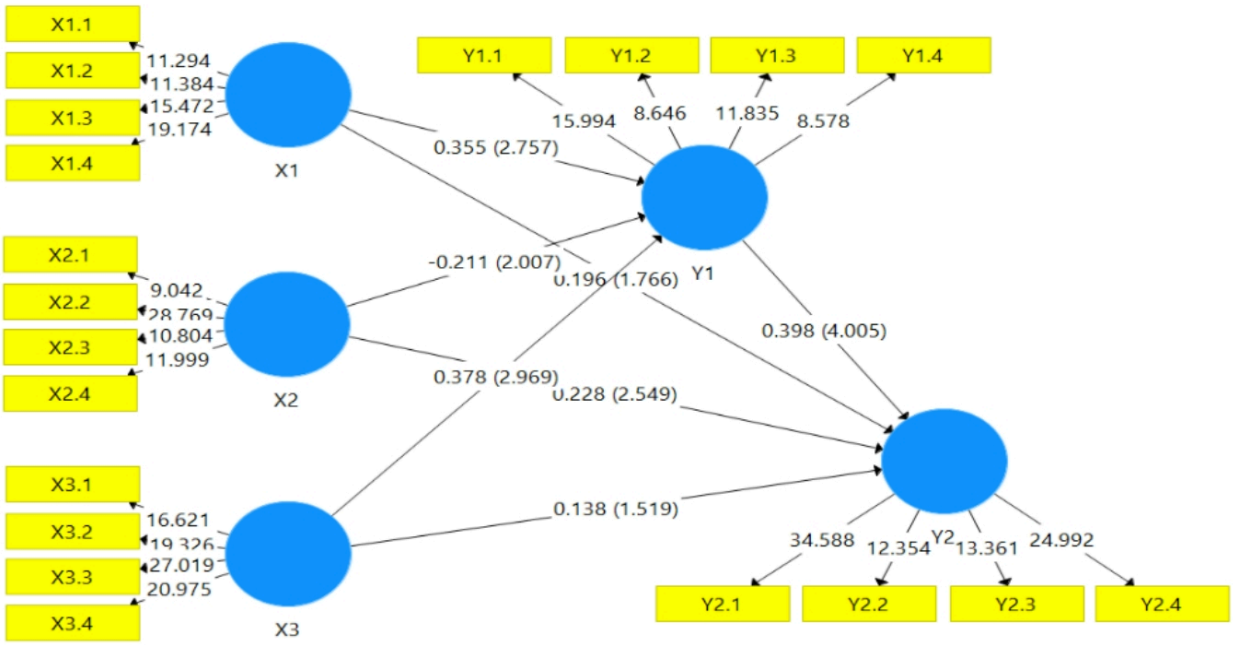



**Figure 3**

PLS-SEM Modeling Showing the Relationships among Variables