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Empowerment Strategy Model For Coastal Horticultural Farmers through Technology Adoption and Innovation among Coastal in Ambal District, Kebumen Regency

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Abstract
Background: Coastal horticulture supports the food security and welfare of farmers in Ambal District, Kebumen, with great potential for cultivating melons, watermelons, and chili peppers. However, since the introduction of technology and innovation is still far from optimal, an effective farmer empowerment strategy is needed.
Objective: This study aims to analyze the factors influencing technology adoption and innovation, assess the level of technology adoption and innovation among coastal horticultural farmers, and develop a strategic framework for farmer empowerment.
Methods: Using the Slovin method in six villages, a quantitative explanatory survey was conducted targeting 344 coastal horticultural farmers. The data was analyzed using structural equation modeling (SEM) with AMOS, investigating agricultural extension workers, social media, social norms, and digital literacy, utilizing social norms and digital literacy as mediators.
Results: Extension workers, social norms, and digital literacy have a significant and positive impact on technology adoption and innovation. Social media has no direct impact but delivers significant indirect effects through digital literacy. Social norms mediate the influence of extension workers. Adoption rates and innovation were highly rated (average = 3,808 points).
Conclusion: Social norms, digital literacy, and the spread of workers are the strongest correlations between technology adoption and innovation, but causal interpretation should be done carefully when considering cross-cutting design. Priority strategies include strengthening farm systems by farm corporations, improving digital literacy, and involving young farmers as drivers of modernization. This is supported by activated outreach services, technology-based regional development, and strong marketing and agricultural business partnerships.

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INTRODUCTION

Globally, the adoption of digital and modern agricultural technologies among smallholder farmers and horticulture is highly uneven, and this trend is widely documented as the digital divide in agriculture. Recent evidence from developing regions suggests that limited infrastructure, low digital literacy, and weak scaling support limit technology adoption even when digital tools are available (Choruma et al., 2024). Additionally, systematic reviews have shown that the effects of agricultural extension vary significantly in filling adoption gaps in socioeconomic and institutional contexts in developing countries (Becerra-Encinales et al., 2024). These global patterns support that regional empowerment interventions examined in this study need to be based not only on technological access but also on technical and social-institutional factors.

Community empowerment is a crucial process in development, where communities actively engage to enhance the capabilities of individuals and groups, creating positive and sustainable change (Harangan, 2023). In Indonesia, according to national agricultural statistics, many small-scale horticultural farmers, including along the Kebumen coast, still rely on conventional cultivation, reflecting the global disparities in technology adoption (BPS, 2023). Therefore, farmer empowerment is necessary not only to increase production but also to close this adoption gap by improving access to knowledge and technology.

A deeper look at empowerment can be described as a concept of economic development that includes community values aimed at building a new paradigm of human-centered, participatory, empowering, and sustainable development (Alim et al., 2022; Chambers, 1996). In other words, development not only meets basic needs but also includes efforts to find alternatives to regional economic growth based on the potential of local communities.

Empowerment refers to efforts and processes aimed at raising the awareness, motivation, and ability of communities to recognize, manage, maintain, protect, and improve their own well-being. In the agricultural context, empowerment is expected to enhance farmers' awareness, capacity, and autonomy in sustainably managing resources (which can be implemented and developed over the long term) (Alim et al., 2022).

While coastal agriculture holds great potential, a careful approach is needed to address the challenges it faces. With the right approach, coastal agriculture can contribute to food security and environmental sustainability in coastal areas. Coastal soils are sandy soil derived from volcanic ash, known as Legosol soil found along the coast (Gunadi, 2002; Indrawan & Sunjoto, 2026). This condition supports the development of various horticultural products such as melons, watermelons, chili peppers, and shallots.

Located on the southern coast of Java Island, Kebumen Regency features a typical geographical condition of vast sandy coastlines affected by the high waves of the Indian Ocean. It also holds great potential for horticultural cultivation, such as watermelons, chili peppers, and melons, which are tolerant of sandy soils.

Horticultural agriculture along the coast of Ambal District and Kebumen Regency faces various challenges in cultivation. Challenges faced include damage from pests and plant diseases, low prices during key harvest periods, and limited access to the latest technologies for farmers. The development of agricultural technology provides solutions to improve agricultural productivity and efficiency. However, the level of modern technology introduction by coastal horticultural farmers in Ambal district is still not optimal. Many farmers prefer traditional methods, even if the results are not optimal. The low adoption rate of this technology is influenced by various factors, including limited access to information, limited capital, low education levels, and social resistance to change. Preliminary local data from the Ambar Agricultural Expansion Center (BPP) and the Kebumen District Agriculture and Food Department showed that prior to this study, the vast majority of coastal horticultural farmers in the six study villages did not consistently apply recommended cultivation techniques such as drip irrigation, high-quality seeds, and biological pest control, instead relying on traditional methods passed down among farmers (Distapang, 2024). These basic conditions do not contradict the high SEM adoption score (mean = 3.808) measured later, but rather reflect that, although adoption has improved afterward, unevenness remains between villages and technology types, precisely the gaps investigated in this study.

The main gap is the suboptimal level of technology adoption by coastal horticultural farmers. Ideally, utilizing modern technologies will improve agricultural productivity, efficiency, and sustainability. However, in reality, many farmers still use traditional methods that do not yield optimal yields. It is necessary to deeply study the gap between ideal and actual conditions in empowering horticultural farmers, and to focus on expanding the adoption of agricultural technology through an empowerment strategy.

The Kebumen District Agriculture and Food Department states that the introduction and adoption of technological innovations among farmers are still uneven. This condition is influenced by several constraints, including declining human resource capacity in technology dissemination, farmer organizations that are not yet fully business-oriented, low interest among the younger generation in the agricultural sector, and the need to improve farmers' capacity and competencies (Distapang, 2024). Here are the details (Kebumen Regional Regulation No. 11, 2024) One of the challenges facing the agricultural sector regarding the regional medium-term development plan is the limited access to technology and funding among farmers.(Sari and Joding, 2024) stated that the main factor hindering technology adoption suggests a lack of access to information. Other Research by (Lily, Suandi, Wahyuni, 2024) stated that 54.20% of farmers have accepted the process of introducing technological innovations recommended by agricultural extension workers. Furthermore, the success of technological innovation is also influenced by the socioeconomic, cultural, and institutional characteristics of farmers (Sihongbing, 2022).

Overall, these studies argue that limited access to information and weak support for expansion are recurring barriers to technology adoption among coastal and horticultural farmers (Lily et al., 2024; Sari & Djodding, 2024; Sihombing, 2022). However, the two differ in scope and method. Sari and Djodding (2024) rely on qualitative explanations of coastal communities dependent on fisheries; Lily, Suandi, and Wahyuni (2024) report adoption rates of single goods without examining psychosocial mechanisms; and Sihombing (2022) emphasizes socioeconomic and institutional factors that do not link structural models. None of these studies simultaneously examined the roles of extension workers, social media, social norms, and digital literacy within a single structural framework, nor did they examine social norms and digital literacy as shared mediation mechanisms. This research has addressed this gap.

Challenges and challenges farmers face when adopting technology include limited access to financial resources, lack of knowledge about new technologies, and socioeconomic barriers such as resilience to habits and changes.

The economic potential of Kebumen Province focuses on the potential of natural resources such as forestry, agriculture, fisheries, plantations, and livestock. Kebumen Province aims for a vision for 2025, aiming for an independent and prosperous Kebumen based on agricultural business (Cahyanto & Afifah, 2025; Mulyani et al., 2018) The Ambal District is one of the districts within Kebumen Province, located along the coast, adjacent to the Indian Ocean, and adjacent to several other districts such as Ktwynannu, Milit, and Burspe Santren (Kebmen, 2024).

The vast majority of the population in Ambal District are engaged in agriculture among food crop farmers and horticultural farmers of various age groups. Table 1 shows the number of agricultural households and the age group of household heads by village in Ambal District.

Table 1
Number of agricultural households by village and age group of household heads in Ambal District in 2023

Village	Age group of head of household							Total
	0-14	15-24	25-34	35-44	44-54	55-64	65+	
Entak	-	-	38	119	134	118	95	504
Plempukankembaran	-	-	15	55	54	65	52	241
Kenoyojayan	-	-	35	78	85	79	65	342
Ambalresmi	-	1	48	132	157	153	153	644
Kaibonpetangkaran	-	1	30	93	144	79	61	408
Kaibon	-	1	40	90	123	87	82	423
Sumberjati	-	-	24	109	119	96	72	420
Blengorwetan	-	-	29	95	101	92	79	396
Blengorkulon	-	1	28	103	123	120	87	462
Benerwetan	-	-	9	66	93	78	63	309
Benerkulon	-	-	24	113	143	151	112	543
Ambalkliwonan	-	1	29	92	131	94	61	408
Pasarsenen	-	1	24	86	124	89	70	394
Pucangan	-	1	15	62	73	71	70	292
Ambalkebrek	-	-	21	67	84	72	55	299
Gondanglegi	-	1	62	120	157	133	95	568
Banjarsari	-	-	9	26	55	49	60	199
Lajer	-	-	10	62	103	105	85	365
Singosari	-	-	15	76	108	119	86	404

Village	Age group of head of household							Total
	0-14	15-24	25-34	35-44	44-54	55-64	65+	
Sidoluhur	-	1	30	179	239	214	190	853
Sinungrejo	-	-	10	53	110	125	113	411
Ambarwinangun	-	-	11	47	99	104	112	373
Peneket	-	-	14	60	88	100	94	356
Sidorejo	-	-	7	46	51	76	62	242
Sidomulyo	-	-	14	44	83	88	89	318
Sidomukti	-	1	11	52	119	117	104	404
Prasutan	-	-	10	32	50	81	61	234
Kradenan	-	-	12	35	68	76	73	264
Pagedangan	-	-	13	78	131	143	131	496
Surobayan	-	-	22	60	89	119	91	381
Dukuhrejosari	-	1	14	69	100	99	71	354
Kembangsawit	-	-	8	31	84	84	59	266
District Ambal	-	11	681	2430	3422	3276	2753	12573

Source: (BPS, 2023)

Ambal district has great potential for development in agriculture, especially in the field of horticultural crops. The development of horticultural crops in the Ambal district has continued for a long time, as shown in Table 2.

Table 2
Development of horticultural crops in the Ambal district

No	Types of Activities	Year	Budget Information Sources
1.	Melon Farming Village	2024	Directorate General of Horticulture, Ministry of Agriculture
2.	Screen House Modern	2024	Directorate General of Horticulture, Ministry of Agriculture
3.	Shallot Development	2023	Directorate General of Horticulture, Ministry of Agriculture
4.	Shallot Development	2022	Directorate General of Horticulture, Ministry of Agriculture
5.	Growing Chili Pepper Plants	2022	Agriculture and plantation office Central Java Province

Source: Ambal Subdistrict BPP

Agricultural extension workers play an important and vital role in the development of the agricultural sector. They serve as bridges of scientific knowledge, technology, and agricultural practices, and also connect agriculture and rancher communities. The role of agricultural extension workers accounts for 63.33%, significantly contributing to the success of the horticultural farmer group in Wonosovo County (Mahmuda, Satomoko, Marudiningshi, 2019)Mentoring activities by agricultural extension workers for cayenne pepper farmers in Wajo Province have been highly effective. (Harima and Jawas, 2024).

Agricultural extension workers function as motivators, communicators, facilitators, and innovators who influence the development of farmer groups (Marbun, et al., 2019; Sakir et al., 2025). The direct extension method has a significant positive effect on the skills of horticultural farmers (Jandu & Utama, 2024). Furthermore, agricultural extension staff also support farmer group organizations through the " Training, Farmer Visits, and Supervision " system based on Minister of Agriculture Regulation No. 67 of 2016.

Agricultural extension workers provide appropriate information, support, and guidance. It contributes to improving productivity, welfare, and sustainability in agricultural businesses. Factors influencing the decline in horticultural products include the social behavior of extension workers, the accuracy of expansion plans, the implementation of extensions, and the fulfillment of farmers' expectations (Sudarko et al., 2022).

The rapid development of information and communication technology has brought significant changes to various aspects of life, including agriculture. Digital transformation is driving the emergence of various technological innovations that can be leveraged to enhance agricultural productivity, efficiency, and competitiveness. In this context, digital literacy is a crucial capability that farmers should have to optimally access, understand, and utilize technology-based information.

Digital literacy includes not only the ability to use technical equipment, but also information management, critical thinking about digital content, and adaptability to dynamic technological innovation. From a scientific perspective, digital literacy is often linked to the ability to access, understand, and utilize digital information, as well as the role it plays in technology adoption (Aranguri et al., 2025). Digital literacy is a crucial factor for improving efficiency and technology adoption. Therefore, digital literacy has become a crucial factor supporting the introduction of technological innovation in the agricultural sector (Xu et al., 2026).

The technological innovations adopted by horticultural farmers in Kebumen Regency, Ambal district can be classified based on various aspects of agricultural activities. From a production technology perspective, they already use high-quality, labeled seeds that offer advantages such as disease resistance, shorter harvest periods, and high yields. Using liquid organic fertilizers or solid organic fertilizers as alternatives to chemical fertilizers to improve soil fertility. Some people use drip irrigation and agricultural machinery such as two- or four-wheeled tractors for cultivation.

Regarding plant pest control (OPT), biochemical agents and black and silver plastic mulch are already used to prevent weed growth. Farmers in Ambal district have adopted some of the above techniques because they have repeatedly used, skillfully, and consistently used them. Furthermore, they fully understand the usefulness of the techniques they use, and not only follow the trend of using them once but also become part of horticultural cultivation. However, not all existing horticultural farmers are leveraging the latest technologies to improve the quantity and quality of their crops. Information about the technologies they adopt comes from local agricultural extension staff, social media, and other communication tools.

In the agricultural context, social media functions as a means to spread information, communication, and interactive learning among farmers, extension staff, researchers, and agricultural institutions. Through platforms like Facebook, WhatsApp, Instagram, YouTube, and TikTok, farmers can share experiences, access technological innovations, and expand their marketing networks for horticultural products. Social media is not just a means of social interaction; it is also a platform for building professional networks, driving business, and widely disseminating information (Qadir & M. Ramli, 2024).

Social media serves as a modern communication channel that accelerates stages such as awareness of new technologies, interest in and evaluation of their benefits, trials based on experiences shared by other farmers, and real-world adoption.

The diffusion of innovation refers to the process of spreading new ideas and technologies to society and social groups. The process of technology adoption by farmers is influenced by five main factors: relative advantage, compatibility, complexity, test stability, and observability. The relative advantages indicate how much profit farmers feel compared to traditional methods (Rogers, 2023). Technological innovation has been used for decades as a means to improve farmers' efficiency and productivity, and even to enhance their economic well-being (Feronika et al., 2020, 2023).

The research gaps discussed here go beyond the practical gap between the ideal technology adoption conditions mentioned above and the actual technology adoption conditions. Previous research on farmers' technology adoption has generally examined the roles of spreading workers, social media, or socioeconomic characteristics individually. (Lily et al., 2024; Sari & Djodding, 2024; Sihombing, 2022) and other recent structural equation studies examine social or subjective norms as a single mediator without incorporating digital literacy into the same model (Yuniarsih et al., 2026). It has not been verified whether social norms and digital literacy function simultaneously, and whether outreach staff and social media serve as parallel intermediaries linking coastal horticultural farmers with technology adoption and innovation. This is the unique research gap addressed in this study.

The novelty of this study lies in integrating the roles of agricultural extension workers, social media, social norms, and the impact of digital literacy into a single structural equation model, and examining social norms and digital literacy as common mediating variables in the context of coastal horticultural agriculture. These factors are examined individually or compared to conventional technology introduction studies that rely on simpler regression analyses (Lily et al., 2024; Sari & Djodding, 2024; Yuniarsih et al., 2026), and this research goes beyond hypothesis testing; it further translates the obtained structural relationships into prioritized, evidence-based farmer empowerment strategies.

Therefore, the main research issues to focus on are the role of agricultural extension workers, the influence of social media, the influence of fellow farmers and social norms, and how digital literacy affects the adoption and innovation level of horticultural technology in Ambal District. Since expansion capacity, farmer institutions, intergenerational interests, and farmer capacity interact rather than independently, structural equation models are needed to identify structural relationships with high priority for empowerment interventions. This cannot be judged by mere descriptive or correlation analysis. This research is important because it can be used to develop more effective, sustainable, and locally appropriate empowerment strategies for coastal horticultural farmers. The formulation of the issue based on the above background asks what factors influence the adoption and innovation of technology among coastal horticultural farmers in Ambal district. What is the level of adoption and technological innovation among horticultural farmers in coastal areas? What are the strategies to empower farmers through the introduction of technology and innovation? The purpose of this study is to investigate the relationship between factors influencing technology adoption and innovation. Analyze the adoption and degree of technological innovation by horticultural farmers in coastal areas. Formulate strategies to empower farmers through the introduction of technology and innovation.

In addition to these goals, this study delivers practical benefits to evidence-based agricultural extension services, farmer organizations, and local governments to prioritize empowerment interventions for coastal horticultural farmers, and provides clearer guidance on the factors that most support technology adoption for farmers themselves. Academically, this research contributes to literature on technology adoption and smallholder empowerment, showing that it serves as a shared mediating mechanism through social norms and digital literacy in coastal horticultural environments.

METHOD

This study employs a quantitative approach with an exploratory research design aimed at explaining the causal relationship between the role of agricultural extension workers, social media, social norms, digital literacy, farmer characteristics, and the adoption and innovation of horticultural technologies. The study was conducted in Ambal Subdistrict, Kebumen Regency, specifically in the villages of Entak, Kenoyojayan, Ambalresmi, Kaibonpetangkaran, Kaibon, and Sumberjati. These locations were selected because they are coastal areas that have developed horticultural businesses through various forms of technological innovation, such as cultivation techniques, plant protection, drip irrigation, postharvest practices, agricultural information technology, mechanization, and locally-based innovations. This study was conducted from January to May 2026.

The study population consisted of farmers who cultivate seasonal horticultural crops in Ambal Regency. The sample size was determined using the Slovin formula with a 5% margin of error, resulting in a sample size of 370 respondents. The sampling technique used was proportional random sampling based on the number of horticultural farming households in each study village. The data used consisted of primary and secondary data. Primary data were obtained through interviews, observations, and questionnaires distributed to respondents, while secondary data were obtained from the Kebumen Regency Food, Agriculture, and Food Agency, the Kebumen Regency Central Statistics Agency, and relevant literature.

The variables in this study include technology adoption and innovation as endogenous variables; the role of agricultural extension workers and the influence of social media as exogenous variables; social norms and digital literacy as mediating variables; and farmer characteristics as control variables. The research instrument was designed as a questionnaire using a 1–5 Likert scale to measure respondents' perceptions of the indicators for each variable. Meanwhile, farmer characteristics such as age, educational level, and land area were measured using categorical options that were then coded ordinally.

Data analysis was conducted using Structural Equation Modeling (SEM) with the aid of AMOS software. The analysis stages included testing the validity and reliability of the instruments, data screening, normality testing, outlier testing, Confirmatory Factor Analysis (CFA), structural model testing, determination coefficient testing, path coefficient testing, and mediation testing. Construct validity was analyzed through factor loadings, Average Variance Extracted (AVE), and discriminant validity, while reliability was tested using Cronbach's Alpha and Construct Reliability (CR). Model fit was assessed based on several goodness-of-fit indices, including Chi-square/df, GFI, AGFI, CFI, TLI, and RMSEA. The results of the analysis were used to test hypotheses and formulate empowerment strategies for coastal horticultural farmers through technology adoption and innovation. The Variable Relationship Model:

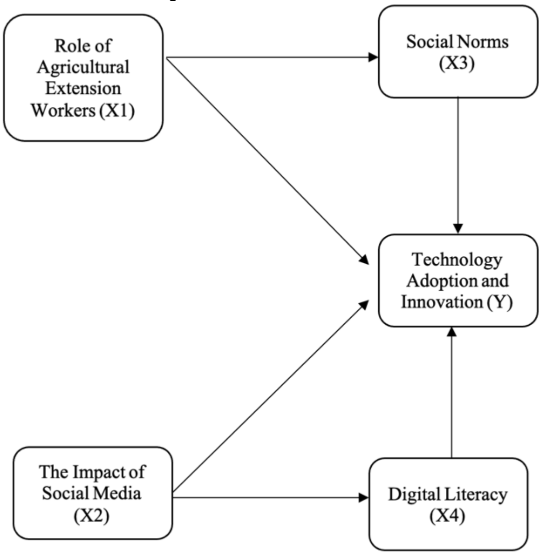

Figure 1. *Variable Relationship Model*

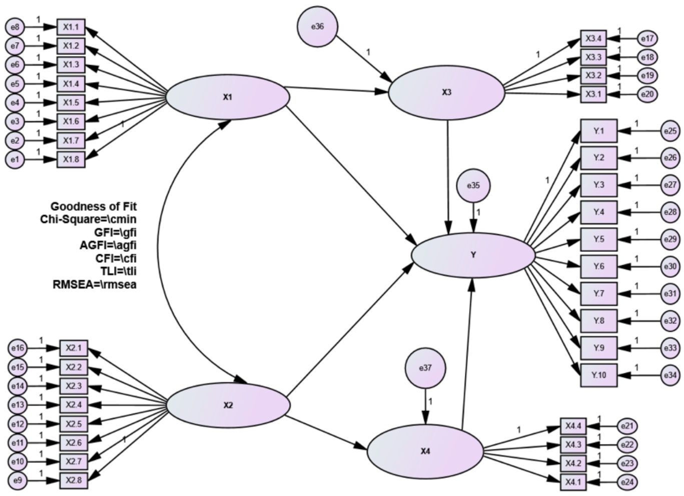

Figure 2. *AMOS SEM Model Scheme*

RESULTS AND DISCUSSION

Results of validity and reliability tests

Preliminary results from validity and reliability tests of the research device

Data collected from questionnaires on the Likert scale 1 to 5 were validated and reliability before SEM analysis. AMOS (Moment Structure Analysis) is software used for statistical analysis based on structural equation modeling (SEM). The term Structural Equation Modeling (SEM) combines two key aspects of the procedure. (1) The process of interactions in research represented by a series of structural equations (e.g., regression analysis); (2) Forming structural relationships in drawings to make it easier for researchers to understand the theoretical concepts (frameworks) in their research (Junaidi, 2021; Yao et al., 2022).

Validity testing is conducted to determine whether research instruments can measure what they need to measure. Validity refers to the level of accuracy and precision of the equipment that discloses data based on the concept of the subject of study. In this study, validity verification was conducted by comparing the calculated r values with r tables. If the calculated value of r at a certain significance level is greater than the value of r in table, the definite item is declared valid. Conversely, if the calculated r value is less than the value in the r table, the statement item is declared invalid and subject to erasure.

Furthermore, reliability testing is conducted to measure the consistency of measurement results. This reliability test was conducted on the Cronbach alpha, with acceptable limits ranging from 0.50 to ≥ 0.70 (Taherdoost et al., 2016; Zumitzavan, 2026) If the intermediate reliability value includes an alpha-Kronbach value of 0.50 to 0.70, an alpha-Kronbach value of 0.70–0.90 is considered a high or good reliability value, and an alpha-Kronbach value ≥ 0.90 is included in a very high or excellent reliability value. The validity and reliability test results using SPSS are shown in Table 3.

Table 3
Preliminary results from validity and reliability tests of the research device

Variable	Indicator	R Count	R Table	Validity	Cronbach's Alpha	Reliable/ Unreliable	If an invalid indicator is removed, the Cronbach's Alpha
The Role of Agricultural Extension (X1)	X1.1	0.580	0.102	Valid	0.920	Reliable	0.916
	X1.2	0.566	0.102	Valid		Reliable	0.912
	X1.3	0.548	0.102	Valid		Reliable	0.905
	X1.4	0.667	0.102	Valid		Reliable	0.904
	X1.5	0.600	0.102	Valid		Reliable	0.908
	X1.6	0.585	0.102	Valid		Reliable	0.905
	X1.7	0.531	0.102	Valid		Reliable	0.908
	X1.8	0.598	0.102	Valid		Reliable	0.917
The Impact of Social Media (X2)	X2.1	0.731	0.102	Valid	0.910	Reliable	0.897
	X2.2	0.706	0.102	Valid		Reliable	0.899
	X2.3	0.775	0.102	Valid		Reliable	0.893
	X2.4	0.698	0.102	Valid		Reliable	0.900
	X2.5	0.675	0.102	Valid		Reliable	0.902
	X2.6	0.748	0.102	Valid		Reliable	0.895
	X2.7	0.667	0.102	Valid		Reliable	0.902
	X2.8	0.678	0.102	Valid		Reliable	0.901
Influence among farmers and social norms (X3)	X3.1	0.423	0.102	Valid	0.610	Fairly reliable	0.515
	X3.2	0.447	0.102	Valid		Fairly reliable	0.507
	X3.3	0.274	0.102	Valid		Fairly reliable	0.642
	X3.4	0.450	0.102	Valid		Fairly reliable	0.495
Digital Literacy (X4)	X4.1	0.781	0.102	Valid	0.905	Reliable	0.878
	X4.2	0.830	0.102	Valid		Reliable	0.860
	X4.3	0.796	0.102	Valid		Reliable	0.873
	X4.4	0.738	0.102	Valid		Reliable	0.893
Technology Adoption and Innovation (Y)	Y1	0.406	0.102	Valid	0.780	Reliable	0.767
	Y2	-0.309	0.102	Invalid		Reliable	0.846
	Y3	0.626	0.102	Valid		Reliable	0.741
	Y4	0.500	0.102	Valid		Reliable	0.756
	Y5	0.477	0.102	Valid		Reliable	0.758
	Y6	0.665	0.102	Valid		Reliable	0.734
	Y7	0.576	0.102	Valid		Reliable	0.748
	Y8	0.602	0.102	Valid		Reliable	0.742
	Y9	0.621	0.102	Valid		Reliable	0.739
	Y10	0.508	0.102	Valid		Reliable	0.755

Source: Processed Primary Data (2026)

Based on the results of the validity test, all indicators are considered valid with a calculated r value greater than the r-table (0.102). Y2 measures barriers to technology adoption and innovation, while the other measures technology adoption and acceptance, meaning decoding is performed on the data under test. From the table 3, the calculated r value for the Y2 indicator is -0.309, which is less than the r-table value of 0.102, so this indicator is declared invalid. Even if the indicator is reverse-coded, its correlation value indicates a negative relationship with the overall construction score. This indicates that the Y2 metric is not consistent with other metrics that measure the same variable. Furthermore, the Cronback alpha result after removing the invalidity indicator (Y2) raises the reliability value from 0.780 to 0.846. Therefore, item Y2 can be considered excluded from subsequent analysis.

Final results of validity and reliability testing of research instruments

Since one indicator was found invalid in the initial results of the reliability test, validity and reliability testing were re-conducted. Validity and reliability results can be found in table 4.

Table 4
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	X1.4	0,667	0,102	Valid	0,920	Reliable	0,904
	X1.5	0,600		Valid		Reliable	0,908
	X1.6	0,585		Valid		Reliable	0,905
	X1.7	0,531		Valid		Reliable	0,908
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	X2.2	0,706		Valid		Reliable	0,899
	X2.3	0,775		Valid		Reliable	0,893
	X2.4	0,698	0,102	Valid	0,910	Reliable	0,900
	X2.5	0,675		Valid		Reliable	0,902
	X2.6	0,748		Valid		Reliable	0,895
	X2.7	0,667		Valid		Reliable	0,902
	X2.8	0,678		Valid		Reliable	0,901
Influence among farmers and social norms (X3)	X3.1	0,423		Valid		Fairly reliable	0,515
	X3.2	0,447		Valid		Fairly reliable	0,507
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Digital Literacy (X4)	X4.1	0,781		Valid		Reliable	0,878
	X4.2	0,830	0,102	Valid	0,905	Reliable	0,860
	X4.3	0,796		Valid		Reliable	0,873
	X4.4	0,738		Valid		Reliable	0,893
Technology Adoption and Innovation (Y)	Y1	0,406		Valid		Reliable	0,767
	Y3	0,626		Valid		Reliable	0,741
	Y4	0,500		Valid		Reliable	0,756
	Y5	0,477		Valid		Reliable	0,758
	Y6	0,665	0,102	Valid	0,846	Reliable	0,734
	Y7	0,576		Valid		Reliable	0,748
	Y8	0,602		Valid		Reliable	0,742
	Y9	0,621		Valid		Reliable	0,739
	Y10	0,508		Valid		Reliable	0,755

Source: Processed Primary Data (2026)

Table 4 show all indicators are valid and that r is a calculated value greater than table r (0.102). The Y2 indicator has been removed, and the alpha value of Kronback has increased to 0.846.

Initial Confirmed Factor (CFA) Analysis Results

Consocomic Factor Analysis (CFA) is an analytical method used to verify the suitability of measurement models based on predetermined theories. CFA aims to assess the relationship between potential components and the indicators that make them up, ensuring that each metric sufficiently represents the components being measured.

Furthermore, CFA is used to verify the quality of measurement models through construct validity and reliability evaluations, including unidimensionality, convergent validity, discriminant validity, and construct reliability. This analysis can also identify metrics that do not meet measurement criteria, such as low load rates or high errors, and allow for exclusion from the model (Hair & Sabol, 2025; Hair Joseph F et al., 2019).

Full Structural Model Analysis

Efforts to obtain a better structural model that meets the Goodness of Fit (GOF) criteria were carried out through a model modification process that took several aspects into account, namely the indicator loading factors, Modification Indices (MI), and the results of the Mahalanobis

Distance test. Indicators with factor loadings less than 0.50 were considered for removal because they did not adequately represent the construct. In addition, Modification Indices were used as a reference to modify the model—while still maintaining its theoretical basis—to improve model fit.

The Mahalanobis Distance test was conducted to detect the presence of multivariate outliers in the research data. An observation is classified as an outlier if its Mahalanobis Distance probability value is less than 0.001. The presence of multivariate outliers has the potential to affect parameter estimates and reduce the model's fit; therefore, appropriate measures must be taken to minimize potential bias in the SEM analysis.

Based on the test results, 26 respondents were identified as multivariate outliers because their Mahalanobis Distance probability values were below 0.001. Therefore, these observations were excluded from the analysis. Consequently, the sample size, which originally consisted of 370 respondents, was reduced to 344 respondents, who were subsequently used in the SEM analysis.

Based on the outlier removal process and model modifications made according to factor loadings and modification indices—while still taking the theoretical framework into account—a structural model with a better goodness-of-fit was obtained. The modified structural model is presented in Figure 3, while the goodness-of-fit evaluation results are presented in Table 5.

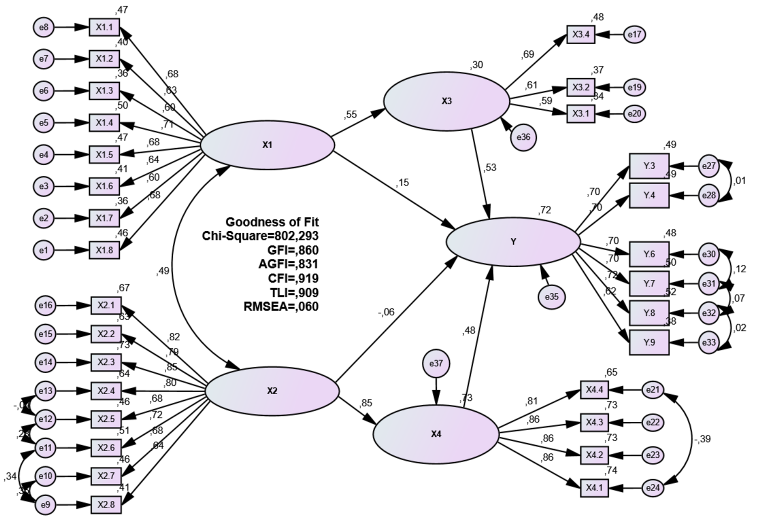

Figure 3. *Path Diagram of the Full SEM Model Estimation Results*

Based on figure 3, the structural model illustrates the relationships among the role of agricultural extension agents (X1), the influence of social media (X2), social norms (X3), digital literacy (X4), and technology adoption and innovation (Y). The path coefficient values indicate the strength of the influence between variables in the research model.

The role of agricultural extension workers (X1) has a positive effect on social norms (X3) of 0.55. This value indicates that the better the role of agricultural extension workers, the stronger the social norms among farmers in supporting the use of agricultural technology. In addition, the role of agricultural extension workers also has a direct effect on technology adoption and innovation (Y) of 0.15; however, this effect is classified as weak.

The influence of social media (X2) on technology adoption and innovation (Y) has a value of -0.06. This value indicates that social media has not yet been able to exert a direct influence on increasing technology adoption. However, social media has a very strong influence on digital literacy (X4) with a coefficient value of 0.85. This indicates that the higher the use of social media, the greater the farmers' digital literacy skills.

Social norms (X3) have a positive effect on technology adoption and innovation (Y) of 0.53. This means that support from the social environment, farmer groups, and fellow farmers is a key factor in encouraging farmers to adopt agricultural technology. Digital literacy (X4) also has a positive effect on technology adoption and innovation, with a value of 0.48. This indicates that farmers' ability to understand and use digital technology can enhance the implementation of agricultural technological innovations.

The structural model can also be explained through the coefficient of determination (R^2).

The social norms variable (X3) has an R^2 value of 0.30, meaning that 30% of the variation in social norms can be explained by the role of agricultural extension workers, while the remainder is influenced by other factors outside the research model. The digital literacy variable (X4) has an R^2 value of 0.73, indicating that 73% of the variation in digital literacy can be explained by the influence of social media. Meanwhile, the technology adoption and innovation variable (Y) has an R^2 value of 0.72. This value indicates that 72% of the variation in technology adoption and innovation can be explained by the role of agricultural extension workers, social media, social norms, and digital literacy, while the remaining 28% is influenced by other factors outside the scope of this study. The structural model results indicate social norms and digital literacy are the factors most influence technology adoption and innovation among coastal horticultural farmers in Ambal District, Kebumen Regency

Table 5
Results of the Model Fit Test (Goodness of Fit) for the Constructs of Variables X1, X2, X3, X4, and Y

Goodness of Fit Indeks	Cut off Value	Results	Model Evaluation
Chi-square	Smaller is better	802,293	sensitive to sample size
CMIN/DF	≤ 2,00 or ≤ 3,00	2,222	Fit
GFI	≥0,90	0,860	Marginal
AGFI	≥0,90	0,831	Marginal
CFI	≥0,90	0,919	Fit
TLI	≥0,90	0,909	Fit
RMSEA	≤0,08	0,060	Fit

Source: Processed Primary Data (2026)

Based on the table of Goodness-of-Fit test results for the confirmatory factor model of constructs X1, X2, X3, X4, and Y, the model meets most of the recommended model fit criteria. A CMIN/DF value of 2.222 indicates that the model has a good level of fit because it falls within the acceptable range, namely ≤ 2.00 or ≤ 3.00.

The CFI value of 0.919 and the TLI value of 0.909 indicate that the model has a good level of fit because it meets the cutoff value of ≥ 0.90. The RMSEA value of 0.060 also indicates a low level of model approximation error, so the model can be said to meet the fit criteria.

The GFI value of 0.860 and the AGFI value of 0.831 are still below the recommended threshold of 0.90; therefore, both indices are categorized as having a marginal fit. On the other hand, the Chi-square value of 802.293 is relatively large. However, the Chi-square index is known to be highly sensitive to sample size; thus, in studies with large sample sizes, the Chi-square value tends to struggle to meet the expected criteria. Therefore, the evaluation of model fit should not be based on a single index but should consider the overall indicators of Goodness of Fit. The test results show that the confirmatory factor model constructed has an acceptable level of fit, so the model is deemed suitable for use in the next stage of analysis.

Hypothesis Test Results

After the results of the structural equation modeling indicated an adequate level of model fit, the next step was to test the research hypotheses. Hypothesis testing aims to analyze the causal relationships among latent constructs in accordance with the conceptual model that had been developed. The decision to accept or reject a hypothesis was made based on the Critical Ratio (CR) value and the significance level (probability value). A hypothesis is accepted if it has a CR value ≥ 1.96 and a probability value ≤ 0.05. Hypothesis testing results are presented in table 6.

Table 6
Hypothesis Testing of Exogenous Variables (X1, X2, X3, and X4) on the Endogenous Variable (Y)

Hypothesis	Relationships Among Variables	Estimating	CR	P	Decision
H1	X1 → Y	0,154	2,152	0,0 31	Significant
H2	X2 → Y	-0,064	-0,605	0,545	Not Significant
H3	X3 → Y	0,526	6,094	***	Significant
H4	X4 → Y	0,477	4,549	***	Significant
H5	X1 → X3	0,550	7,002	***	Significant
H6	X2 → X4	0,855	11,501	***	Significant

Source: Processed Primary Data (2026)

Based on the table 6, Hypothesis 1 is accepted because variable X1 has a positive and significant effect on Y, with an estimated value of 0.154, a CR value of 2.152, and a probability value of 0.031 (<0.05). This indicates that an increase in X1 can increase Y. Hypothesis 2 is rejected because variable X2 has no significant effect on Y, with an estimated value of -0.064, a CR value of -0.605, and a probability value of 0.545 (>0.05). This indicates that X2 is not capable of directly influencing Y. Therefore, the hypothesis is rejected. Hypothesis 3 is accepted because variable X3 has a positive and significant effect on Y, with an estimated value of 0.526, a CR value of 6.094, and a probability value of 0.000 (<0.05). This indicates that the better X3 is, the greater the increase in Y. Therefore, the hypothesis is accepted. Hypothesis 4 is accepted because variable X4 has a positive and significant effect on Y, with an estimated value of 0.477, a CR value of 4.549, and a probability value of 0.000 (<0.05). This indicates that an increase in X4 can increase Y. Therefore, the hypothesis is accepted. Hypothesis 5 is accepted because variable X1 has a positive and significant effect on X3, with an estimated value of 0.550, a CR value of 7.002, and a probability value of 0.000 (<0.05). This indicates that the higher the value of X1, the greater the increase in X3. Thus, the hypothesis is accepted. Hypothesis 6 is accepted because variable X2 has a positive and significant effect on X4, with an estimated value of 0.855, a CR value of 11.501, and a probability value of 0.000 (<0.05). This indicates that an increase in X2 leads to an increase in X4. Therefore, the hypothesis is accepted.

The results of the AMOS SEM analysis showed that the research model met the model fit criteria, and it was found that all research hypotheses (H1, H3, H4, H5, and H6) were accepted with a CR > 1.96 and P < 0.05; however, H2 was not significant because it had a CR > 1.96 and P < 0.05. The social norm variable (X3) was the most dominant factor in the direct relationship influencing farmers' adoption and innovation of technology, followed by digital literacy (X4) and the role of agricultural extension workers (X1). Mediation hypothesis testing was conducted to determine the role of the mediating variables (X3 and X4) in bridging the relationship between the exogenous variables (X1, X2) and the endogenous variable (Y). The mediating effects were observed through the values of the direct and indirect effects.

Table 7
Hypothesis Testing for Mediating Variable

Hypothesis	Channel Mediation	Immediate Effects	Indirect Effects	Types of Mediation	Description
H7	X1 → X3 → Y	0,154	0,289	Partial Mediation	Accepted
H8	X2 → X4 → Y	-0,064	0,408	Full Mediation	Accepted

Source: Processed primary data (2026)

Based on table 7, Hypothesis 7 is accepted since variable X3 was found to mediate the effect of X1 on Y, with an indirect effect of 0.289. Since the direct effect of X1 on Y remains significant, X3 is classified as a partial mediator. This indicates that the effect of X1 on Y occurs not only directly but also through an increase in X3. Hypothesis 8 is accepted because variable X4 was found to mediate the effect of X2 on Y, with an indirect effect of 0.408. Since the direct effect of X2 on Y is not significant, X4 is classified as a full mediator. Variable X4 fully mediates the effect of X2 on Y. This indicates that X2 cannot directly influence Y, but this effect occurs through X4 as the mediating variable. Thus, the inclusion of mediating variables provides a more comprehensive explanation of the mechanisms underlying the relationships among the variables. These results indicate social norms and digital literacy skills play a significant role in driving technological transformation among coastal horticultural farmers in Ambal District, Kebumen Regency.

Table 8
Technology and Innovation Adoption Rates

Indicator	Meaning	Standard Deviation	Interpretation
Y 3	3,898	0,711	Tall
Y.4	3,907	0,738	Tall
Y.6	3,811	0,773	Tall
Y.7	3,887	0,701	Tall
Y.8	3,805	0,782	Tall
Y.9	3,541	0,828	Medium - High
Average Y	3,808	—	Tall

Source: Processed primary data (2026)

Based on the table 8, the results of the descriptive statistical analysis for the variables of technology adoption and innovation (Y) show that the mean values for each indicator range from 3.541 to 3.907. The highest mean value was found in indicator Y.4, at 3.907 with a standard deviation of 0.738, while the lowest mean value was found in indicator Y.9, at 3.541 with a standard deviation of 0.828.

Overall, the average value of the technology adoption and innovation variables is 3.808, indicating that the level of technology adoption and innovation among coastal horticultural farmers in Ambal Regency falls into the high category. These results indicate that the majority of farmers have been able to accept, implement, and utilize agricultural technological innovations in their horticultural farming activities.

Furthermore, the standard deviation values for all indicators are relatively smaller than their mean values, indicating that the respondents' answers tend to be homogeneous and do not show significant deviation. Thus, it can be concluded that coastal horticultural farmers in Ambal Regency have a fairly good level of acceptance and implementation of technological innovations to support the development of horticultural agriculture.

Discussion

The Impact of the Role of Agricultural Extension Workers on Technology Adoption and Innovation

SEM analysis shows that the role of agricultural extension workers has a significant impact on the adoption of technology and innovation among coastal horticultural farmers in Ambal District. The standard estimate of 0.154 indicates that the direct effect of extension workers is relatively small compared to the indirect impact through social norms. This shows that the success of agricultural extension depends not only on the individual relationship between extension workers and farmers, but also on their ability to build a social system of farmer groups that support innovation.

The significant impact of agricultural extension workers on technology adoption shows that the presence of extension workers is the main source of trust for farmers when embracing new innovations. This situation shows that the digital transformation of coastal agriculture has not fully replaced the face-to-face role of extension workers. These results Roggers (Roggers, 2023) The theory of innovation diffusion positions communication channels as a crucial element in the process of introducing innovation. Furthermore, these results support research (Xu et al., 2026) showing that the latest extension services can significantly improve farmers' technology adoption rates and productivity.

The Impact of Social Media on Technology Adoption and Innovation

The findings of this study indicate that social media does not have a direct and significant impact on technology adoption or innovation. Information obtained through social media is highly dependent on an individual's level of digital literacy, so farmers often do not immediately understand or utilize it. Social media only provides access to information, and the ability to understand, filter, and utilize that information is greatly influenced by farmers' digital literacy levels.

Furthermore, information on social media is highly diverse and does not necessarily align with farmers' needs. Many farmers struggle to distinguish between valid and ineffective information, so information from social media does not directly promote the application of technological innovation. Social media has the potential to be an effective extension media, but to maximize its effectiveness, support from various stakeholders such as governments, extension organizations, and communities is also necessary Putra (2025).

The impact of fellow farmers and social norms on technology adoption and innovation

Social norms have been shown to have a significant impact on technology adoption and innovation. Because farmers tend to imitate the success of their peers, the spread of innovation naturally occurs through social interaction. These findings align with the following studies. Kerr and others (2023)The document states that the actions of farmers in the horticultural sector when introducing and innovating technology are greatly influenced not only by technical and economic aspects but also by psychological and social factors.

This study shows that subjective attitudes and norms play a crucial role in encouraging farmers to intend to adopt sustainable agricultural innovations. In such cases, farmers tend to imitate the success of their peers, so social norms strengthen acceptance of innovation.

The Impact of Digital Literacy on Technology Adoption and Innovation

The empirical research in this study confirms that there is a significant impact on the relationship between digital literacy, technology adoption, and innovation. These findings align with the following studies. Arangri et.al (2025) This highlights that in the context of modern agriculture, digital literacy is a crucial capability for farmers to adopt technological innovation and improve agricultural efficiency.

Other Research Klerkx (2023) A new generation of agricultural innovation (often called AIS 4.0) increasingly relies on digitalization, weather data, simple sensors, e-commerce, and institutional collaboration integration, all of which suggest improving the accuracy of farmers' decision-making. This supports that innovation is not limited to "new tools" but also includes changes in production processes, farm management, and market relationships. Digital literacy is the main foundation for modernizing coastal agriculture.

The Impact of the Role of Agricultural Extension Workers on Farmers and Social Norms

The results of this study confirm that there is a significant impact on the role of agricultural extension workers and their relationship with farming peers and social norms. This finding aligns with Putra et al. (2025), which shows that the role level of farmer group leaders is very high at 62.43%. In other words, farmer group leaders can serve as motivators, communicators, facilitators, and organizers.

The Impact of Social Media on Digital Literacy

The empirical research in this study confirms that there is a significant impact on the relationship between the influence of social media and digital literacy. The standard estimate of 0.855 indicates that social media has a very strong impact on digital literacy. This indicates that social media has become a crucial tool supporting the digital transformation of the agricultural sector. These findings align with Gwelo's (2025) research, which stated that social media platforms like Facebook and WhatsApp expand access to agricultural information, enabling smallholders to become active participants of agricultural innovation rather than just passive recipients. The results of this study show that social media functions as an informal learning tool for farmers. The more frequently farmers use social media to search for agricultural information, the greater their ability and understanding of digital technology will become.

Analysis of the Mediating Effect of Social Norms on the Role of Agricultural Extension Workers, Adoption Opportunities, and Technological Innovation

SEM AMOS analysis shows that social norms function as important mediating variables in the relationship between the role of agricultural extension workers and the adoption and innovation of technology. The indirect effect value of 0.289 exceeded the direct effect of 0.154 that agricultural extension workers had on technology adoption and innovation. These results suggest that the success of agricultural extension in promoting technology adoption is more effective thanks to strong support from the social environment of farmers.

Mediation analysis of digital literacy in the relationship between the impact and adoption of social media and technological innovation

The empirical research in this study confirms that digital literacy functions as a key mediating variable in the relationship between the influence of social media and the adoption and innovation of technology. The analysis showed that the indirect impact of social media on technology adoption and innovation was 0.408, which is higher than the direct effect of social media on technology adoption.

This demonstrates that digital literacy acts as a complete intermediary. This is because, while the direct effects of social media were not significant in this study, the indirect effects were significant. In other words, social media cannot promote the spread of technology without the support of farmers' digital literacy skills.

Social media does not automatically promote the adoption of agricultural technology. Social media only provides access to digital information, and farmers' ability to understand, filter, evaluate, and apply that information is greatly influenced by their level of digital literacy. Therefore, the higher a farmer's digital literacy skills, the more effective the use of social media will be in supporting the adoption of agricultural technology and the innovation process.

Therefore, expanding the use of social media in agricultural development requires programs that enhance farmers' digital literacy through training, mentoring, and technology-based expansion, ensuring that modern agricultural transformation proceeds more effectively and sustainably.

Comparing these findings with broader literature strengthens his interpretation. The significant effect of extension workers observed here aligns with scope review evidence that extension quality is a key determinant of technology adoption in agriculture in developing countries (the effect depends heavily on context, (Becerra-Encinales et al., 2024). It also aligns with Pakistan's evidence that more robust extension services increase the likelihood of multi-technology adoption (Marbun, et al., 2019; Sakir et al., 2025). The direct impact of social media is fully mediated through digital literacy, reflecting the finding that social media information only leads to adoption when farmers have sufficient digital literacy to evaluate it (Gwelo, 2025; Wang et al., 2025), and social norms that emerge as dominant elements rather than functioning as autonomous drivers, align with evidence of structural similarities where subjective and social norms strongly shape adoption intentions in collectivist agricultural communities (Yuniarsih et al., 2026). It emphasizes that adopting at Ambal is not only about calculating individual cost-effectiveness but also about the expectations of peers and the community. Finally, digital literacy serves as a mediating mechanism, supported by evidence from a recent systematic review that digital literacy is one of the most powerful factors consistently predicting the adoption and efficiency of agricultural technology adoption (Xu et al., 2026; Choruma et al., 2024) suggest that digital literacy programs are likely to have the broadest impact on the other three pathways identified in this study.

The development of a strategic concept not only considers the magnitude of each variable’s influence but also takes into account implementation aspects through the establishment of action plans, implementing actors, success indicators, and implementation stages. Thus, the resulting empowerment strategy concept is expected to be more practical and to serve as input for local governments and stakeholders in developing empowerment programs for coastal horticultural farmers. A summary of the empowerment strategy concept is presented in Table 9.

Table 9
Strategic Concepts for the Empowerment of Coastal Horticultural Farmers Based on the Results of the SEM-AMOS Analysis

Strategy Priorities	Research Findings Overview	Action Plan	Performing Actor	Success Indicators
Strengthening social and institutional norms through farmers’ cooperatives	Social norms have the greatest influence on the adoption and innovation of technology	Training of champion farmers, demonstration plots, field schools, field meetings, and strengthening of farmer groups and Gapoktan toward Farmer Corporation	Department of Agriculture, BPP, Agricultural Extension Officers, Gapoktan, Farmers' Groups	An increase in the number of farmers adopting technology, increased participation in group activities, and the formation of farmers’ cooperatives
Improving Digital Literacy	Digital literacy has a significant impact on technology adoption and innovation	Training on how to use smartphones to access information on cultivation, market prices, and weather forecasts; training on how to use WhatsApp groups, YouTube, and social media as tools for learning and marketing horticultural products	Department of Agriculture, Agricultural Extension Agency, Agricultural Extension Officers, Universities, Digital Communities	Improved digital literacy among farmers, increased use of digital media for farming businesses, and improved access to agricultural information

Strategy Priorities	Research Findings Overview	Action Plan	Performing Actor	Success Indicators
Developing Millennial Farmers as Drivers of Horticultural Modernization	Social media exerts influence by improving digital literacy (through mediation)	Training and mentoring in horticultural agribusiness entrepreneurship, digital marketing, the use of agricultural technology, and strengthening business networks for young farmers.	Department of Agriculture, Universities, Millennial Farmers' Community	The growing number of active young farmers, the expansion of horticultural agribusiness ventures, and the rise in innovations initiated by young farmers
Revitalizing the Role of Agricultural Extension Workers Through a Participatory Approach	The role of extension workers has a significant impact	Participatory guidance, field schools, agribusiness clinics, monitoring and evaluation of technology adoption, digital-based extension services	BPP, Agricultural Extension Officer	Increased intensity of assistance, farmer satisfaction with extension services, and technology adoption rates
Development of horticultural areas based on technological innovation	Farmers' rate of technology adoption is already high, so efforts are now focused on regional development	The implementation of drip irrigation, agricultural mulch, high-yielding varieties, balanced fertilization, integrated pest management (IPM), agricultural mechanization, and the use of digital technology in crop production	Local Government, Department of Agriculture, Farmers' Groups	Increases in productivity, farming efficiency, crop quality, and the amount of land where the technology is implemented
Strengthening the marketing system and agribusiness partnerships in horticulture	The results of the observation indicate that there are still marketing challenges	Collective marketing through Gapoktan or farmer cooperatives, partnerships with off-takers, the use of online marketplaces and social media, and the development of Agribusiness Sub-Terminals (STA)	Farmers' Groups, Cooperatives, Village-Owned Enterprises, Department of Agriculture, Private Sector Partners	Increased market access, farmers' bargaining power, stable selling prices, and farmers' income

These six empowerment strategy concepts are designed to be easy to implement and will be rolled out gradually in accordance with priority levels, resource availability, the institutional readiness of farmers, and the direction of agricultural development policy in Ambal District. Programs focused on building farmers' capacity—such as field schools, demonstration plots, the development of champion farmers, and digital literacy training—are prioritized in the short term.

In the medium term, implementation will focus on strengthening farmer institutions through farmer cooperatives, developing millennial farmers, digitizing extension services, and strengthening agribusiness-based marketing systems. In the long term, the strategy is directed toward developing technology-innovation-based horticultural zones, strengthening agribusiness partnerships, and developing Agribusiness Sub-Terminals (STA) as part of efforts to realize a modern, competitive, and sustainable coastal horticultural agribusiness system. The roadmap for implementing this empowerment strategy is presented in Table 10.

Table 10
Roadmap for Implementing the Strategic Concept for Empowering Coastal Horticultural Farmers

Stages	Focus	Priority Programs	Performance Targets	Relationship to Local Policies
Short Term (1–2 years)	Peningkatan kapasitas petani	Demonstration plots, field schools, digital literacy training, training of pioneer farmers, and optimization of farmers' groups	Knowledge, skills, and technology adoption are on the rise	Supporting agricultural extension programs, capacity building for farmers, the digital transformation of agriculture, and the institutional strengthening of farmers' groups—all of which are routine programs of the Department of Agriculture and the Agricultural Extension Service (BPP).

Stages	Focus	Priority Programs	Performance Targets	Relationship to Local Policies
Medium Term (3–5 years)	Institutional and Agribusiness Strengthening	Farmer cooperatives, development of millennial farmers, digitization of extension services, development of digital marketing	Farmers' organizations are growing stronger, their bargaining power is increasing, and marketing is becoming more efficient	In line with policies on the development of farmer cooperatives, the renewal of the farming workforce, the strengthening of farmers' economic institutions, and the digital-based downstream processing and marketing of agricultural products.
Long Term (>5 years)	Development of a sustainable agribusiness system	Technology-based horticultural zones, agribusiness partnerships, development of Agribusiness Sub-Terminals (STA), supply chain integration	The realization of a modern, competitive, and sustainable coastal horticultural agribusiness	Supporting the development of sustainable horticultural areas, strengthening agribusiness value chains, enhancing the competitiveness of regional flagship commodities, and promoting regional food security.

The division of the roadmap into short-term, medium-term, and long-term phases is intended to ensure that the strategy is implemented in stages, in accordance with the availability of resources, the institutional capacity of farmers, budget availability, and regional agricultural development priorities. This implementation roadmap aligns with the direction of regional agricultural development policy, which emphasizes improving the quality of agricultural human resources, strengthening farmer institutions, digital transformation in agriculture, developing farmer cooperatives, and enhancing the competitiveness of horticultural commodities. Therefore, the proposed strategic concept has a greater chance of being integrated into the work programs of the Kebumen Regency Agriculture Office and the Ambal Subdistrict Agricultural Extension Center.

The implementation roadmap developed in this study represents the operationalization of the SEM-AMOS analysis results into stages of an empowerment program that can serve as a reference for local governments, Agricultural Extension Centers, agricultural extension workers, and farmer groups in designing empowerment programs for coastal horticultural farmers. Through a phased approach, the proposed strategy is expected not only to increase technology adoption and innovation but also to strengthen farmer institutions, enhance the competitiveness of the horticultural agribusiness sector, and support sustainable agricultural development in Ambal Subdistrict, Kebumen Regency.

This roadmap for implementing the strategy to empower coastal horticultural farmers has been developed in alignment with agricultural development policy directions at both the regional and national levels. Its implementation is guided by policies that prioritize improving the quality of human resources in agriculture, strengthening farmer institutions, accelerating the digital transformation of agriculture, developing farmer cooperatives, and enhancing the competitiveness of horticultural commodities. This alignment is expected to support the effective implementation of the program while strengthening synergies among stakeholders in achieving sustainable agricultural development. The documents used as references in drafting this roadmap include the Kebumen Regency Medium-Term Development Plan (RPJMD), the Strategic Plan (Renstra) of the Kebumen Regency Agriculture and Food Service, and the Ministry of Agriculture's Strategic Plan as a representation of national agricultural development policy.

The Ambal Subdistrict Agricultural Extension Office (BPP) serves as the primary implementer of extension activities, farmer mentoring, and capacity building, while the Kebumen Regency Agriculture Office is responsible for policy formulation, budget allocation, program facilitation, and cross-stakeholder coordination. Thus, this roadmap is relevant to regional policy directions and can serve as a reference in the development of empowerment programs for coastal horticultural farmers.

Given that the resulting strategy is a conceptual one based on quantitative analysis, its operational implementation requires further validation through Focus Group Discussions (FGDs) involving local government officials, agricultural extension workers, farmer groups, academics, business operators, and other stakeholders. This process is essential to ensure that the formulated strategies align with on-the-ground needs, resource availability, and regional development priorities, and that they have a high likelihood of successful implementation.

CONCLUSION

The profile of coastal horticultural farmers in Ambal Regency is dominated by farmers of working age with a secondary education and considerable farming experience. Most farmers own small to medium-sized farm plots. These conditions indicate that farmers have good potential to adopt and implement agricultural technological innovations. Research findings show that the adoption of agricultural innovations among coastal horticultural farmers is influenced by several internal and external factors, namely the role of agricultural extension workers, social media, social norms, and digital literacy. The role of agricultural extension workers influences farmers' increased understanding of the use of cultivation technologies and their access to agricultural information. Agricultural extension agents serve as facilitators, motivators, and mentors in the process of changing farmers' behavior. Social media makes it easier for farmers to obtain agricultural technology information quickly and widely. However, the influence of social media on technology adoption becomes stronger when farmers have a good level of digital literacy. Social norms also influence farmers' decisions to adopt innovations. Farmers tend to follow practices implemented by farmer groups or other farmers who are considered successful. Digital literacy is a key factor because farmers' ability to access, understand, and utilize digital information determines the success of technological innovation implementation. The higher farmers' digital literacy, the more likely they are to adopt new technologies. Based on the results of SEM analysis using IBM SPSS Amos, the variable that most influences technology adoption and innovation is social norms, followed by digital literacy, both as a direct variable and a mediating variable. The level of technology adoption and innovation among coastal horticultural farmers in Ambal Regency is classified as high. This is indicated by a mean score of 3.808, which falls within the "high" category based on the Likert scale used in this study. This suggests that respondents tend to agree with the indicators of technology adoption and innovation. These results indicate that the majority of farmers have been able to accept, implement, and utilize technology in their coastal horticultural farming activities.

This high level of technology adoption and innovation reflects farmers' openness to change, their willingness to try new technologies, and their ability to adapt technologies to environmental conditions and agricultural needs in the coastal areas of Ambal Regency. The strategic concept for empowering coastal horticultural farmers in Ambal Regency should prioritize strengthening farmer group institutions through farmer cooperatives, enhancing digital literacy, and developing millennial farmers as drivers of agricultural modernization. This strategy is further reinforced through the revitalization of agricultural extension services, the development of horticultural land based on technological innovations, and the strengthening of marketing systems and horticultural agribusiness partnerships. This approach demonstrates that the success of empowering coastal horticultural farmers is not only determined by technical cultivation skills but is also influenced by social institutions, human resource capacity, farmers' economic conditions, the effectiveness of extension services, and the development of an integrated and sustainable horticultural agribusiness system.

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AUTHOR CONTRIBUTION STATEMENT

Intan Wiji Ekawati: Research conceptualization, methodology development, data collection and curation, data analysis, visualization, and preparation of the initial draft. Ardiansyah: Conceptualization, research supervision, refinement of methodology, validation of research results, and review and editing of the manuscript. Masrukin: Research supervision, validation of results and analysis, and review and editing of the manuscript. Nurul Hidayat: Validation of research results, provision of scientific input, and review and editing of the manuscript. Lilik Kartika Sari: Validation of research results, provision of scientific input, and review and editing of the manuscript.

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