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Determinants of Innovation Uptake and Productivity in Smallholder Beef Cattle Farming: A Case Study of Manokwari, West Papua

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Abstract: This study aimed to analyze the determinants of technological innovation performance in smallholder beef cattle farming systems in Manokwari Regency, West Papua, Indonesia. The research was conducted from June to December 2023 using a survey method involving 100 respondents selected through purposive sampling. Data were analyzed using both descriptive statistics and inferential analysis, specifically multiple linear regression. The results revealed that the level of technological innovation adoption among farmers was relatively varied. The most widely adopted innovation was the utilization of improved forage (100%), while the adoption of more complex innovations such as artificial insemination and e-marketing remained low. Regression analysis showed that herd size, non-formal education, and institutional participation had positive and highly significant effects on technological innovation performance ($p < 0.01$). The model demonstrated strong explanatory power, with an adjusted R^2 value of 0.906. These findings indicate that the adoption of technological innovations is influenced not only by individual farmer characteristics but also, more importantly, by access to information, extension services, and the presence of farmer institutions. Therefore, efforts to develop the beef cattle sector should prioritize strengthening extension systems and farmer institutions to enhance productivity and ensure the sustainability of smallholder livestock farming.

Keywords: Beef cattle, innovation adoption, technological innovation, smallholder farming, farmer institutions

Introduction

Beef cattle represent an important component of local livestock resources maintained by smallholder farmers in Manokwari Regency, West Papua, Indonesia. This sector holds considerable potential for development as a source of household income (Rahut and Ali 2018; Hartono and Rohaeni 2014), supported by extensive land availability (Suwarto and Prihantoro 2020; Wahyono et al. 2021) and abundant local forage resources for feeding (Rostini et al. 2014; Sharifian et al. 2023). The predominant breed raised by farmers is Bali cattle, which are well adapted to local environmental conditions (Sharifian et al. 2023; Tavirimirwa et al. 2013). Beef cattle farming in this region is generally practiced as an integral part of mixed farming systems, where livestock activities complement crop production. Due to the relatively long production cycle required for cattle to reach market weight, beef cattle farming is typically managed as a secondary enterprise rather than the primary livelihood activity.

Despite its potential, the growth of the beef cattle population in Manokwari has been relatively slow. Official statistics indicate that the population increased modestly from 21,212 head in 2020 to 22,272 head in 2021 and 22,569 head in 2022 (Fatubun et al. 2018). This limited growth suggests underlying constraints in productivity and management efficiency, which may be addressed through the adoption of appropriate technological and managerial innovations.

Improving productivity in smallholder beef cattle systems requires the effective uptake of innovations that are aligned with the socio-economic characteristics of farmers. Innovation, as defined in Kamus Besar Bahasa Indonesia, refers to a new discovery that differs from existing knowledge or practices. Meanwhile, Everett M. Rogers describes innovation as an idea, practice, or object perceived as new by individuals or groups (Guo et al. 2020; Kebebe 2019). Within a broader socio-economic context, innovation extends beyond technological inventions to include new products, services, processes, and market strategies aimed at creating added value. Therefore, innovation in beef cattle farming encompasses not only technical improvements in husbandry practices but also business models, marketing approaches, and resource management strategies that enhance efficiency, productivity, and farmers' welfare.

The performance of technological innovation uptake in smallholder beef cattle farming is influenced by multiple factors. These include herd size, farmer age, farming experience, formal and non-formal education, household income, and the level of participation in farmer institutions such as livestock groups . Farmer institutions play a critical role in facilitating access to production inputs, improving production processes, and strengthening post-production activities including processing and marketing. According to the Agricultural Extension and Human Resource Development Agency of the Ministry of Agriculture (2015), farmer institutions are organizations developed by and for farmers to strengthen cooperation and advocate for their interests, commonly structured as farmer groups (*Kelompok Tani*) and farmer group associations (*Gabungan Kelompok Tani*).

Materi Dan Metode

Study Area and Period

This study was conducted from June to December 2023 in Manokwari Regency, West Papua, Indonesia. The research covered four major beef cattle production areas, namely Warmare, Prafi, Masni, and Sidey Districts, which are recognized as key development centers for smallholder beef cattle farming.

Data Collection Techniques

Data were collected using a survey approach. Primary data were obtained through structured interviews guided by a standardized questionnaire, complemented by in-depth interviews and direct field observations to capture both quantitative and qualitative information.

Types and Sources of Data

The study utilized both primary and secondary data sources. Primary data were derived directly from farmer respondents, while secondary data were obtained from relevant institutional reports, statistical records, and official publications related to livestock development in the study area.

Sampling Method

Respondents were selected using purposive sampling. The selection criteria included: (1) farmers actively engaged in beef cattle farming within the designated study areas, (2) a minimum of two years of farming experience, and (3) prior experience in selling cattle. A total of 100 respondents were selected, consisting of 25 farmers from each district.

Observed Variables

Table 1. Operational Definition of Observed Variables

No	Variable	Indicator	Parameter	Operational Definition	Unit	Scale	Reference
1	Socio-demographic Characteristics	Age	Years of farmer's life	Age of respondent at time of survey	Years	Ratio	Callo-Concha et al. (2013)
		Formal Education	Years of schooling	Total years of formal education completed	Years	Ordinal/Ratio	
		Non-formal	Training participation	Number of trainings attended	Frequency	Ratio	

		Education		related to livestock			
		Primary Occupation	Main job	Main source of livelihood (farming/non-farming)	Category	Nominal	
		Household Income	Monthly income	Total household income from all sources	IDR/month	Ratio	
		Family Size	Household members	Number of individuals in household	Persons	Ratio	
2	Farm Business Characteristics	Herd Size	Number of cattle owned	Total number of beef cattle owned by farmer	Head	Ratio	Góngora et al. (2019)
		Farming Experience	Years in cattle farming	Duration of involvement in cattle farming	Years	Ratio	
		Management System	Type of system	Extensive, semi-intensive, or intensive system	Category	Nominal	
		Production Objective	Purpose of farming	Subsistence, savings, or commercial purpose	Category	Nominal	
3	Technological Innovation	Artificial Insemination (AI)	Adoption level	Use of AI in breeding practices	Yes/No or Score	Binary/Ordinal	Hilmawan et al. (2023)

	Performance						
		Improved Forage	Use of superior grasses	Adoption of improved forage species	Yes/No or Score	Binary/Ordinal	
		Farmer Group Participation	Membership	Involvement in livestock/farmer groups	Yes/No	Binary	
		Housing System	Cattle housing	Availability and quality of housing system	Score	Ordinal	
		Composting	Manure utilization	Practice of compost production from manure	Yes/No	Binary	
		E-marketing	Digital marketing use	Use of online platforms for selling cattle	Yes/No	Binary	
		Animal Health Management	Health practices	Use of drugs, vitamins, and preventive care	Score	Ordinal	
4	Innovation Performance (Dependent Variable)	Composite Innovation Index	Adoption score	Aggregate score of all innovation practices applied	Index	Interval	Benoît Govoeyi et al. (2019); Kebebe (2019)

5	Determinants of Innovation	Socio-economic Factors	Multiple variables	Combined effect of age, education, income, etc.	Index/Score	Interval	Govoeyi et al. (2019); Kebebe (2019)
		Institutional Factors	Group participation	Level of involvement in farmer institutions	Score	Ordinal	

Data Analysis

To analyze the determinants of technological innovation performance, a multiple linear regression model was employed. The general form of the regression model is presented as follows; $Y = a + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + e$, Where: Y= technological innovation performance (score), a= constant (intercept), X_1= herd size (livestock units), X_2= formal education (years), X_3= household income (IDR/month), X_4= age (years), X_5= non-formal education (score), X_6= farming experience (years), X_7= institutional dummy variable (1 = member of farmer group; 0 = non-member), and e= error term.

The collected data were analyzed using both descriptive and inferential statistical approaches. Descriptive statistics were employed to summarize the data, including measures of central tendency and dispersion such as means, percentages, and standard deviations. Inferential analysis was conducted using multiple linear regression to examine the effects of independent variables on the dependent variable (innovation performance). The analysis was performed using IBM SPSS Statistics 25.

Results

Respondent Characteristics

The characteristics of smallholder beef cattle farmers in Manokwari Regency were analyzed based on socio-demographic aspects and farm business characteristics, as presented in Tables 1 and 2.

From a socio-demographic perspective, the average age of respondents was 49.64 years, indicating that most farmers fall within the productive age group, indicating that most farmers are still actively engaged in farming activities. The majority of respondents had completed primary education (elementary school), followed by senior high school and junior high school levels. Participation in non-formal education was relatively limited, typically ranging from one to two training sessions, mainly obtained through extension programs conducted by government agencies and universities.

Most respondents identified livestock farming as their primary occupation, with household income levels largely below the Regional Minimum Wage of Manokwari Regency. The average household size ranged from four to six members, which potentially provides a source of family labor to support livestock farming activities.

In terms of farm business characteristics, most farmers owned fewer than five head of cattle, indicating the small-scale nature of the production system. Farming experience was relatively extensive, with the majority of respondents having more than four years of experience in cattle farming. The dominant management system applied was semi-intensive, and the primary objective of raising cattle was as a form of savings or financial security rather than as a main commercial enterprise.

Table 2. Socio-Demographic Characteristics of Respondents

Component	Number (n = 100)	%
Age (Years)		
Productive (15–64 years)	90	90.00
Non-productive (> 64 years)	10	10.00
Mean ± SD	49.64 ± 11.80	–
Formal Education		
No formal education	3	3.00
Primary school (Elementary)	41	41.00
Junior high school	22	22.00
Senior high school	29	29.00
Diploma (D3)	1	1.00
Bachelor's degree (D4/S1)	4	4.00
Non-formal Education (Extension/Training)		
1–2 times	86	86.00
3–4 times	14	14.00
Primary Occupation		
Livestock farmer	74	74.00
Non-livestock farmer	26	26.00
Average Monthly Household Income *(based on Regional Minimum Wage / UMR: IDR 3,200,000)*		
< UMR	84	84.00
≥ UMR	16	16.00
Household Size (persons)		
1–3	40	40.00
4–6	55	55.00
7–9	5	5.00

Source: Processed primary data (2023)

Livestock farming serves as the primary occupation for most respondents (74%), while the remaining 26% rely on non-livestock activities. Household income levels are relatively low, with 84% of respondents earning below the regional minimum wage. In addition, the average household size ranges between 4–6 members (55%), suggesting the availability of family labor to support farming activities. Overall, these characteristics reflect typical smallholder conditions with limited resources but strong reliance on agriculture-based livelihoods.

Table 3. Characteristics of Beef Cattle Farming

Component	Number (n = 100)	%
Herd Size (head)		
< 5	48	48.00
5–10	34	34.00
> 10	18	18.00
Farming Experience (years)		
< 5 years	8	8.00
5–10 years	46	46.00
> 10 years	46	46.00
Management System		
Extensive	12	12.00
Semi-intensive	84	84.00
Intensive	4	4.00
Farming Objective		
Savings (asset accumulation)	97	97.00
Children's education expenses	3	3.00

Source: Processed primary data (2023)

Table 3 indicates that beef cattle farming in the study area is predominantly small-scale, with nearly half of the farmers (48%) owning fewer than five head of cattle, while only 18% manage more than ten head. In terms of experience, most farmers have substantial involvement in cattle farming, with 92% having more than five years of experience.

The dominant management system is semi-intensive (84%), reflecting a combination of grazing and controlled feeding practices, while only a small proportion apply intensive (4%) or extensive (12%) systems. Regarding farming objectives, the vast majority of farmers (97%) raise cattle primarily as a form of savings or asset accumulation, whereas only a small proportion (3%) use it to support specific expenses such as children's education.

Overall, these findings confirm that beef cattle farming in Manokwari is characterized by smallholder, experience-based systems with a strong orientation toward financial security rather than purely commercial production.

Technological Innovation Performance in Beef Cattle Farming

Technological innovation performance in beef cattle farming reflects the extent to which farmers adopt and utilize innovations to improve farm productivity and efficiency. Based on Table 3, the types of technological innovations implemented by farmers include artificial insemination (AI), housing systems, e-marketing, participation in livestock farmer groups, utilization of improved forage, animal health management, and composting practices.

The findings indicate that the most widely adopted innovation was the use of improved forage (100%), highlighting its importance as a readily accessible and practical strategy for enhancing feed availability. This was followed by composting practices (30%), participation in farmer groups (29%), and animal health management (27%). In contrast, lower adoption rates were observed for housing systems (15%), artificial insemination (10%), and e-marketing (7%).

These results suggest that farmers tend to prioritize innovations that are relatively low-cost, easily applicable, and directly linked to daily farm operations, while more complex or resource-intensive innovations remain less widely adopted.

Table 4. Types and Frequency of Technological Innovation Utilization in Beef Cattle

Farming

Component	Frequency (n = 100)	%
Artificial Insemination (AI)	10	10.00
Housing System	15	15.00
E-marketing	7	7.00
Farmer/Livestock Group Participation	29	29.00
Improved Forage Utilization	100	100.00
Animal Health Management	27	27.00
Composting	30	30.00

Source: Processed primary data (2023)

Determinants of Technological Innovation Performance in Beef Cattle Farming

The multiple linear regression model estimating the determinants of technological innovation performance in beef cattle farming in Manokwari Regency is expressed as follows:

follows:

$$Y = 0.063 + 0.032X_1 - 0.022X_2 - 0.00001339X_3 + 0.001X_4 + 0.286X_5 + 0.006X_6 + 1.079X_7 + e$$

Where: Y= technological innovation performance (score), a= constant (intercept), X_1= herd size (livestock units), X_2= formal education (years), X_3= household income (IDR/month), X_4= age (years), X_5= non-formal education (score), X_6= farming experience (years), X_7= institutional dummy variable (1 = member of farmer group; 0 = non-member), and e= error term. This model captures the combined influence of socio-economic and institutional factors on the level of innovation performance among smallholder beef cattle farmers.

Table 5. Determinants of Technological Innovation Performance in Beef Cattle Farming

Variable	Coefficient	t-value	Sig.
Constant	0.063	0.231	0.818
Herd Size (LU) (X_1)	0.032	2.757	0.007**
Formal Education (X_2)	-0.022	-1.517	0.133
Household Income (X_3)	-0.00001339	-0.235	0.814
Age (X_4)	0.001	0.203	0.839
Non-formal Education (X_5)	0.286	14.655	0.000**
Farming Experience (X_6)	0.006	0.382	0.704
Institutional Dummy (X_7)	1.079	8.582	0.000**
R Square (0.913) Adjusted R Square (0.906) F.137.809 (0.000[b])			

Note:** indicates highly significant at p < 0.01. Source: Processed primary data (2023)

The regression results indicate that the model explains a very high proportion of variation in technological innovation performance, with an Adjusted R^2 of 0.906 and a highly significant overall F-test (p < 0.01). Among the explanatory variables, herd size (X_1), non-formal education (X_5), and institutional participation (X_7) have positive and highly significant effects (p < 0.01) on innovation performance. This suggests that farmers with larger herd ownership, greater exposure to training and extension activities, and active involvement in farmer groups are more likely to adopt and implement technological innovations.

In contrast, formal education (X_2), household income (X_3), age (X_4), and farming experience (X_6) do not show statistically significant effects on innovation performance (p > 0.05). These findings imply that, within smallholder beef cattle systems, access to information, learning opportunities, and institutional support are more influential than individual demographic or economic characteristics in driving innovation adoption.

Discussion

The characteristics of respondents indicate that beef cattle farming in Manokwari Regency remains a small-scale, smallholder-based enterprise integrated with crop farming systems. As such, farm development is strongly influenced by the

limited resources available to farmers. These findings are consistent with previous studies showing that the adoption of agricultural technologies is shaped by socio-economic factors such as farm size (Mwaura et al. 2021; Bernués et al. 2011), access to resources (Deb 2019; Gomiero et al. 2011), and farmer characteristics (Ilatsia et al. 2012; Solano et al. 2000; Sesay et al. 2022). In addition, the diffusion of innovations theory explains that technology adoption is influenced by social interactions and access to information within a given social system (Adnan et al. 2019; Mauludin et al. 2012; Salmon et al. 2018). Participation in institutional arrangements, such as farmer or livestock groups, plays a crucial role in enhancing innovation uptake by providing access to information, training, and technical support (Darmawi 2011; Shikuku et al. 2017; Pateda and Rokhyati 2022). Conversely, the low adoption rates of certain technologies may be attributed to behavioral factors, limited knowledge, and economic constraints faced by farmers (Mhlanga et al. 2018; Shikuku et al. 2017; Gil et al. 2015).

The high adoption rate of improved forage suggests that innovations which are simple, low-cost, and compatible with local conditions are more readily accepted by farmers. In contrast, the low adoption of technologies such as artificial insemination and e-marketing reflects constraints related to limited access to information, insufficient technical skills, and weak institutional support.

Non-formal education was found to have a positive and highly significant effect on innovation performance, indicating that extension services and training programs play a critical role in enhancing farmers' capacity to adopt new technologies. This finding aligns with the diffusion of innovation theory, which emphasizes the importance of information access and social learning processes in determining adoption levels (Gil et al. 2015; Shikuku et al. 2017; Ugochukwu and Phillips 2018). Similarly, institutional participation (e.g., livestock farmer groups) showed a significant positive effect on innovation performance. Farmers who are members of such groups benefit from improved access to information, technologies, and business support services. This is supported by previous research highlighting the importance of social networks and institutional structures in accelerating agricultural technology adoption (Ugochukwu and Phillips 2018; Adnan et al. 2018; Cortner et al. 2019).

On the other hand, variables such as formal education, household income, age, and farming experience were not statistically significant. This suggests that, in the context of smallholder livestock systems, access to information and institutional engagement may play a more dominant role than individual farmer characteristics. Similar findings have been reported in earlier studies, where barriers to innovation adoption were often linked to social and behavioral factors (Muniesa 2015; Agustina and Beilin 2012) rather than purely demographic attributes (Włodarczyk-Marciniak et al. 2020; Ayantunde et al. 2011; Thurlow et al. 2019).

Herd size was found to have a positive and significant effect on innovation performance, indicating that farmers with larger herd ownership tend to have greater resource capacity and are therefore more capable of adopting technological innovations. This

supports previous findings that farm scale and resource endowment are key determinants of agricultural technology adoption (Ngaiwi et al. 2023; Kebebe 2019; Adejuwon, Ilori, and Taiwo 2016). Furthermore, the significant role of non-formal education underscores the importance of strengthening extension intensity and capacity-building programs to enhance innovation uptake among farmers.

Institutional involvement also demonstrated a strong positive influence, reinforcing the idea that collective action and organized farmer groups improve access to technical assistance, market opportunities, and innovation diffusion. This finding is consistent with studies emphasizing the role of institutional and social capital in promoting agricultural development (Paul et al. 2018; Abbas and Muhtarom 2018; Shalini et al. 2024). Meanwhile, the limited influence of other variables on innovation adoption may be explained by constraints such as restricted access to information, behavioral resistance, and socio-economic barriers faced by farmers (Ojiem et al. 2006; Fiore et al. 2024; Martin et al. 2015).

Overall, these findings are in line with a growing body of evidence in Indonesia, which highlights that education (particularly non-formal), access to information, and institutional support are key drivers in enhancing the adoption of innovations in the agricultural and livestock sectors.

Conclusion

This study demonstrates that beef cattle farming in Manokwari Regency is still predominantly characterized by smallholder production systems with varying levels of technological innovation adoption. Innovations that are simple and compatible with local conditions, such as the use of improved forage, exhibit high adoption rates. In contrast, innovations requiring greater technical support and more complex access to information—such as artificial insemination and e-marketing—remain relatively low in adoption.

The regression analysis indicates that herd size, non-formal education, and institutional participation have a positive and statistically significant effect on technological innovation performance in beef cattle farming. The model shows a very strong goodness-of-fit, with an adjusted R^2 value of 0.906, suggesting that the selected variables explain a substantial proportion of the variation in innovation performance.

From a practical perspective, these findings highlight that the adoption of technological innovations is not solely determined by individual farmer characteristics, but is more strongly influenced by access to information, extension services, and the presence of effective farmer institutions. Therefore, strategies for developing the beef cattle sector should focus on strengthening extension systems, enhancing farmers' capacities through non-formal education and training, and reinforcing farmer group institutions.

This study is limited by its reliance on cross-sectional data, which does not fully capture the temporal dynamics of innovation adoption. Future research is therefore

recommended to employ longitudinal approaches in order to provide a more comprehensive understanding of innovation processes over time.

Novelty

This study provides a novel contribution by integrating technological, socio-economic, and institutional dimensions into a single analytical framework to explain innovation performance in smallholder beef cattle systems in Eastern Indonesia. Unlike previous studies that primarily focus on adoption levels of individual technologies, this research develops a composite perspective of innovation performance based on multiple technological components (e.g., forage, health, marketing, and breeding practices).

Furthermore, the study highlights the dominant role of non-formal education and institutional participation over conventional factors such as formal education, income, and age—offering new empirical evidence from a relatively under-researched region, namely Manokwari, West Papua. The high explanatory power of the regression model (Adjusted R^2 = 0.906) also strengthens the robustness of the findings and provides a comprehensive basis for policy and development interventions in smallholder livestock systems.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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