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Trends and Dynamics of Smart Farming Research in Agricultural Education in Indonesia: A Bibliometric Analysis (2020–2025)

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Abstract

Smart farming represents a transformative approach in agriculture, integrating digital technologies, automation, and data analytics to improve productivity, sustainability, and efficiency. This study employs a bibliometric analysis to examine research trends, thematic structures, and influential publications on smart farming within agricultural education in Indonesia from 2020 to 2025. Data were collected from Google Scholar using Publish or Perish and filtered to include 833 peer-reviewed journal articles, which were subsequently analyzed using **VOSviewer**. The analysis identified four primary thematic clusters: (1) technology-driven systems emphasizing IoT, artificial intelligence, big data, and precision agriculture; (2) capacity-building and community engagement focusing on training, extension programs, and skill development; (3) socio-behavioral and institutional factors affecting technology adoption; and (4) contextual and demographic considerations, including generational differences and situational disruptions. Citation analysis revealed that highly cited studies primarily address human resource competency development, entrepreneurship, and agricultural modernization. The findings indicate a growing research focus on technological innovation, while integration of smart farming into agricultural education curricula remains limited. This study provides insights into current research trends and highlights opportunities for pedagogical innovation and strategic integration of digital agricultural technologies in Indonesia's agricultural education system.

Keywords: *smart farming; agricultural education; bibliometric analysis; Indonesia; VOSviewer; research mapping*

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INTRODUCTION

Smart farming represents a contemporary agricultural paradigm that utilizes digital technologies, automation, and data analytics to improve efficiency, productivity, and sustainability in agricultural systems. This approach integrates multiple technologies—including the Internet of Things (IoT), soil and climate sensors, big data, artificial intelligence, drones, robotics, and geographic information systems—to support precision decision-making throughout the agricultural value chain (Wolfert et al., 2017). The transition toward data-driven production systems enables real-time monitoring and optimization of inputs such as water, fertilizers, pesticides, and energy, thereby promoting more efficient and sustainable agricultural practices (Klerkx et al., 2019).

In the context of global sustainability, smart farming has emerged as a strategic response to challenges such as climate change, resource scarcity, urbanization, and increasing food demand. Intelligent agricultural technologies enhance system resilience by optimizing resource use, reducing production losses, and improving product quality and traceability (Mutengwa et al., 2023). Empirical evidence further indicates that smart farming implementation contributes significantly to agricultural productivity and operational efficiency (Pratio et al., 2024).

The successful adoption of smart farming depends on the availability of agricultural human resources possessing adequate technical, digital, and managerial competencies. Agricultural education therefore plays a strategic role in preparing individuals capable of understanding, adopting, and further developing modern agricultural technologies. Beyond the mastery of agronomic and agribusiness theories, agricultural education emphasizes practical skills, entrepreneurship, and technological adaptability through integrated vocational learning (Handayani et al., 2020). Educational curricula—from vocational secondary schools to higher vocational institutions—are designed to balance theoretical knowledge and field-based practice in order to meet the demands of modern agricultural industries (Astuti et al., 2024).

Alongside digital transformation, agricultural education increasingly focuses on developing competent, creative, and adaptive learners capable of addressing twenty-first-century challenges. Practical competence, digital literacy, and experiential learning have become central components of curriculum development and instructional practices (Mustofa et al., 2024; Sulaiman et al., 2023). However, despite the rapid growth of smart farming research, studies that explicitly integrate digital agricultural technologies into curriculum design and pedagogical models remain limited and fragmented. This gap reflects a disconnect between technological advancement in agriculture and pedagogical innovation in agricultural education.

Accordingly, a comprehensive mapping of research developments is necessary to understand existing patterns and identify future research directions. This study employs a bibliometric analysis to examine research trends, thematic structures, and potential research opportunities related to smart farming in agricultural education during the 2020–2025 period.

RESEARCH DESIGN AND METHODOLOGY

This study employed a structured bibliometric approach to examine research trends and developments in smart farming and agricultural education in Indonesia. The methodology comprised three stages: (1) data collection through targeted bibliographic searches, (2) filtering and selection of relevant publications, and (3) bibliometric analysis using specialized software to visualize research networks and

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thematic trends. This approach ensured that the dataset was both comprehensive and focused on the national research context.

Search Stage

Google Scholar was employed to identify bibliographic sources for the database used in this study. It was selected because it is one of the largest databases providing access to peer-reviewed literature. The search was limited to specific criteria to ensure relevance, focusing on journal article titles, abstracts, and keywords. The search was conducted using the keywords: "smart farming, agricultural education, Indonesia."

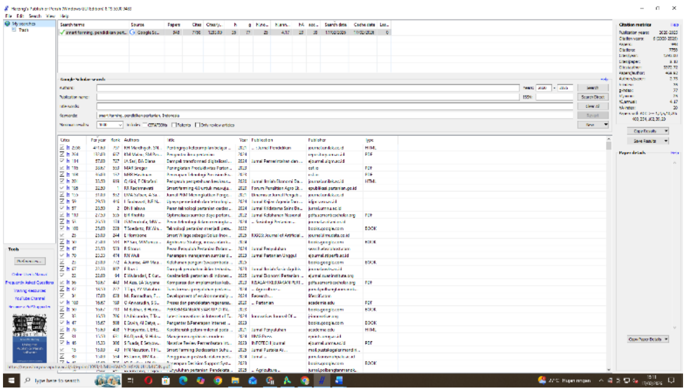

Figure 1. Search Stage

Filtering Stage

In the filtering stage, a selection process was conducted to identify articles suitable for analysis. The bibliographic data considered included article titles, abstracts, keywords, and document types such as research articles or reviews. The initial search in Google Scholar yielded 948 bibliographic records. After screening, books (69 records) and items without a publication year (45 records) were excluded, resulting in a final dataset of 834 articles selected for analysis (see Table 1).

Publication Year	Article Selected
2020	31
2021	47
2022	49
2023	138
2024	206
2025	362
Total	833

Table 1. Results of Bibliographic Selection

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Bibliometric Analysis Stage

Bibliometric analysis was conducted using VOSviewer, a software tool designed to visualize bibliometric maps and networks. Its text-mining functionality allows the identification and visualization of relationships, including co-authorship, keyword co-occurrence, and co-citation patterns. Bibliometric analysis benefits greatly from computerized data processing, and the increasing volume of publications in recent years has made such analyses particularly valuable. To ensure statistical reliability, the dataset must be sufficiently large and systematically organized (Ellegaard & Wallin, 2015).

The filtered bibliographic records exported from Google Scholar in RIS file format were first imported into Mendeley for organization and then exported for use in VOSviewer. Bibliometric maps were generated from the data to visualize patterns of author collaboration, keyword relationships, and thematic clusters. This approach provided clear insights into the structure and development of research networks within the field of smart farming and agricultural education in Indonesia. The resulting visualizations facilitated both descriptive and analytical interpretation of publication trends, key authors and institutions, and thematic evolution within the research domain (Van Eck & Waltman, 2010).

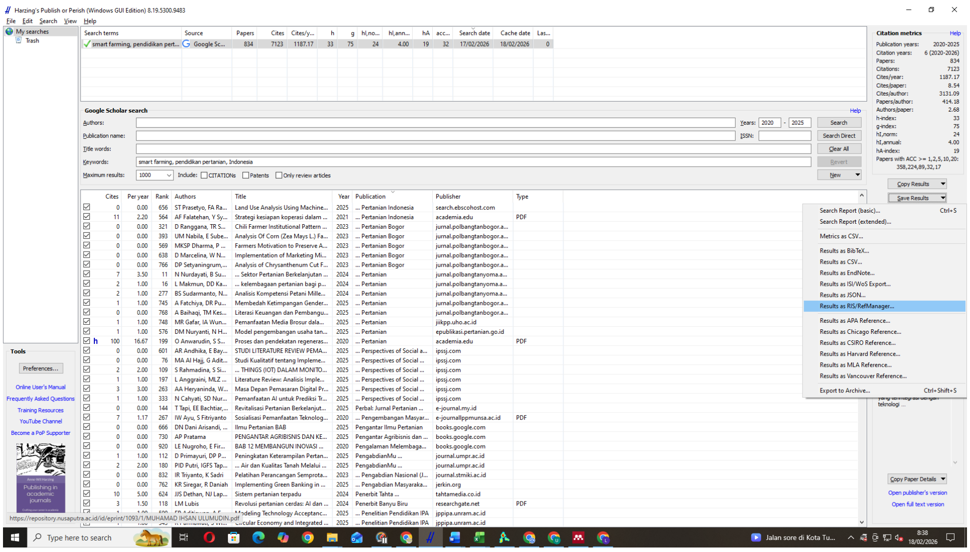

Figure 2. Export file RIS Excel

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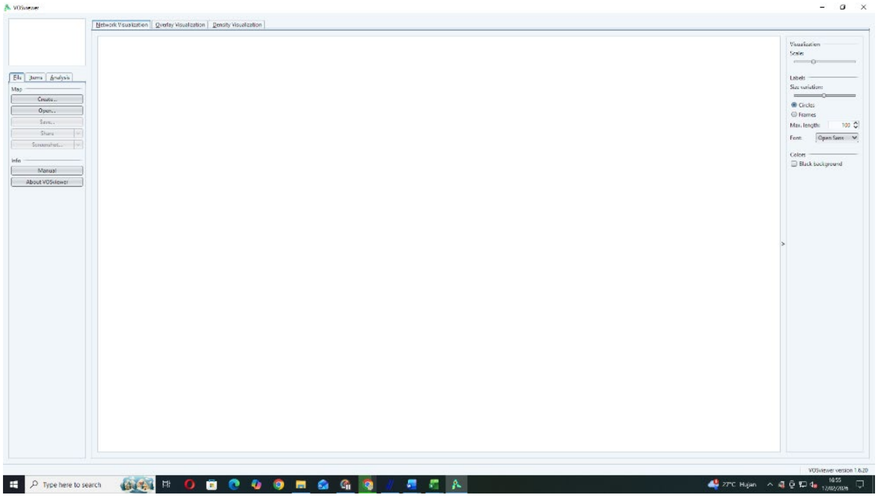

Figure 3. Accessing VOSviewer to Visualize the Analysis Results

RESULTS AND DISCUSSION

A bibliographic search using **Publish or Perish** via Google Scholar with the keywords *smart farming, agricultural education, Indonesia* initially yielded 948 records. After filtering to exclude books and entries without a publication year, 833 articles were retained for analysis. The annual distribution of publications reveals a clear and significant upward trend: 31 articles in 2020, 47 in 2021, 49 in 2022, 138 in 2023, 206 in 2024, and 362 in 2025. The sharp increase from 2023 onwards suggests that research on smart farming within the context of agricultural education in Indonesia has gained broader attention. This growth can be attributed to the accelerated digital transformation of the agricultural sector, national agricultural digitalization programs, and the increasing integration of IoT and precision agriculture technologies in both research and educational practices. Overall, this trend indicates that the field is currently in a **research growth phase**.

Network Visualization of Co-occurring Keywords

The bibliometric analysis using **VOSviewer** generated a network visualization illustrating relationships among keywords derived from article titles, abstracts, and author-assigned keywords. The mapping revealed four primary clusters (Table 2), representing the thematic structure of research in the field. In the network, larger nodes indicate keywords with higher frequency, while thicker lines denote stronger co-occurrence relationships. These visualizations provide a clear depiction of the major themes, research focus areas, and interconnected concepts within smart farming and agricultural education in Indonesia, highlighting both established topics and emerging trends.

No	Cluster	Cluster Keyword
1	Cluster 1	Artificial Intelligence
		bidang
		Big data

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No	Cluster	Cluster Keyword
		Climate smart agriculture
		csa
		di indonesia
		drone
		Greenhouse
		iklim
		Indonesia
		Internet
		iot
		Irrigation
		Metode
		Pangan
		Pertanian Cerda
		Pest
		Petani
		Produktivita
		Real time
		Sektor
		Sensor
		System
		Smart
		Smart agriculture
		Soil moisture
		Studi kasus
		Teknologi
		Temperature
		thing
2	Cluster 2	Access
		activity
		Agriculture productivity
		article
		Community service
		Community service activity
		Community serive program
		Concept
		effort
		Farmer group
		Field
		Future
		Increase
		Information technology
		Journal
		Knowledge
		Kwt
		Modern agriculture

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No	Cluster	Cluster Keyword
		number
		Partner
		Precision farming
		Service
		skill
		Smart farming system
		Socialization
		Stage
		Student
		Sustainability
		Training
		year
		Young farmer
3	Cluster 3	Agricultural extension
		Agricultural extension worker
		Agricultural land
		Ambulu district
		Characteristic
		Descriptive analysis
		Extension
		Extension worker
		Factor
		Farmer behavior
		Influence
		Interview
		Level
		Luwu regency
		Motivation
		Observation
		Performance
		Production
		Relationship
		Research method
		Respondent
		Rice farmer
		Sem
		Sl csa
		Success
		welfare
4	Cluster 4	Age
		Change
		Covid
		Day
		Impact
		Intervention arm
		Patient

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No	Cluster	Cluster Keyword
		strategy

Table 2. Source: Researcher-processed primary and secondary data using VOSviewer (2025)

The co-occurrence analysis conducted using VOSviewer identified four major thematic clusters (figure 4) that collectively represent the intellectual structure of smart farming research in Indonesia. The network configuration reveals a strong technological concentration, with comparatively weaker integration of educational and sustainability dimensions as core epistemological foundations.

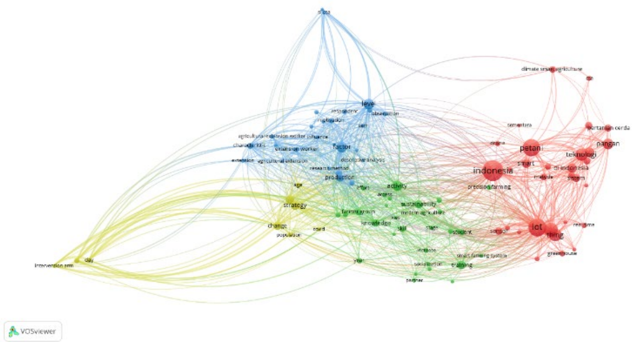

Figure 4. Network Visualization of Smart Farming and Agricultural Education Research in Indonesia

Cluster 1. Technology-Driven Core

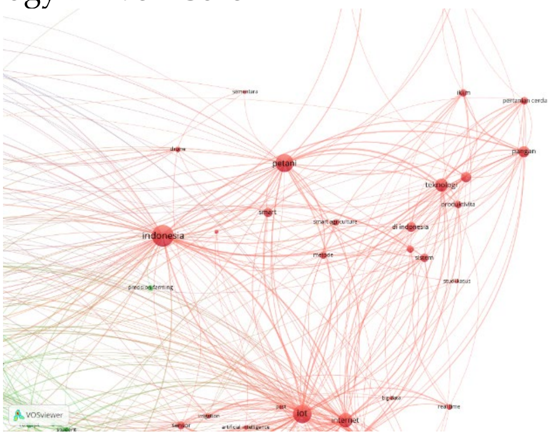

Figure 5. Cluster 1. Technology-Driven Core

Cluster 1 (Red) in Figure 5 represents the technology-driven core of the smart farming research landscape in Indonesia. This cluster is the most dominant and centrally positioned within the network, indicating a high level of keyword co-occurrence and conceptual interconnectedness. The cluster includes key terms such as *IoT*, *artificial intelligence*, *big data*, *sensor*, *real-time*, *smart agriculture*, *precision farming*, *drone*, *greenhouse*, *soil moisture*, *temperature*, *irrigation*, *climate-smart agriculture* (*CSA*), *technology*, *Indonesia*, and *farmer*. The prominence and dense linkages among these terms suggest that current research is primarily oriented toward technological system

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development and digital infrastructure integration in agricultural practices. The central position of *IoT* and related sensor-based technologies indicates that the dominant discourse revolves around automation, environmental monitoring, and data-driven decision-making. The frequent association between *smart agriculture* and technical components such as sensors, temperature control, and irrigation systems reflects a systems-engineering approach, where agricultural productivity is enhanced through real-time data acquisition and algorithmic optimization. Although *climate-smart agriculture* appears within this cluster, its integration is largely technological rather than conceptual. Sustainability is framed in terms of technological efficiency and climate adaptation tools rather than as a broader socio-ecological transformation paradigm.

Overall, Cluster 1 demonstrates that smart farming research in Indonesia remains strongly embedded in a techno-centric paradigm, prioritizing innovation in digital tools, hardware systems, and automation mechanisms. This dominance suggests that technological advancement is currently the primary driver of scholarly inquiry in the field, while educational and institutional transformation remain secondary themes within the broader network structure.

Cluster 2 capacity-building and community engagement

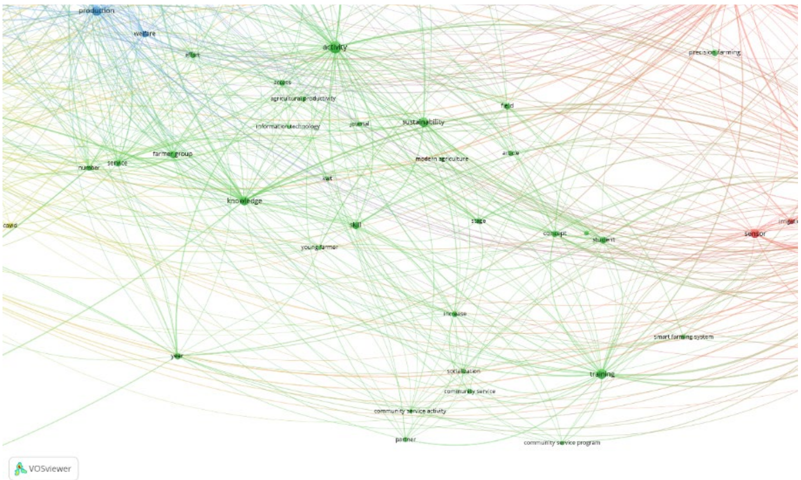

Figure 6. Cluster 2 capacity-building and community engagement

Cluster 2 (Green) in Figure 6 represents the capacity-building and community engagement dimension of smart farming research in Indonesia. Compared to the technology-dominant Cluster 1, this cluster reflects a more socio-institutional orientation, emphasizing knowledge transfer, human capital development, and participatory implementation processes. The cluster includes keywords such as *training*, *student*, *farmer group*, *knowledge*, *skill*, *community service*, *community service activity*, *socialization*, *sustainability*, *young farmer*, *smart farming system*, *modern agriculture*, *precision farming*, and *information technology*. The co-occurrence pattern suggests that smart farming is frequently associated with extension-based education, community empowerment programs, and practical skill enhancement initiatives. The presence of terms such as *student* and *training* indicates that educational elements are incorporated into the discourse; however, their network position suggests that education functions primarily as an implementation mechanism rather than a

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structural domain of curricular reform. In other words, this cluster reflects applied capacity development—focusing on workshops, field training, and community-based programs—rather than formal curriculum redesign or digital pedagogical innovation. Furthermore, the inclusion of *sustainability* within this cluster signals an awareness of long-term agricultural resilience. Nevertheless, sustainability appears operationally linked to skill improvement and programmatic interventions rather than embedded within an integrated sustainability education framework. Overall, Cluster 2 illustrates that smart farming research in Indonesia acknowledges the importance of human resource development and community participation. However, the semi-central position of this cluster indicates that capacity building remains supportive to technological innovation, rather than serving as the primary driver of transformation. This suggests that educational integration is present but not yet institutionalized within formal agricultural education systems.

Cluster 3 Socio-Behavioral And Institutional Extension

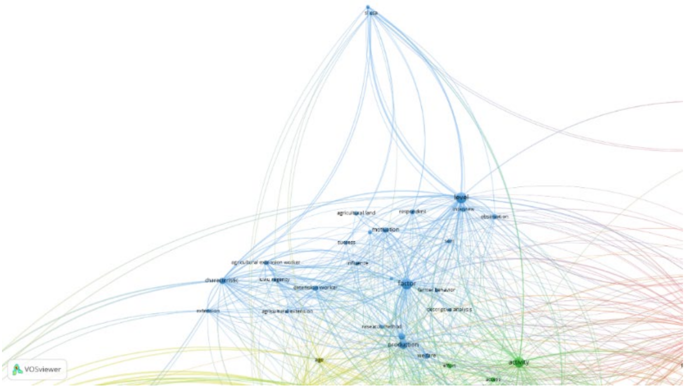

Figure 7. Cluster 3 Socio-Behavioral And Institutional Extension

Cluster 3 (Blue) in Figure 6 represents the socio-behavioral and institutional extension dimension of smart farming research in Indonesia. This cluster emphasizes the human and organizational factors influencing the adoption and effectiveness of digital agricultural technologies. The cluster includes keywords such as *agricultural extension*, *extension worker*, *farmer behavior*, *motivation*, *performance*, *production*, *welfare*, *success*, *rice farmer*, *factor*, *influence*, *relationship*, *respondent*, *interview*, *observation*, *descriptive analysis*, and *SEM*. The presence of these terms indicates a strong analytical focus on identifying determinants that affect farmers' acceptance, adaptation, and utilization of smart farming technologies. Unlike Cluster 1, which is technology-centered, Cluster 3 is structured around adoption dynamics and behavioral responses. The frequent use of methodological keywords such as *SEM* and *descriptive analysis* suggests that quantitative modeling approaches dominate this line of research, particularly in examining causal relationships between extension services, farmer characteristics, motivation levels, and production outcomes. The centrality of *agricultural extension* and *extension worker* highlights the strategic role of institutional intermediaries in facilitating technology diffusion. This aligns with an innovation diffusion perspective, where extension agents act as change agents bridging technological development and farmer-level implementation. However, despite its importance in understanding adoption mechanisms, this cluster remains primarily productivity-oriented. The analytical emphasis is placed on improving production,

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welfare, and performance rather than transforming educational systems or embedding digital literacy into formal agricultural curricula.

Overall, Cluster 3 demonstrates that smart farming research in Indonesia recognizes the critical role of social structures and behavioral determinants in technology adoption. Nevertheless, the focus remains on optimizing diffusion and performance outcomes, rather than redefining agricultural education or institutional learning systems as central drivers of digital transformation.

Cluster 4 Contextual and Demographic

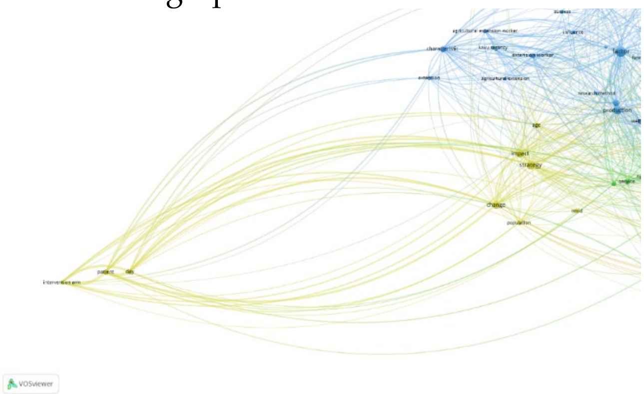

Figure 8. Cluster 4 Contextual and Demographic

Cluster 4 (Yellow) in Figure 6 represents the contextual and demographic dimension within the smart farming research network. Compared to the other clusters, this cluster appears more peripheral, indicating a lower level of thematic centrality and interconnection within the overall structure. The cluster includes keywords such as age, change, impact, COVID, strategy, day, intervention arm, and patient. The presence of these terms suggests that this body of research incorporates external contextual variables and demographic characteristics when examining agricultural transformation processes. In particular, age reflects generational factors influencing technology adoption, while COVID and impact point to situational disruptions affecting agricultural systems and extension activities. However, the relatively weak connectivity of this cluster indicates that demographic and contextual variables are generally treated as supplementary or control variables rather than as core structural determinants shaping smart farming systems or educational reform. These factors are often included to explain variation in adoption behavior, strategic responses, or short-term adaptive measures, rather than to construct comprehensive transformation models. The inclusion of terms such as strategy and change implies recognition of dynamic agricultural environments. Nevertheless, these concepts are not strongly integrated with the dominant technological cluster or the capacity-building cluster, suggesting limited conceptual synthesis between systemic change and digital agricultural innovation. Overall, Cluster 4 reflects a contextual analytical layer within the research landscape. It highlights awareness of demographic diversity and external shocks but remains marginal in driving the primary research agenda. This peripheral positioning suggests that future research could more deeply integrate generational

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change, crisis resilience, and adaptive strategy into the core discourse of smart farming and agricultural education transformation.

Citation Analysis and Most Influential Articles

In addition to analyzing publication trends and keyword cluster mapping, this study also identified the most highly cited articles as an indicator of academic influence within the relevant research field. Based on data processed through **Publish or Perish** (Google Scholar) for the period 2020–2025, the three articles with the highest citation counts are presented in Table 3. The most cited article is by Mardhiyah et al., (2021), with 2,358 citations. This article emphasizes the importance of 21st-century skills in human resource development, conceptually linking to the need for digital and adaptive competencies in the era of technology-based agriculture. The next most cited article is by Aini and Oktafani (2020)**.** with 201 citations, which discusses factors influencing students' entrepreneurial interest, relevant to strengthening entrepreneurial capacity in the modern agribusiness sector. Following this Rachmawati (2021) received 195 citations for a study on Smart Farming 4.0 as a strategy for modernizing Indonesian agriculture. These findings indicate that highly cited articles tend to focus on human resource competency development, entrepreneurship, and agricultural sector modernization. Meanwhile, research that specifically integrates smart farming into curriculum design or agricultural education learning models remains relatively limited. This highlights an opportunity for further research on the pedagogical integration of digital agricultural technologies within agricultural education systems in Indonesia.

No	Authors	Year	Title	Journal	Citations
1	Mardhiyah et al., 2021	2021	Pentingnya Keterampilan Belajar di Abad 21 sebagai Tuntutan dalam Pengembangan SDM	Lectura: Jurnal Pendidikan	2,358
2	Aini & Oktafani, 2020	2020	Pengaruh Pengetahuan Kewirausahaan dan Motivasi terhadap Minat Berwirausaha Mahasiswa	Jurnal Ilmiah Ekonomi dan Bisnis	201
3	Rachmawati, 2021	2021	Smart Farming 4.0 untuk Mewujudkan Pertanian Indonesia Maju, Mandiri, dan Modern	Forum Penelitian Agro Ekonomi	195

Figure 9. Table 3. Articles with the Highest Citations Related to Smart Farming and Agricultural Education (2020–2025)

CONCLUSION

This bibliometric study provides a comprehensive overview of research trends, thematic structures, and influential publications on smart farming within agricultural education in Indonesia during the 2020–2025 period. The analysis reveals a marked increase in research output, particularly from 2023 onward, reflecting growing attention to technological integration, digital transformation, and precision agriculture in the national agricultural education context. Network visualization identified four major thematic clusters: (1) a technology-driven core emphasizing IoT, artificial intelligence, big data, and smart agriculture systems; (2) capacity-building and community engagement, highlighting extension programs, training, and skill development; (3) socio-behavioral and institutional extension, focusing on farmer adoption, motivation, and organizational factors; and (4) contextual and demographic variables, reflecting external factors such as generational differences and situational disruptions. The predominance of technology-focused research indicates that innovation in digital tools and automation remains the primary driver of scholarly

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inquiry, while educational integration, curriculum development, and pedagogical innovation are secondary and less systematically explored. Citation analysis further demonstrates that the most influential studies emphasize human resource competency, entrepreneurship, and the modernization of agricultural practices, suggesting that research impact is strongly linked to both technological adoption and capacity development. Despite these advancements, there remains a research gap in integrating smart farming technologies into formal agricultural education curricula and pedagogical frameworks.Overall, this study highlights the need for future research to bridge the gap between technological innovation and educational implementation. Specifically, integrating digital agricultural technologies into curriculum design, experiential learning, and pedagogical models could strengthen the preparedness of agricultural graduates to meet the demands of modern, technology-driven farming systems. The findings provide valuable guidance for policymakers, educators, and researchers seeking to align smart farming innovation with human resource development and sustainable agricultural practices in Indonesia.

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