The synergy of agricultural extension and farmer group leadership in promoting farmers' independence in the digital era

Fara Shaliza[12*], *Sumardjo* Sumardjo[2], *Dwi* Sadono[2], and *Zaim* Uchrowi[2]

[1]Graduate School of IPB University, Dramaga Campus IPB, Bogor, West Java, 16680, Indonesia
[2]Department of Communication and Community Development Sciences, Faculty of Human Ecology, IPB University, Dramaga Campus IPB, Bogor, West Java, 16680, Indonesia

Abstract. Enhancing agricultural productivity and promoting farmer independence remain critical challenges to sustainable rural development in Indonesia. Agricultural extension services and farmer group leadership serve as key institutional innovations, empowering farmers to make informed decisions independently and address agricultural challenges. This study examined the influence of agricultural extension support on farmer group leadership and its subsequent effects on farmer independence. Using a quantitative approach complemented by qualitative insights, data were collected through structured questionnaires administered to 301 farmers in Riau Province, Indonesia, specifically at four locations: Dumai City, Bengkalis, Kuantan Singingi, and Indragiri Hilir Regencies. Data were analyzed using descriptive and inferential statistical methods, and Structural Equation Modeling (SEM) was conducted using SmartPLS software to explore the structural relationships between variables. The results indicate that agricultural extension support significantly improves farmer group leadership and independence. Additionally, effective leadership in farmer groups substantially contributes to farmers' independence and decision-making capacity. These findings highlight the synergistic role of extension support and leadership in driving socioeconomic transformation in the agricultural sector. This study offers policy-relevant insights for promoting sustainable innovation and community empowerment in tropical bioresource management, particularly in the digital era.

1 Introduction

Farmer groups serve as grassroots institutions that play a pivotal role in ensuring the success of agricultural development programmes. Farmer groups are important in marketing, collaboration, and production to boost agricultural productivity and improve farmers' welfare. Increasing productivity is a key strategy to combat hunger and promote global food security, as well as to help alleviate poverty [1]. Concerns about food availability have prompted the Indonesian government to implement farmer empowerment programs using a farmer group-based approach. Such programs are crucial considering the role of the

* Corresponding author: farashaliza@apps.ipb.ac.id

agricultural sector as a contributor to the national economy. Nonetheless, increasing food productivity has remained challenging owing to barriers, including the risk of crop failure due to climate change factors, floods, droughts, and attacks by pests and plant diseases. These barriers have contributed to decreasing rice production [2].

Riau Province is one of the areas in Indonesia that is experiencing crop failure. From 2020 to 2022, owing to plant insect infestations, droughts, and floods, less land was harvested and less rice was produced. The rice harvested area in Riau Province in 2020 was 64.73 thousand hectares, with production reaching 243.69 thousand tons of dry-milled grain [3]. This figure decreased in 2021, with a harvested area of 53.06 thousand hectares and production reaching 217.46 thousand tons of dry-milled grain [4]. In 2022, the harvested area shrank to 51.05 thousand hectares, yielding 213.56 thousand tons of dry-milled grain [5].

To address farming challenges, farmers require agricultural extension support, including information on seeds, fertilizers, and methods for managing plant pests and diseases. Agricultural extension workers are one of the main sources of information for controlling pests and plant diseases due to farmers' limited access to digital technology [6]. However, the implementation of the extension has obstacles in terms of budget and the availability of agricultural extension workers [7]. Therefore, effective leadership is crucial for disseminating information to farmer groups, facilitating the adoption of sustainable agricultural practices, and enhancing their overall performance [8]. As an opinion leader, the group leader is a source of information trusted by its members and plays a role in encouraging knowledge-sharing behaviors to increase the capacity of group members. Opinion leaders are key actors in the communication process that influences others' attitudes and behaviors through interpersonal networks, making them essential in accelerating the adoption of innovations within social systems [9].

Building on this background, studying the empowerment of farmers' independence through agricultural extension support and effective group leadership is essential. Despite increasing attention to agricultural extension and leadership in rural development, studies that simultaneously examine how two elements interact to influence farmer independence are limited. In particular, there is a paucity of research focusing on institutional dynamics within farmer groups and how extension services and internal leadership jointly shape farmer decision-making and independence. This study seeks to strengthen the institutional components of farmer groups, which urgently require improvement. Therefore, this study aims to examine how agricultural extension support affects both the level of farmer independence and the role of group leadership as well as how group leadership influences farmer independence. This study highlights the crucial role of agricultural extension support and farmer group leadership in enhancing the independence of farmers. These findings provide valuable insights for policymakers in designing effective empowerment programs by optimizing extension services and strengthening leadership within farmer groups. Practically, these insights can help extension workers develop more effective strategies and enable farmers to recognize the importance of leadership in improving their decision-making and problem-solving abilities.

2 Methodology

This study was conducted in four regions of Riau Province (01°05'00" South latitude to 02°25'00" North latitude and 100°00'00" to 105°05'00" east longitude), which were purposively selected based on regional typology considerations and are areas of rice cultivation. The four locations were as follows: Dumai City as an urban typology, Bengkalis Regency as an island typology, Kuantan Singingi Regency as a mainland typology, and Indragiri Hilir Regency as a coastal typology, as illustrated in Fig 1.

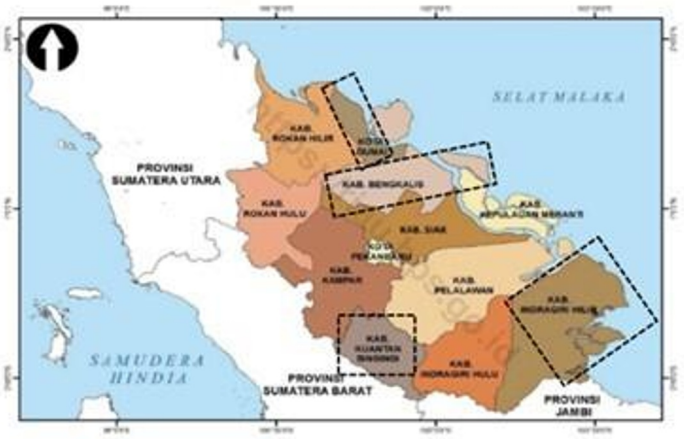

Fig. 1. Research places.

A quantitative research methodology that involved conducting a survey using a questionnaire was adopted to fulfil the research objectives. The study population consisted of rice farmers who belonged to farming organizations and were enrolled in the Agricultural Extension Information System (*Simluhtan-Sistem Informasi Manajemen Penyuluhan Pertanian*). As shown in Fig 2, 301 respondents were chosen using a stratified random selection procedure based on farmer group classes.

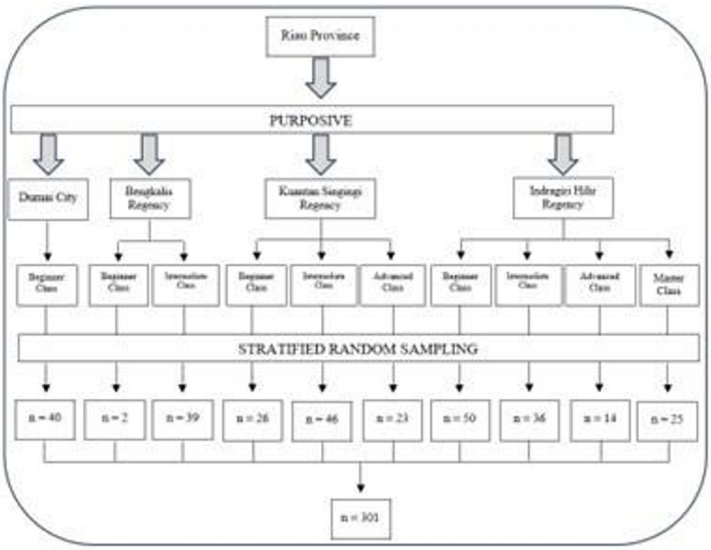

Fig. 2. Sampling techniques**.**

The variables tested in this study were agricultural extension support (AES), level of farmer independence (LFI), and the role of group leadership (RGL). The hypotheses proposed are as follows: Hypothesis 1 (H1): Agricultural Extension Support (AES) has a positive and significant effect on the Role of Group Leadership (RGL), Hypothesis 2 (H2): Agricultural Extension Support (AES) has a positive and significant effect on the Level of Farmer Independence (LFI), and Hypothesis 3 (H3): The Role of Group Leadership (RGL) has a positive and significant effect on the Level of Farmer Independence (LFI).

The relationship between the variables was examined using Structural Equation Modeling (SEM) analysis with SmartPLS software. This method allows for the simultaneous evaluation of measurement and structural models, making it very effective for the development of theory and correlation analysis between variables [10]. In SmartPLS, data analysis involves the evaluation of both external and internal models. For reflective relationships, the external model assesses the loading of indicators, construct validity, and reliability. Additionally, the internal model evaluates the significance, quantity, and direction of variable relationships.

3 Results and discussion

3.1 Research respondents' qualifications

This study outlines the qualifications of the respondents, which encompass age, level of formal education, farming experience, group motivation, training intensity, and cosmopolitan level, as described in Table 1.

Table 1. Respondent qualifications.

Qualifications	Category	Measurements	Frequency n=301	Percentage (%)
Age	Young	< 31 y.o	10	3.3
	Early adulthood	31-45 y.o	93	30.9
	Adulthood	46-60 y.o	142	47.2
	Old	> 60 y.o	56	18.6
Level of formal education	Very low	< 7 yrs	152	50.5
	Low	7-9 yrs	81	26.9
	Medium	10-12 yrs	60	19.9
	High	> 12 yrs	8	2.7
Farming experience	Less experienced	< 6 yrs	26	8.6
	Fairly experienced	6-10 yrs	51	17.0
	Experienced	11-15 yrs	50	16.6
	Highly experienced	> 15 yrs	174	57.8
Group motivation	Very low	< 3 motifs	20	6.6
	Low	3-4 motifs	41	13.6
	Medium	5-6 motifs	14	4.7
	High	> 6 motifs	226	75.1
Training intensity	Very low	< 2 times	288	95.7
	Low	2-3 times	7	2.3
	Medium	4-5 times	5	1.7
	High	> 5 times	1	0.3
Level of cosmopolitan	Less cosmopolitan	< 3 relations	209	69.4
	Quite cosmopolitan	3-4 relations	78	25.9
	Cosmopolitan	5-6 relations	12	4.0
	Very cosmopolitan	> 6 relations	2	0.7

Based on Table 1, it can be seen that 47.2 percent of respondents are classified as adults (46-60 years old), while 3.3 percent of the respondents are young (less than 31 years old). Regarding the level of formal education, 50.5 percent of the respondents fell into the Elementary School category, whereas only 2.7 percent had completed a Diploma or Bachelor's degree. In terms of farming experience, 57.8 percent of respondents were categorized as highly experienced (more than 15 years). Most of the respondents were highly motivated (75.1 percent). Over the past year, the intensity of training was very low (less than 2 times) for 95.7 percent of the respondents. The cosmopolitan level of the respondents was

69.4 percent, indicating that most had limited cosmopolitan connections (less than three relations). In other words, most farmers rely on agricultural extension workers as their primary source of information.

3.2 Measurement model evaluation

The initial stage of the outer model evaluation in the hierarchical component model assessed the relationship between questionnaire items (indicators) and lower-order constructs (dimensions). This stage is important to ensure that each indicator is substantially and strongly correlated with its corresponding dimensions. Thus, the validity of the lower-order constructs was confirmed before proceeding to the second evaluation stage. The findings of this study are presented in Table 2.

Table 2. First-stage outer-model testing results.

Variable	Question Item	Loading Factor	Composite Reliability	Average Variance Extracted (AVE)
Agricultural Extension Support (AES)	Competence of Agricultural Extension Workers 1 (AES_COMP1)	0.888	0.895	0.682
	Competence of Agricultural Extension Workers 2 (AES_COMP2)	0.853		
	Competence of Agricultural Extension Workers 3 (AES_COMP3)	0.867		
	Competence of Agricultural Extension Workers 4 (AES_COMP4)	0.678		
	Dissemination of ICT Benefits 1 (AES_DIS1)	0.930	0.967	0.879
	Dissemination of ICT Benefits 2 (AES_DIS2)	0.949		
	Dissemination of ICT Benefits 3 (AES_DIS3)	0.936		
	Dissemination of ICT Benefits 4 (AES_DIS4)	0.934		
	Intensity of Agricultural Extension 1 (AES_INT1)	0.725	0.820	0.604
	Intensity of Agricultural Extension 2 (AES_INT2)	(*)		
	Intensity of Agricultural Extension 3 (AES_INT3)	0.814		
	Intensity of Agricultural Extension 4 (AES_INT4)	0.789		
The Level of Farmer Independence (LFI)	Adaptability 1 (LFI_ADP1)	(*)	0.940	0.839
	Adaptability 2 (LFI_ADP2)	0.905		
	Adaptability 3 (LFI_ADP3)	0.929		
	Adaptability 4 (LFI_ADP4)	0.914		
	Competitiveness 1 (LFI_COMP1)	(*)	0.918	0.848
	Competitiveness 2 (LFI_COMP2)	(*)		
	Competitiveness 3 (LFI_COMP3)	0.940		
	Competitiveness 4 (LFI_COMP4)	0.901		
	Filtering Power 1 (LFI_FIL1)	0.856	0.920	0.744
	Filtering Power 2 (LFI_FIL2)	0.810		
	Filtering Power 3 (LFI_FIL3)	0.906		
	Filtering Power 4 (LFI_FIL4)	0.874		

Table 2. First-stage outer-model testing results (*continue*).

Variable	Question Item	Loading Factor	Composite Reliability	Average Variance Extracted (AVE)
	Partnership 1 (LFI_PART1)	0.863	0.953	0.834
	Partnership 2 (LFI_PART2)	0.940		
	Partnership 3 (LFI_PART3)	0.915		
	Partnership 4 (LFI_PART4)	0.933		
The Role of Group Leadership (RGL)	Decision Making Role 1 (RGL_DEM1)	0.910	0.950	0.827
	Decision Making Role 2 (RGL_DEM2)	0.892		
	Decision Making Role 3 (RGL_DEM3)	0.923		
	Decision Making Role 4 (RGL_DEM4)	0.912		
	Informational Role 1 (RGL_INF1)	0.885	0.948	0.821
	Informational Role 2 (RGL_INF2)	0.925		
	Informational Role 3 (RGL_INF3)	0.906		
	Informational Role 4 (RGL_INF4)	0.909		
	Interpersonal Roles 1 (RGL_INP1)	0.896	0.947	0.817
	Interpersonal Roles 2 (RGL_INP2)	0.922		
	Interpersonal Roles 3 (RGL_INP3)	0.912		
	Interpersonal Roles 4 (RGL_INP4)	0.885		

Table 2 reveals that most indicators met the factor loading criteria of 0.6, and some even exceeded 0.7, except for AES_INT2, LFI_ADP1, LFI_COMP1, and LFI_COMP2, which were not included because their factor loading values were below 0.6. The results of the reliability test showed that all the constructs had composite reliability values above the recommended value of 0.7, indicating consistent and reliable measurements. To determine the robustness of the research model, the Average Variance Extracted (AVE) value for each construct was determined. An AVE value of more than 0.5 indicates that most of the indicator variations can be explained by each construction. To test discriminant validity, the Fornell and Larcker criteria were used, in which the diagonal values were consistently higher than the corresponding off-diagonal values in their respective rows and columns, as presented in Table 3.

Table 3. First stage of discriminant validity.

	AES_ COMP	AES_ DIS	AES_ INT	LFI_ ADP	LFI_ COMP	LFI_ FIL	LFI_ PART	RGL_ DEM	RGL_ INF	RGL_ INP
AES_COMP	**0.826**									
AES_DIS	0.648	**0.937**								
AES_INT	0.659	0.558	**0.777**							
LFI_ADP	0.684	0.521	0.554	**0.916**						
LFI_COMP	0.311	0.256	0.185	0.391	**0.921**					
LFI_FIL	0.521	0.356	0.419	0.477	0.475	**0.862**				
LFI_PART	0.499	0.592	0.448	0.600	0.220	0.267	**0.913**			
RGL_DEM	0.678	0.607	0.483	0.683	0.342	0.531	0.529	**0.909**		
RGL_INF	0.729	0.582	0.536	0.744	0.306	0.522	0.577	0.798	**0.906**	
RGL_INP	0.655	0.500	0.498	0.706	0.294	0.457	0.548	0.786	0.835	**0.904**

The dimensions of each variable served as testing indicators in the second phase of the outer model evaluation. The latent variable score of the lower-order construct was measured using a high-order construct by applying another dimension in the assessment of the outer

model. The latent and dimension variables have a reflective relationship, which means that the latent variable is reflected in the dimensions. This reflective nature ensures that even if one dimension is eliminated because it does not meet the outer model evaluation standards, the remaining dimensions can adequately explain or describe the latent variable while maintaining the construct representation. Table 4 displays the results of the second phase of evaluation of the outer model. The analysis showed that the majority of the loading indicators for the dimensions exceeded 0.6. Additionally, all the variable composite reliability values were above 0.6, meeting the construct reliability requirements. The evaluation of Average Variance Extracted (AVE) also shows a value greater than 0.5, which confirms the fulfillment of convergent validity.

Table 4. Second-stage outer-model testing results.

	Factor Loading	**Cronbach's Alpha**	**Composite Reliability**	**AVE**
AES_COMP	0.907	0.831	0.899	0.747
AES_DIS	0.844			
AES_INT	0.841			
RGL_DEM	0.922	0.926	0.953	0.871
RGL_INF	0.943			
RGL_INP	0.934			

The analysis shows that the majority of indicator loadings for the dimensions show a value that exceed 0.6. In addition, the composite reliability score of all variables is above 0.6, indicating that they meet the criteria for construct reliability. The evaluation of the Average Variance Extracted (AVE) also shows that the value is greater than 0.5, which meets the requirements for convergent validity.

Table 5 presents an assessment of the discriminant validity based on the Fornell-Larcker criteria. The square roots of the AVE for AES and RGL were 0.865 and 0.933, respectively, both of which were higher than the correlation between AES and RGL (0.734). This shows that each construct (AES and RGL) contributes more variance to their respective indicators than the other constructs, thus confirming that discriminant validity has been achieved. Consequently, AES and RGL are distinct constructs that measure different concepts, further ensuring the reliability and validity of the model.

Table 5. Second stage of discriminant validity evaluation.

	AES	**RGL**
AES	**0.865**	
RGL	0.734	**0.933**

The next stage was the evaluation of the formative model to determine the significance of the external weight and collinearity between the indicators. Each indicator makes a proportional contribution to the formative construct related to the importance of an external weight. If the evaluation results of the external weight indicate a significant value, then the indicator has a significant impact. Additionally, collinearity between indicators also needs to be assessed because high collinearity can indicate redundancy or dependency, which can compromise the interpretation of the results. Therefore, a critical assessment of the external weight and collinearity is very important to ensure the accuracy and validity of formative models. The evaluation results are listed in Table 6.

Table 6. Formative outer model.

Path	VIF	Outer Weight		Outer Loading	
		Coeff	p-value	Coeff	p-value
LFI_ADP -> LFI	1.946	0.614	0.000	0.933	0.000
LFI_COMP -> LFI	1.353	-0.052	0.154	0.408	0.000
LFI_FIL -> LFI	1.485	0.319	0.000	0.671	0.000
LFI_PART -> LFI	1.563	0.311	0.000	0.753	0.000

The outer model test for formative relationships showed that all indicators had a Variance Inflation Factor (VIF) value below three, indicating no collinearity problems between indicators. The indicators LFI_ADP, LFI_FIL, and LFI_PART had a significant outer weight ($p < 0.05$), demonstrating their significant contribution to the LFI construct. Although LFI_COMP had an insignificant outer weight (p-value = 0.154), it was retained in the model because of its significant outer loading (p-value = 0.000), which shows a strong relationship with the LFI construct. Overall, this evaluation indicates that all indicators can be retained in formative models without collinearity problems and that they make sufficient contributions to the constructs.

3.3 Structural model evaluation

A structural model evaluation was conducted to understand the strength and direction of the relationship between the latent variables in the model. This evaluation involves assessing the significance and magnitude of the structural path coefficients that are used to assess the level of significance of the path coefficient. Procedurally, the bootstrapping method was used, which is a statistical estimate generated from 5,000 subsamples. The bootstrapping process produced p-values and t-statistics. If the p-value is less than 0.05, then the path coefficient is significant at the 5 percent significance level, and if the t-statistic value is greater than 1.96, it indicates significance at the 5 percent level. The results of the structural model evaluation indicate a significant relationship between AES, RGL, and LFI, as shown in Fig 3.

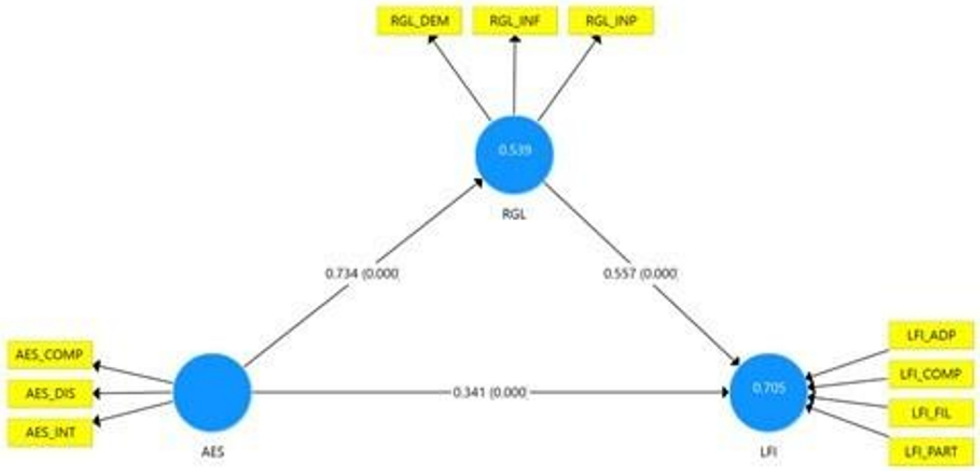

Fig. 3. Structural model of the research results**.**

The structural model evaluation also provides information that, in this model, all VIF scores were less than 5. Table 7 displays the coefficients, t-values, and significance levels (p-values).

Table 7. Results of t-statistic and path coefficient.

Hypotheses	Path	VIF	Path Coeff	T Values	P Values	Confidence Interval		Result
						Lower	Upper	
H1	AES -> RGL	1.000	0.734	21.912	0.000	0.679	0.789	Supported
H2	AES -> LFI	2.171	0.341	5.417	0.000	0.236	0.444	Supported
H3	RGL -> LFI	2.171	0.557	9.300	0.000	0.460	0.655	Supported

Table 7 shows that AES has the most substantial relationship with RGL, with a path coefficient of 0.734, t-value of 21.912, and p-value of 0.000. This indicates that AES plays a crucial role in strengthening group leadership in farming communities, which has broader implications for enhancing leaders' competencies and sustainability of farmer groups. Extension support is essential to optimize the leadership role within farmer groups, especially in terms of the competence of extension workers, intensity of extension, and dissemination of the benefits of Information and Communication Technology (ICT). Intensive and effective extension services, by providing clear information, can help farmers access resources and increase their participation in agricultural programs [11]. This can support the sustainability of agricultural activities and enhance the environmental and economic resilience in the agribusiness sector. Group leaders serve as a bridge for the flow of information and enhance farmers' ability to filter and process the information [12].

The path from AES to LFI shows a positive and statistically significant effect, with a path coefficient of 0.341, t-value of 5.417, and p-value of 0.000. Although the effect size is small, this indicates that AES contributes positively to the level of farmer independence. The competence of agricultural extension workers and intensive extension programs play a crucial role in supporting farmers to adopt technological innovations and utilize new technologies to improve production outcomes and achieve independence [13]. Farmers' independence can be demonstrated through their ability to filter accurate and useful information (filtering power), increase the quantity and quality of products (competitiveness), expand networks with the government or the private sector (partnerships), and adapt to climate change (adaptability).

The relationship between RGL and LFI has a strong and highly significant impact, with a path coefficient of 0.557, t-value of 9.300, and p-value of 0.000. This shows that strong leadership within farmer groups significantly enhances the independence of farmers. The leadership role manifests through interpersonal, informational, and decision-making roles. Visionary and adaptive farmer leadership is the main driver of independence and its strategic role as an agent of change in the community [14]. This can be considered by policymakers in formulating strategies to increase productivity, encourage commercialization, and reduce poverty in rice farming households through the application of agriculture technology, access to market information, and developing relationships with extension service agents [15].

3.4 Implications for practical and theoritical agricultural development

The results of this study have significant practical and theoretical implications for agricultural development. The results of this study highlight the importance of sustainable agricultural extension support and strong farmer group leadership in realizing farmer independence.

Therefore, government and agricultural institutions must improve extension services by enhancing the competence of extension workers, increasing the frequency of training, and utilizing digital technology for information dissemination. Furthermore, strengthening farmer group leadership through leadership training, technical capacity building, and mentoring can empower farmers to make independent and effective decisions to overcome agricultural challenges. To improve the competence of extension workers, concrete actions include training focused on participatory facilitation methods, digital literacy, and problem-solving approaches tailored to the local context. This training is expected to improve extension workers' skills in building better interactions with farmers and efficiently conveying relevant information. At the farmer organization level, leadership training is being conducted for farmer group leaders, covering organizational management, collective decision-making, conflict resolution, and financial literacy. Furthermore, mentoring from experienced and young farmer group leaders is provided to encourage learning among farmers. This strategy is expected to strengthen the institutional capacity and dynamics of farmer groups in sustainable empowerment efforts. Theoretically, this study enriches the literature on agricultural policy and rural sociology by confirming the positive relationship between agricultural extension support, group leadership, and farmer independence. In addition, the application of Structural Equation Modeling (SEM), specifically SmartPLS, provides a strong methodological approach for analyzing complex social relationships in agricultural development.

Despite its valuable contributions, this study had several limitations. First, this study was conducted only in Riau Province, which may limit the generalizability of the results to other regions with different agricultural, economic, and social conditions. Second, this study focused mainly on quantitative data collected through questionnaires, which did not fully capture the qualitative aspects of farmers' experiences, leadership dynamics, and personal perceptions. Finally, this study did not include other external factors, such as government agricultural policies, market access, or climate change adaptation strategies, which may also affect farmer empowerment. Based on these limitations, we suggest that future research should consider the geographical factors of the study location to accommodate a broader context. The research approach can be combined with a qualitative approach, such as case studies through interviews, which can reveal a deeper understanding of farmers' perspectives and experiences. In addition, it is necessary to consider the addition of several variables such as government regulations, economic conditions, and climate change, which affect the independence of farmers. By integrating a more comprehensive approach, policymakers can gain better insight into creating a more effective, efficient, and sustainable agricultural empowerment program.

4 Conclusion

This study revealed a positive and significant relationship between agricultural extension support, group leadership roles, and the level of farmer independence. Agricultural extension support, through the competence of agricultural extension workers, the intensity of agricultural extension activities, and the dissemination of the benefits of Information and Communication Technology (ICT), has a positive impact on the role of group leadership, which includes interpersonal roles, informational roles, and decision-making roles. Furthermore, it strongly influences the level of farmer independence through filtering ability, competitiveness, partnership power, and adaptability. Therefore, sustainable agricultural extension support in accordance with farmers' needs, as well as strengthening the leadership capacity of farmer groups both technically and socially, is needed to increase farmer independence, especially in dealing with climate change. Agricultural extension support and strengthening of the leadership role of farmer groups can be achieved through leadership

training, increasing technical capacity, utilizing digital technology, mentoring, and strengthening group dynamics. These efforts enable farmers to independently solve problems and make effective decisions.

For funding this study, the authors are grateful to the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia's Directorate of Research, Technology, and Community Services; the Directorate General of Research, Technology, and Higher Education (Grant Numbers: 027/E5/PG.02.00.PL/2024). Special thanks are extended to the Directorate of Research and Innovation of IPB University for coordinating and facilitating this research. The author also expresses gratitude to the Riau Provincial Government for granting permission to conduct this study. Finally, the authors are grateful to the reviewers for their insightful comments, which improved this article.

References

1. J. Wang, Z. You, P. Song, Z. Fang, Rainfall's impact on agricultural production and government poverty reduction efficiency in China. Sci Rep. **14**, 1, 1–21 (2024). https://doi.org/10.1038/s41598-024-59282-2
2. W. Estiningtyas, E. Surmaini, Suciantini, E. Susanti, A. Mulyani, B. Kartiwa, Sumaryanto, Perdinan, Y. Apriyana, A.D. Alifia, Analysing food farming vulnerability in Kalimantan, Indonesia: Determinant factors and adaptation measures. PLoS One. **19**, 1 (2024). https://doi.org/10.1371/journal.pone.0296262
3. [BPS Provinsi Riau] Badan Pusat Statistik Provinsi Riau, Luas Panen dan Produksi Padi di Provinsi Riau 2020, (2021)
4. [BPS Provinsi Riau] Badan Pusat Statistik Provinsi Riau, Luas Panen dan Produksi Padi di Provinsi Riau 2021, (2022)
5. [BPS Provinsi Riau] Badan Pusat Statistik Provinsi Riau, Luas Panen dan Produksi Padi di Provinsi Riau 2022, (2023)
6. D.P. Darmawan, G.M.K. Arisena, A.A.A.W.S. Djelantik, A.A.K. Krisnandika, N.K.S. Utari, N.T.L. Korri, Farmers' independence level in the urban area of Subak Sembung Denpasar City, Bali Province, Indonesia. The Journal of Agricultural Sciences - Sri Lanka. **18**, 1 40–54, (2023). https://doi.org/10.4038/jas.v18i1.10097
7. T. Lukhalo, E.M. Zwane, The influence of budget allocation to implement the policy of extension and advisory services in South Africa. South African Journal of Agricultural Extension. **50**, 1, 1–19 (2022). https://doi.org/10.17159/2413-3221/2022/v50n1a14199
8. T. Lin, A.P. Ko, M.M. Than, D.C. Catacutan, R.F. Finlayson, M.E. Isaac, Farmer social networks: The role of advice ties and organizational leadership in agroforestry adoption. PLoS One. **16**, 8, 1–18 (2021). https://doi.org/10.1371/journal.pone.0255987
9. E.M. Rogers, Diffusion of Innovations, Fifth. (Free Press, New York, 2003).
10. J. Hair, A. Alamer, Partial Least Squares Structural Equation Modeling (PLS-SEM) in second language and education research: Guidelines using an applied example. Research Methods in Applied Linguistics. **1**, 3 (2022). https://doi.org/10.1016/j.rmal.2022.100027
11. S.T. Guynn, W.K. Player, M.G. Burns, Underserved farmers' barriers to adoption of the U.S. Department of Agriculture Natural Resources Conservation Service climate-smart agricultural practices in South Carolina. J Agric Food Syst Community Dev. **13**, 4. 121–133 (2024). https://doi.org/10.5304/jafscd.2024.134.008
12. S. Sumardjo, A. Firmansyah, L. Dharmawan, Social transformation in peri-urban communities toward food sustainability and achievement of SDGs in the era of disruption. Sustainability. **15**, 13, 1–17 (2023). https://doi.org/10.3390/su151310678
13. G. Banda, Evolution of Zimbabwe's maize innovation ecosystems: Building an institutional innovation infrastructure that supported food security. Africa Development. **47**, 3, 167–195 (2022). https://doi.org/10.57054/ad.v47i3.2679

14. W.J. de Lange, F. van der Bank, M.E. Volscheck, T.E. Kleynhans, Farmer competencies for successful farming in Sub-Sahara Africa. J Rural Stud. **114**, (2025). https://doi.org/10.1016/j.jrurstud.2024.103549
15. A. Assaye, E. Habte, S. Sakurai, D. Alemu, Impact assessment of adopting improved rice variety on farm household welfare in Ethiopia. J Agric Food Res. **10**, 1–12 (2022). https://doi.org/10.1016/j.jafr.2022.100428