Research Article

Identifying Leverage Points for Building Smallholder Dairy Resilience to Foot-and-Mouth Disease in West Java, Indonesia

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Abstract | The Foot-and-Mouth Disease (FMD) outbreak has had a significant impact on dairy farming, particularly on small-scale farmers such as members of the West Java Dairy Farmers Association (KPSBU). This study aims to analyze the level of dairy farm resilience and the factors that influence resilience during the FMD outbreak. The research was conducted in TPK Pojok, the KPSBU working area with the highest FMD spread and the largest dairy cattle population. A total of 52 farmers were selected using proportional random sampling. Primary data were collected through structured interviews, while secondary data were obtained from cooperatives and relevant agencies. The analysis employed Multi-Dimensional Scaling (MDS) with leverage analysis to identify sensitive attributes across ecological, economic, sociocultural, technological, and institutional dimensions. The results showed that most dairy farms in the study area had low resilience. Low livestock ownership contributes to vulnerability because limited herd size restricts milk production and income. This condition reflects the structural characteristics of smallholder dairy systems, whose risks intensify when technological, economic, and institutional support is insufficient. With appropriate interventions such as heifer rearing programs that enable gradual herd expansion, allocating proceeds from male calf sales to forage land or barn improvements, and low-interest cooperative credit. Key attributes influencing resilience included barn location, forage land, and organic waste utilization (ecological); milk price, number of cattle, and farmer savings (economic); farming experience, extension participation, and off-farm jobs (sociocultural); vaccination, medication, and sanitation (technological); and the roles of farmer groups and livestock agencies (institutional). These attributes shape economic security, livestock health, environmental efficiency, and institutional support factors essential for maintaining dairy farming sustainability during outbreaks. Based on the findings, resilience improvement should prioritize strengthening animal health technology and daily management practices, such as improving barn sanitation and applying routine vaccination. Institutional strengthening is also crucial, particularly through enhancing the functions of farmer groups and cooperatives, along with intensive extension focused on biosecurity, feed management, and farmer financial management to increase adaptability to disease risks and price fluctuations during FMD.

Keywords | Dairy farm resilience, Foot-and-mouth disease (FMD), Multi-dimensional scaling (MDS), Dairy farmers cooperative, Smallholder dairy farming, Rural livelihood resilience

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INTRODUCTION

West Java Province is one of the largest centers for dairy cattle development in Indonesia, with a population of 111,191 head and contributing 20% of the national population (Central Bureau of Statistics, 2023). However, the dairy sector faces a significant risk of Strategic Infectious Animal Diseases (PHMS), particularly Foot and Mouth Disease (FMD). FMD is a highly contagious disease caused by the *Aphthovirus* genus (*Picornaviridae* family) and affects cloven-hoofed animals, causing fever, anorexia, hypersalivation, and lesions in the mouth, feet, and udder (Adjid, 2020; Firman *et al*., 2022; Ismail, 2023). As of December 2022, West Java reported 67,590 affected ruminants across 13 regencies/cities, with West Bandung Regency recording the highest number of cases: 16,067 cows sick, 1,856 cows conditionally slaughtered, and 1,383 cows dead (Food Security and Livestock Service Office of West Java, 2023). This situation has led to decreased milk production, reproductive disorders, and significant economic losses (Knight-Jones and Rushton, 2013; Salsabilah *et al*., 2024).

Dairy farming in West Java, particularly in West Bandung Regency, is dominated by smallholder farmers with 2–5 cows and milk production of 10–15 liters/cow/day. The small scale and limited resources are chronic structural vulnerabilities in the dairy farming system, and the FMD outbreak was a sudden shock that further worsened the condition of dairy farming in West Java. Therefore, dairy farming resilience means not only coping with sudden shocks such as FMD, but also overcoming chronic structural pressures that undermine farmers' long-term sustainability. This outbreak prompted the government and cooperatives to form a task force to reduce livestock mortality and maintain business sustainability. The dairy agribusiness system in Indonesia follows a vertical chain, where fresh milk is collected by cooperatives before being distributed to the milk processing industry (Ao *et al*., 2021). Thus, cooperatives play a strategic role in providing services such as milk collection, feed provision, artificial insemination, animal health, and financial support, therefore, the stability of cooperatives is crucial for the welfare of dairy farmers.

One of the dairy cattle centers in West Java is the North Bandung Cattle Breeders Cooperative (KPSBU), which has also been seriously impacted by FMD. A total of 4,984 cows have been confirmed positive and 5,511 are suspected cases of FMD, increasing the economic vulnerability of smallholder farmers. They face decreased milk production, increased treatment and prevention costs, and lower livestock and milk prices. Chronic FMD can reduce milk production by up to 80% and increase calf mortality by 2–3% (Raina *et al*., 2023). These impacts demonstrate how FMD weakens the assets and resilience of smallholder farmers' households (Orsango *et al*., 2023).

Therefore, resilience is a crucial aspect for maintaining business sustainability amidst FMD outbreaks and various other threats. Resilience should be conceptualized as the farmers' capacity to withstand sudden shocks, as well as their ability to adapt to and transform long-term structural weaknesses. The agricultural sector routinely faces economic, social, environmental, and institutional pressures (Prat-Benhamou *et al*., 2024). Resilience in agricultural systems is defined as the ability to maintain system function despite complex and repeated disturbances (Meuwissen *et al*., 2019). Resilient livestock systems possess three key capacities: robustness, adaptability, and transformability (Darnhofer, 2014; Meuwissen *et al*., 2019; Prat-Benhamou *et al*., 2024). Robustness allows businesses to survive without major structural changes, adaptability allows for management adjustments without altering core functions, and transformability involves major changes in business structure to address new conditions (Daniele *et al*., 2022).

During the FMD outbreak, resilient livestock farmers demonstrated robustness through increased biosecurity, livestock movement restrictions, utilization of feed reserves, and reduced operational costs, as farmers in Spain did during the crisis (Daniele *et al*., 2022). Adaptability is evident in the reorganization of family labor, the formation of a livestock health and nutrition task force, and modifications to feeding strategies when logistics are disrupted (Suryanah *et al*., 2025). Transformability emerges through the adoption of animal health technology, strengthening institutional roles, and participation in livestock insurance. These measures help farmers not only respond to sudden shocks but also gradually overcome structural vulnerabilities such as limited capital, knowledge gaps, and institutional support.

Based on these conditions, research is needed to identify factors influencing the resilience of dairy farmers to FMD outbreaks in the West Java KPSBU area. Referring to Meuwissen *et al*. (2019), Prat-Benhamou *et al*. (2024), and Reidsma *et al*., (2020), resilience is conceptualized from specific attributes to broader dimensions. This study integrates Scoones' (1998) five livelihood: Assets human, natural, financial, social, and physical capital and Chambers and Conway's (1991) rural development principles of community-oriented, participatory, empowering, and sustainable. By combining ecological, economic, sociocultural, technological, and institutional dimensions, this study makes a novel contribution by demonstrating that disease resilience depends not only on technical measures but also on cross-dimensional interactions. For instance, preliminary observations indicate that low economic capacity can limit farmers' ability to adopt essential technological practices such as sanitation or routine vitamin and medication use, while uneven institutional support can

reduce farmers' participation in extension activities that shape their knowledge and social capacity during disease outbreaks. These patterns show that vulnerabilities emerge both from chronic stresses and acute shocks, highlighting the need for interventions addressing both. Through MDS and leverage analysis, this study identifies key attributes that shape the adaptive and institutional capacity of smallholder farmers, and determines the level of resilience of dairy farmers in West Java in facing FMD outbreaks.

MATERIALS AND METHODS

Research object, location, and sampling technique

The object of this study is the set of factors influencing the resilience of dairy farming systems to FMD, while the research subjects consist of dairy farmers within the operational area of the West Java Dairy Farmers Cooperative (KPSBU). The study was conducted purposively in the service area of the Cooperative Service Center (TPK) Pojok, under the KPSBU, West Java, which operates within the cooperative's broader service area spanning three districts: West Bandung, Subang, and Bandung Regency TPK Pojok was selected based on two key considerations. First, it represents the area with the highest incidence of FMD cases within KPSBU. Second, it holds the largest dairy cattle population among the TPKs, making it a strategically relevant and representative site for examining resilience dynamics in the context of disease outbreaks.

To obtain an appropriate and representative sample of dairy farmers, respondents were selected using a proportional random sampling technique. This method ensured that the sample reflected the distribution of farmers across the population within the TPK Pojok area. The total sample size was determined using the Slovin formula, which provides the minimum number of respondents needed from a finite population to estimate population proportions with acceptable precision. Through this approach, the study aims to capture a robust representation of farmer experiences and the factors shaping their resilience to FMD. The formula for sample calculation using the Slovin method is as follow:

$$n = \frac{N}{1 + Ne^2}$$

$$n = \frac{110}{1 + 110.0.1^2}$$

$$n = 52.4 \approx 52 \text{ sample}$$

Description: n= sample size, N= population size, e^2 = margin of error (0.1).

Data collection techniques

The data used in this study consisted of primary and secondary data. Primary data were collected through interviews with 52 farmers in TPK Pojok using a questionnaire and direct observation. Secondary data were obtained from the North Bandung Cattle Farmers Cooperative (KPSBU) in West Java, the local Agriculture/ Livestock Service, and a review of the relevant literature.

Variable operationalization

Dairy business resilience is defined as the ability of a dairy business to continue operating despite various disruptions and even to grow. Resilience in this study is viewed from various dimensions, namely.

Ecological dimension

This dimension relates to ecosystem stability and the availability of natural resources that support livestock maintenance. The use of waste as organic fertilizer, the availability of agricultural waste as livestock feed, and the use of land for livestock feed demonstrate the ability of farmers to utilize natural resources to survive during FMD. Meanwhile, the distance of the livestock business location is an indicator of the farmer's ability to deal with the spread of FMD.

Economic dimension

The economic dimension assesses the farmer's ability to survive financially and maintain the sustainability of productive assets during the FMD period. Attributes such as income level, number of livestock, and number of workers describe the resilience of income and production assets. The indicators for farmer income attributes were reviewed using the West Bandung Regency minimum wage as the minimum standard for meeting the living needs of workers in the study area, which is IDR 3,736,741. According to Dasipah *et al.* (2020), the average monthly income per dairy cow at KPSBU is IDR 947,533. It is known that in the research location, farmers have an average of three cows, so it is assumed that their dairy cow business income ranges from ± IDR 2.8–3 million, equivalent to the minimum wage in West Bandung Regency at the time of the study. Meanwhile, the price of milk shows the ability of farmers to maintain economic stability during FMD. Savings and participation in livestock insurance can ensure business continuity.

Socio-cultural dimension

This dimension examines the individual and social capacity of farmers to adapt to the FMD crisis. Farming experience, farmer age, and education level indicate the individual ability of farmers to recognize, understand, and adapt during the FMD period. Meanwhile, the frequency of extension services and social participation indicates access to information and community support. Other work refers to the labor and time that farmers devote outside of their

livestock business to meet their household needs, especially during the FMD outbreak crisis.

Technological dimension

The technological dimension assesses the extent to which the application of innovation supports business resilience to FMD. The use of vitamins, medicines, sanitation, and biosecurity practices, and the use of biogas technology are indicators of farmers' readiness to maintain livestock health and business efficiency during an outbreak.

Institutional dimension

This dimension highlights the importance of structural support and social networks in strengthening farmers' resilience during an FMD outbreak. The existence of farmer groups and cooperatives plays a role in disseminating information, collecting milk, and stabilizing the economy. Meanwhile, the role of the livestock service (Task Force) demonstrates policy support and assistance in controlling outbreaks.

The attributes examined in the dairy business resilience dimension in this study are described in Table 1.

Table 1: Attributes assessed in each dimension of dairy cattle business resilience.

No	Dimension and Indicator	Score
Ecological Dimension		
1	Is there waste utilization for organic fertilizer?	(0) Not utilized (2) Partially utilized (2) Fully utilized
2	Is there agricultural waste utilization for livestock feed?	(0) Not utilized (1) Partially utilized (2) Fully utilized
3	How is the availability of land for livestock feed	(0) Low (<50%) (1) Medium (50% - 75%) (2) High (>75%)
4	How close is the livestock business location to residential areas?	(0) Within a residential area (1) Near residential areas (50 – 100 m) (2) Far from residential areas (>100 m)
Economic Dimension		
1	How much income is earned from the dairy cattle business?	(0) Below the regional minimum wage (1) Equal to the regional minimum wage (2) Above the regional minimum wage
2	What is the average milk price? (Standard milk price in KPSBU West Java: IDR. 5,800/liter)	(0) < IDR 5,800 (1) = IDR 5,800 (2) > IDR 5,800
3	How many workers assist the respondent?	(0) None (1) 1 person (2) > 1 person
4	Do farmers have savings?	(0) Not available (1) Available
5	How many cows does the farmer own?	(0) 1 – 3 heads (1) 4 – 6 heads (2) >6 heads
6	Does the farmer insure their livestock?	(0) Not insured (1) Only 1 cow insured (2) All cows insured
Socio-Cultural Dimension		
1	What is the respondent's farming experience?	(0) 1 – 5 years (1) 6 – 10 years (2) > 10 years
2	How often does the respondent attend counseling and training?	(0) Never (1) Once (2) More than once
3	How much does the respondent participate in social activities?	(0) 0 – 1 (1) 2 – 3 (2) > 4
4	Does the respondent have another job besides farming?	(0) > 1 job (1) 1 job (2) None
5	What is the age of the farmer?	(0) ≥61 years old (1) 41 – 60 years old (2) 20 – 40 years old
6	What is the educational level of farmers?	(0) Elementary School (1) Junior High School (2) Senior High School (3) University
Technological Dimension		
1	How regularly are vitamins and medicines used to support livestock health?	(0) Never (1) Occasionally (2) Regularly
2	How are the livestock business operational vehicles used by respondents?	(0) Traditional (1) Simple (2) Modern
3	Is biogas technology available?	(0) Not available (1) Available
4	Does the farmer implement sanitation and biosecurity measures?	(0) Not available (1) Available
Institutional Dimension		
1	Is there a livestock farmers' group?	(0) Not available (1) Available but inactive (2) Available and active
2	Is there a role of the government agency?	(0) Not available (1) Available but inactive (2) Available and active

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3	Is there a role of the cooperative?	(0) Not available (1) Available but inactive (2) Available and active

Note: The scoring for "Other jobs" reflects the time allocation required in smallholder dairy systems. Off-farm work reduces farmers' available labor for daily cattle management, thereby lowering the sustainability of the dairy enterprise during disease shocks such as FMD.

Validity and reliability test

The validity and reliability test were conducted on the research instrument, namely the questionnaire, using SPSS (Statistical Package for Social Sciences) software. The validity test was conducted to ensure the validity or ability of each question item in the questionnaire to accurately measure the concept that it was intended to measure. The validity test in this study used Karl Pearson's Product-Moment formula. The basis for decision-making in this test was to compare the correlation values r. The r value obtained was compared with the table r value. If the calculated r value is higher than the table r value, then the instrument was declared valid.

The content of the research instrument was also evaluated through expert assessment (academics and field extension officers) to ensure that each item was appropriate and relevant to the variables being measured. Yusup (2018) states that validity testing is conducted through expert evaluation, followed by revisions based on their suggestions and feedback until the items are deemed content-valid by the experts.

For reliability, Cronbach's Alpha was calculated to assess internal consistency. The basis for decision-making in this test is that if the Cronbach Alpha coefficient ≥ 0.6, then the instrument can be declared reliable. However, it should be noted that this measure is typically intended for psychometric scales measuring a single underlying construct. Since the questionnaire includes a diverse set of objective attributes (e.g., number of cows, land availability), Cronbach's Alpha provides limited information. Therefore, content validity through expert review was emphasized as the primary method to ensure the appropriateness of the questionnaire items for this study.

Analysis method

The data obtained were analyzed using a multidimensional scaling (MDS) approach with Rapfish (Rapid Appraisal of Fisheries) software to determine the level of resilience of the KPSBU West Java dairy business across various dimensions. Rapfish, originally developed by the University of British Columbia to assess fisheries sustainability, has since been widely adapted for research on the sustainability of other natural resource systems (Mulyana *et al*., 2017). This is supported by Idris *et al*. (2023), who stated that Rapfish is now used in various sectors such as agriculture, forestry, and tourism because it is capable of producing a quick and comprehensive sustainability analysis in the form of numerical outputs, which can then serve as a basis for formulating appropriate policies. Ningsih *et al*., (2023) also applied Rapfish in their study on sustainable agroforestry systems using customized dimensions and attributes, similar to Idris *et al*. (2023), who examined the sustainability of tourist areas in Malang City using Rapfish.

The MDS analysis results produced: (1) stress values and determination coefficients (R2) that indicate the accuracy of the model, (2) a Monte Carlo that describes the level of analysis stability, and (3) a resilience index, which is then categorized into high, moderate, and low levels of resilience. The resilience index values were then analyzed using leverage to determine the attributes that most influenced each dimension of resilience.

The following are the stages of analysis in this study:

1. Determination of the data matrix: All dimensional attributes (ecological, economic, socio-cultural, technological, and institutional) are given ordinal scores and arranged into a matrix (respondents x attributes). The scoring was simplified to allow aggregation through MDS. The score thresholds (e.g., 50–75% feed land availability = 1) were determined in a non-standardized manner but based on rational considerations, including field practices and previous literature. This limitation is acknowledged, and the results should be interpreted with this simplification in mind
2. Analysis of attribute scores using modified Rapfish software to determine points that reflect resilience status in each dimension. The MDS algorithm in Rapfish calculates the similarity distance (Euclidean distance) between each respondent based on all attributes. The more similar the values between respondents, the smaller the distance. MDS places all respondents in a two-dimensional field (2D plot). The position of each point shows the level of similarity between respondents in terms of resilience. The configuration of the ordination results is normalized to a continuous scale of 0–100, which shows the resilience index for each dimension. The categorization of the index and resilience status refers to (Pitcher and Preikshot, 2001) as shown in Table 2.
3. Examine the index values and resilience status of each dimension. Resilience status is obtained through the average of the resilience index values for each dimension.
4. Model suitability is tested using Stress Square Correlation (SQR), the coefficient of determination (R2), and the Monte Carlo (MC) value. Stress values

are used to determine the accuracy of MDS analysis, correlation coefficients are used to determine whether it is necessary to add attributes so that the dimensions being examined reflect actual conditions, and Monte Carlo (MC) is used to estimate the effect of error in the statistical analysis process (Vatria, 2020). An acceptable SQR value is <0.25, an acceptable R2 value is close to 1, which means that the number of attributes used to examine the dimensions is accurate, and in MC, the smaller the difference between MDS and MC (<1), the smaller the error in the analysis (Kavanagh and Pitcher, 2004; Tesfamichael and Pitcher, 2006; Vatria, 2020).

5. Examine sensitive attributes that affect resilience using leverage analysis. This analysis is performed to measure the sensitivity of each attribute to the MDS ordination results. The leverage process is carried out using a one-at-a-time perturbation approach, which involves removing or changing the value of one attribute while the other attributes remain unchanged. MDS is then rerun without that attribute, and the change in the configuration of the ordination points is compared to the initial configuration. The magnitude of the change is calculated using the Root Mean Square (RMS) value of the distance difference between the points in the two configurations. The attribute with the highest RMS value is considered the most sensitive attribute because a small change in that attribute results in a large change in the ordination structure and resilience index.

Table 2: Index categories and resilience status.

Index value	Resilience category
0.00 – 33.33	Low
33.34 – 66.66	Moderate
66.67 – 100.00	High

RESULTS AND DISCUSSIONS

Level of dairy farm resilience

The level of dairy farm resilience was analyzed using Multi-Dimensional Scaling (MDS) with Rapfish software. The analysis results comprised three parts: (1) stress values and determination coefficients, (2) Monte Carlo values, and (3) resilience index values.

Stress values (SQR) and determination coefficients (R2)

A research model is considered good if the stress value is <0.25 and R2 is close to 1. The results of the stress value and coefficient of determination analysis are shown in Table 3. Table 3 shows that the stress values for each dimension and multidimension are in the range of 0.18–0.27, and the multidimension value is 0.2, which is considered good because it is <0.25. However, the stress value for the Technology dimension (0.27) slightly exceeds the 0.25 threshold, indicating a minor limitation in the model's goodness of fit. Similarly, the R2 values for each dimension and their average are in the range of 0.84–0.92. Generally, these values are close to 1 and are considered acceptable. Based on these two statistical parameters, it can be concluded that all attributes used in each dimension capable of describing the resilience of the TPK Pojok KPSBU West Java dairy business.

Table 3: Statistical parameters of the dairy cattle business resilience analysis.

Statistical parameter	Dimension					Multi dimension
	Ecology	Economy	Social	Technology	Institutional	
Stress	0.19	0.19	0.25	0.27	0.18	0.216
R^2	0.92	0.88	0.84	0.84	0.91	0.878

Monte carlo values

Monte Carlo values are used to validate and evaluate the effect of errors on the process of estimating the dairy cow business resilience index value. Monte Carlo values are obtained by calculating the difference between the multidimensional (MDS) value and the Monte Carlo value. The smaller the difference (<1), the smaller the random error in the analysis process. The Monte Carlo analysis results, as shown in Table 4, indicate that the difference between the MDS and Monte Carlo values within 90% confidence interval is very small (<1). This indicates that the random error is relatively small because: (1) the error in scoring each attribute is relatively small, (2) the variation in scoring due to differences in opinion is relatively small, (3) the repeated MDS analysis process is relatively stable, (4) data entry errors and missing data can be avoided, and (5) the analysis reviewed has a high level of confidence. Based on the statistical test parameters used, the model is quite good and stable for use as a quantitative evaluation tool for dairy cattle business resilience.

Table 4: Monte Carlo analysis results.

Dimension	MDS	Monte Carlo	Difference
Ecology	13.9158	16.0058	-2.0900
Economy	17.6385	19.1247	-1.4862
Socio-Cultural	34.0012	34.0327	-0.0315
Technology	41.6729	41.995	-0.3221
Institutional	50.7435	50.7771	-0.0336

Resilience index value

Each attribute is given an ordinal score and then compiled into a data matrix. The MDS procedure, implemented in Rapfish, calculates the Euclidean distance between all observations to determine their relative position in

multidimensional space. The resulting configuration is normalized to a scale of 0–100, representing the resilience index for each dimension. The resulting resilience index values in this study are based on assessments of attributes covered in five dimensions (described in Table 1) as follows:

- Ecological Dimension (4 attributes)
- Economic Dimension (6 attributes)
- Socio-Cultural Dimension (6 attributes)
- Technological Dimension (4 attributes)
- Institutional Dimension (3 attributes)

The resilience index values were then categorized into three statuses: low, moderate, and high (as explained in Table 2). Based on the research results presented in Table 5, it is evident that most dairy cattle business resilience statuses fall into the unsustainable category. In general, this is because dairy farms are still small-scale, with 1-3 lactating cows and low milk production (average of 10-12 liters). These small-scale dairy farms have low capacity, low production, limited resources, and inadequate infrastructure (Wibowo, 2023). This situation is exacerbated by the FMD outbreak, which has resulted in the loss of lactating cows and reduced milk production. This condition occurs in developing countries where FMD is an endemic disease that severely limits livestock production, complicates sales, reduces farmers' income, and disrupts the food supply chain (Patidpong *et al*., 2025). This shows that dairy farming is the commodity most vulnerable to the FMD outbreak. Tawaf (2018) states that 98% of dairy farms are controlled by smallholder livestock businesses, making them vulnerable to intervention and the FMD outbreak. This is one of the interventions that can have a major impact on the development of the national dairy industry.

Table 5: Dairy cattle business resilience status in TPK Pojok, KPSBU West Java.

No.	Resilience category	Total	
		Farmers	%
1	Low	32	61.53
2	Moderate	20	38.46
3	High	0	0
Total		52	100.00

Table 6: Resilience status by dimension of dairy cattle business.

No	Dimension	Category (% of Respondents)			Total
		High	Moderate	Low	
1	Ecology	1.92	7.69	90.39	100
2	Economy	0.00	13.47	86.53	100
3	Socio-Cultural	3.84	44.24	51.92	100
4	Technology	3.84	73.03	23.13	100
5	Institutional	38.46	30.77	30.77	100

The findings of this study revealed several dimensions with low scores, which will affect the overall resilience of dairy farming. Based on Table 6, the level of resilience in the ecological, economic, and socio-cultural dimensions is mostly in the "unsustainable" category, while the technological dimension is in the "sufficient" category and the institutional dimension is spread evenly across all categories.

These results indicate that the West Java KPSBU dairy farming system remains at a basic level of resilience, meaning that farmers are still at the stage of maintaining business continuity amid the pressure of FMD outbreaks and lack of strong adaptive capacity to adjust their management practices and reduce the impact of future shocks. Farmers are still highly dependent on local resources, have limited access to capital and technology, and are not yet fully capable of mitigating the risk of productivity loss when outbreaks occur. Meanwhile, according to Darnhofer *et al.* (2010), resilience is not only the ability to maintain livestock businesses when facing shocks but also to adapt and adopt new systems if necessary, especially the resilience capacity of farmers in facing external disturbances. Therefore, improving resilience needs to be directed at strengthening adaptive capacities, such as income diversification, savings, and technical training, as well as enchancing institutional capacities including collaboration between farmers, cooperatives, and the government.

Factors affecting the resilience of dairy cattle businesses to foot-and-mouth disease outbreaks

The resilience index value comprises of various attributes (ecological, economic, socio-cultural, technological, and institutional dimensions) which are then analyzed using leverage to determine the attributes that have the most influence on each dimension of resilience. The analysis was conducted by examining the influence of each Root Mean Square (RMS). The greater the RMS change due to the loss of an attribute, the greater its role as a determinant of resilience in dairy farming. The following is a leverage analysis for each dimension of resilience.

Ecological dimension

The ecological dimension refers to natural environmental factors that support the sustainability of dairy farming. Figure 1 presents the results of the ecological dimension leverage analysis. Sensitive attributes were determined by selecting attributes with the highest Root Mean Square (RMS) change values. The results of the study show that 3 of the 4 attributes analyzed have an effect on dairy farming, namely: (1) barn location, (2) availability of grassland for animal feed, and (3) utilization of organic fertilizer waste.

Barn location is a sensitive attribute because it is directly related to the risk of FMD spread. Considering that FMD can spread rapidly through animal and product traffic, vehicles, and objects contaminated with the virus, an ideal barn location can help prevent the acceleration of FMD spread (Rohma *et al*., 2022). Ideally, dairy cattle barns should be located at least 100 meters away from residential areas to prevent contamination and should be situated in areas free from livestock diseases, such as anthrax and FMD (Islamy, 2018). However, research shows that most barns are located very close to residential areas due to land constraints and population density, which increases the likelihood of FMD cross-contamination. This condition reveals ecological vulnerability due to village layout conditions that hinder optimal biosecurity implementation. Thus, barn location attributes describe structural limitations in ecological robustness.

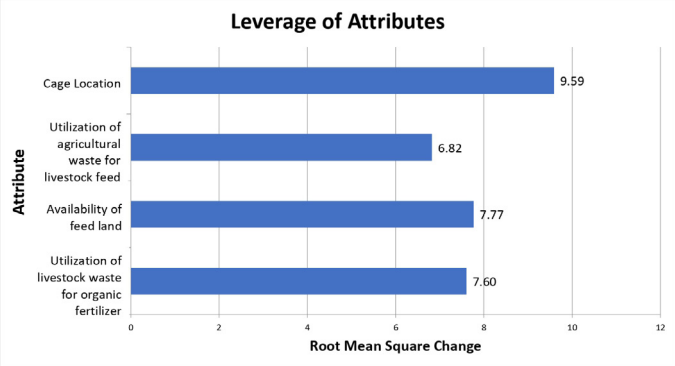

Figure 1: Results of the ecological dimension leverage analysis. A higher RMS value indicates that removing this attribute from the analysis causes a larger shift in the resilience score meaning it is a more influential lever.

The availability of forage land determines the ability of farmers to maintain feed continuity, reduce costs, and maintain production during periods of decreased income due to FMD. This aligns with the findings (Martin *et al*., 2017) that sustainable feed production, rationing, and nutrition management are the foundation for a resilient dairy industry. During an outbreak, when milk production declines and income decreases, the availability of forage land becomes a crucial buffer to mitigate additional costs. Research Salsabilah, Firman *et al*. (2024) indicates that the Pangalengan Dairy Farm experienced a decline in financial performance during the FMD outbreak due to a decrease in the dairy cow population and milk production, yet farmers still incurred livestock maintenance costs. This aligns with the opinion of Cradock-henry (2021), who stated that farmer welfare, food security, and livelihood sustainability are significantly influenced by the availability of forage and environmental factors, such as extreme temperatures and natural disasters. Thus, the availability of forage land reflects both robustness and adaptability, as it enables farmers to survive when income declines.

Waste utilization is the third sensitive attribute that reflects farmers' efforts to reduce environmental burdens while increasing added value. When waste is utilized as organic fertilizer, compost, or biogas, it is no longer a burden but a source of additional income or cost savings (Huda and Wikanta, 2017). The processing of dairy cattle waste is a sustainable practice that benefits farmers both economically and ecologically, as it reduces production costs while producing organic products of market value (Shamsuddoha and Tasnuba, 2024). Generally, dairy cattle waste is utilized as compost fertilizer and a source of biogas energy (Mulijanti *et al*., 2016). Based on interviews conducted, it is known that KPSBU has collaborated with PT Permodalan Nasional Madani (PNM) through the Empowerment Program to process dairy cattle waste into biogas, organic fertilizer, and worm cultivation media, thereby encouraging the utilization of waste as a resource for these purposes. This indicates that waste utilization has significant potential for adaptability and can be further developed through enhanced technical capacity and institutional support.

Overall, the three attributes in the ecological dimension indicate that KPSBU farmers in West Java are still at a basic level of robustness, specifically maintaining production functions through biosecurity despite less-than-ideal barn locations, ensuring a stable nutrient supply (through forage land), and utilizing local resources (waste processing). However, there are still limitations in terms of space, land asset variation, and unequal access to technology, which have resulted in suboptimal adaptive capacity. This is supported by the statement Serphina *et al*., (2024) that natural capital is one of the livelihood assets needed by farmers to survive.

Economic Dimension

The economic dimension relates to financial matters that form the basis of dairy business resilience, such as income, milk prices, and asset ownership. Figure 2 presents the results of the economic dimension leverage analysis. Of the six attributes analyzed, three sensitive attributes that impact the dairy business were livestock numbers, milk prices, and savings.

The number of cattle is the most sensitive attribute because it directly affects milk production potential and farmer income. Households with more productive cows have a greater capacity to maintain income stability during shocks such as FMD (Londa *et al*., 2013; Saniyyah *et al*., 2024). In the study area, most farmers own only 1–3 productive cows (53.8%), and few have more than 6 cows (3.8%), showing that small-scale farming is a structural condition.

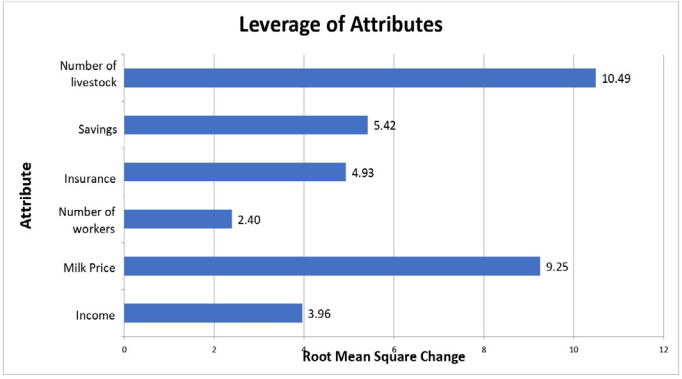

Figure 2: Results of the economic dimension leverage analysis. A higher RMS value indicates that removing this attribute from the analysis causes a larger shift in the resilience score meaning it is a more influential lever.

Expanding herd size remains one strategy to enhance robustness and income. Increasing livestock ownership is positioned as a long-term strategy, but it must be aligned with the actual capacity of smallholder farmers. A feasible approach for small-scale farmers is the rearing of female calves as future replacement heifers, since this does not create debt burdens like cow-purchase credit schemes and allows farmers to expand gradually. The revenue from selling male calves can also be allocated to acquiring additional forage land or improving housing facilities, ensuring that herd expansion is accompanied by increased feed-resource capacity rather than additional financial strain.

Credit-based cow procurement through cooperatives can still be an option, but it must be supported by low interest rates, managerial guidance, and improvements in milk-production practices so that the resulting increase in income enables farmers to repay installments without increasing vulnerability. Therefore, herd expansion is recommended only when feed availability, housing facilities, and farmers' financial capacity have been strengthened, ensuring that additional cows genuinely enhance rather than weaken the resilience of the dairy enterprise.

The price of milk is the main indicator of dairy farmers' income. When prices are stable or high (e.g., IDR 5,800/liter in KPSBU West Java), farmers have sufficient income to cover operational costs such as feed, medicine, and cattle care. Conversely, low milk prices exacerbate vulnerability because farmers struggle to maintain business sustainability. This is supported by research (Aziz *et al.*, 2020) which states that milk prices affect the development of smallholder dairy farming in Tasik and research (Mastuti, 2018) that supports the economic sustainability index of dairy farming in Batu City. Therefore, improving farmers' bargaining power and providing incentives for high-quality milk production by cooperatives need to be enhanced to ensure profitable selling prices. This is because most dairy businesses in Indonesia are small-scale community-based farms that are members of cooperatives (Mauludin and Sari, 2018). The FMD outbreak, which caused a decline in milk production and price fluctuations, weakened economic resilience and adaptability and contributed to low economic resilience.

Apart from livestock ownership and milk production, additional income can be obtained from diversifying worm farming businesses developed through the Madani Village Empowerment Program. In this program, worms are priced at IDR 25,000/kg, with yields varying between farmers from 8–80 kg, equivalent to IDR 200,000 to IDR 2,000,000 per month. This diversification reflects an adaptive strategy that is particularly relevant during a crisis, although the achievements vary among farmers depending on their ability to manage their businesses effectively. This variation in results shows that not all farmers have the same adaptive capacity, and the success of diversification is highly dependent on assistance, access to capital, and managerial skills. Worm farming diversification is a form of on-farm diversification that complements dairy farming, does not reduce the amount of time farmers spend on their work, and can strengthen transformability capacity.

Savings reflect farmers' financial adaptive capacity in the face of crises such as FMD outbreaks. Savings serve as a reserve when income declines, covering cattle treatment costs, emergency feed purchases, and household needs without having to sell productive assets This is in line with the statement (Serphina *et al.*, 2024) that financial assets, such as savings or deposits, are one of the most important assets for survival. Based on the results of the research interviews, the Madani Village Empowerment Program, carried out by KPSBU in collaboration with PT Permodalan Nasional Madani (PNM), strengthens financial capacity through business diversification (worm farming) and effective financial management. Meanwhile, a different situation occurred in KPBS Pangalengan, where farmers were forced to sell their dairy cows to meet their daily needs during the FMD (Salsabilah *et al.*, 2024). As a lesson, the government can adopt the Farm Management Deposits (FMD) scheme in Australia, which enables farmers to save income that can be deducted from taxes and used to help mitigate income declines due to climate change, market fluctuations, and disease outbreaks. A similar savings scheme is also available in Canada with the Agrilnvest program (OECD, 2020).

Overall, the three attributes in the economic dimension show that the economic resilience of dairy farmers is supported by their ability to maintain productive assets, adjust business strategies through milk price bargaining power and product diversification, and build financial reserves.

Links Researchers

Socio-cultural dimension

The socio-cultural dimension relates to the behavior, experiences, and interactions of farmers that influence their ability to maintain their businesses amid the pandemic. Based on the analysis results (Figure 3), of the six attributes analyzed, three attributes are most sensitive in shaping resilience, farming experience, other jobs, and extension participation.

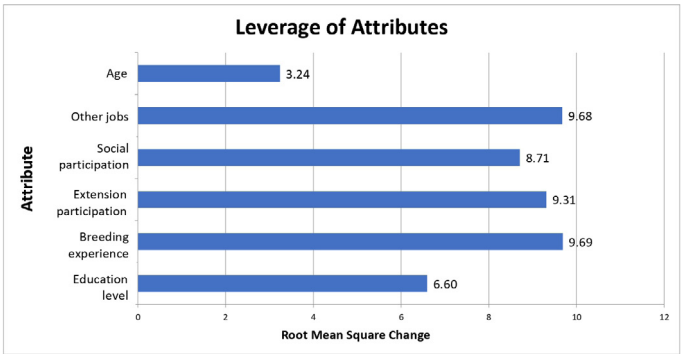

Figure 3: Results of the socio-cultural dimension leverage analysis. A higher RMS value indicates that removing this attribute from the analysis causes a larger shift in the resilience score meaning it is a more influential lever.

Farming experience is a highly sensitive attribute because farmers who have long managed dairy cows have better technical skills and are more responsive in making decisions during a crisis, thereby reducing the risk of business failure. This is supported by statements Bere and Rifa'i (2021); Fathan *et al.* (2022), that farming experience affects farmers' decision-making abilities and business resilience, making it a factor for success in farming businesses. In the context of FMD, farmers with more experience are expected to be better prepared to deal with FMD outbreaks, take faster action, and maintain stable livestock productivity, thus demonstrating robustness.

The other jobs attribute shows high sensitivity in leverage analysis because it is related to the amount of time and focus that farmers devote to managing their dairy businesses. As much as 98% of dairy businesses in Indonesia are controlled by smallholder livestock farmers who make their livestock farming their primary source of income to support their household needs, as most of their working time is spent on dairy cow maintenance activities (Firman *et al.*, 2024; Tawaf, 2018). On the one hand, other jobs can reduce the focus and labor devoted to livestock management (Fajri *et al.*, 2016).

However, during the FMD outbreak, it was discovered that some farmers took on additional jobs to meet their household needs. Although livelihood resilience studies indicate that job diversification can help support the economic livelihoods of farmers (Firman *et al.*, 2024; Orsango *et al.*, 2023), within highly labor-intensive smallholder dairy systems, off-farm work tends to weaken the sustainability of the dairy enterprise itself. Farmers in the study area have no additional labor, so when they pursue off-farm employment, the time that should be devoted to feeding, sanitation, and monitoring animal health becomes reduced, limiting their adaptive capacity during the FMD crisis.

Field findings further show that income from off-farm work is rarely reinvested into the dairy business, but is instead used to meet household consumption needs. As a result, although job diversification indeed strengthens household-level economic resilience, it simultaneously poses risks to the sustainability of the dairy enterprise, because farmers' focus on livestock decreases, disease treatment may be delayed, and production performance declines. Thus, in this study context, "other jobs" support household livelihood resilience but negatively affect dairy farm resilience, reducing farmers' adaptive capacity and weakening the overall resilience of smallholder dairy farming during the FMD outbreak.

Extension participation also emerged as a sensitive attribute that strengthens transformability capacity, as it provides knowledge, fosters behavioral change, and promotes social learning about FMD prevention measures and biosecurity practices (Amrullah *et al.*, 2023; Nurdin *et al.*, 2020). This finding aligns with the study of Moffo *et al.* (2020) in Cameroon, which demonstrated that knowledge has a positive impact on changes in farmer behavior, including the use of antimicrobials and the adoption of sanitation practices. Menghi *et al.* (2024) supported the statement that curiosity and willingness to learn, supported by the social network of farmer groups, are important elements in sustainable livestock development. However, in practice, the lack of participation of some farmers in the West Java KPSBU means that the benefits of extension are not distributed evenly. The combination of unequal experience, limited time due to other jobs, and low participation in extension services has resulted in unbalanced development of social capacity in terms of robustness, adaptability, and transformability. This explains why the MDS results indicate that the socio-cultural dimension is one of the dimensions with low resilience, despite some attributes having a strong influence on the resilience of dairy farming during the FMD outbreak.

Technology dimension

The technology dimension relates to the use of technological equipment and the application of technology that supports dairy farming. Based on the leverage analysis (Figure 4), the two attributes in the technology dimension that are most sensitive in shaping resilience are sanitation and the use of

vitamins/medicines. The sensitivity of these two attributes shows that simple technologies related to livestock health play a role in maintaining the basic functions of small-scale dairy farming during FMD outbreaks.

Sanitation received the highest RMS score because it is the main preventive factor that directly affects the level of exposure to the FMD virus. There is also greater variation in sanitation practices among farmers, so that small changes in this attribute result in large changes in the index. This attribute is an important aspect of livestock maintenance because it acts as the first line of defense against disease and decline in milk quality. Unhygienic maintenance practices increase the risk of microbial contamination and mastitis, thereby reducing milk quantity and quality. Therefore, dairy cattle maintenance should refer to the Good Dairy Farming Practice (GDFP) standard (Syamsi *et al*., 2020). Previous studies conducted by Soediarto *et al*. (2018) and Suranindyah *et al*. (2015) showed that sanitation of barns, feeding areas, and milking processes can improve the physical, chemical, and microbiological quality of milk, thereby increasing its selling price. Thus, improving sanitation plays a crucial role not only in maintaining livestock health but also in enhancing the productivity and economic competitiveness of farmers. In the context of resilience, sanitation functions as a form of robustness, because it maintains production stability through preventive measures that preserve the basic functions of the business even when external pressures occur.

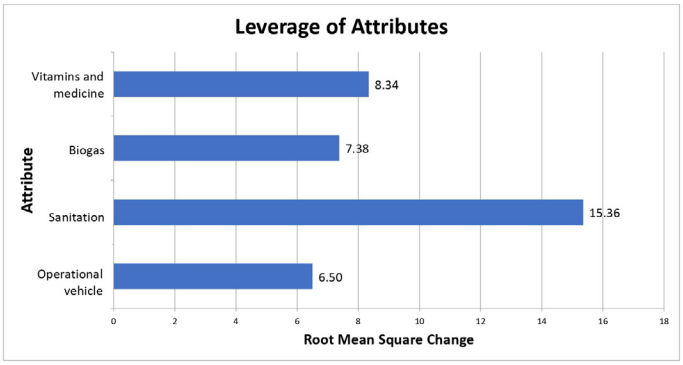

Figure 4: Results of the technology dimension leverage analysis. A higher RMS value indicates that removing this attribute from the analysis causes a larger shift in the resilience score meaning it is a more influential lever.

The second sensitive attribute is the use of vaccinations, vitamins, and medications, which play a major role in reducing the biological impact of FMD. FMD outbreaks cause physiological stress and a decline in udder function in dairy cows making preventives measures very important (Nofitasari *et al*., 2023; OIE, 2022). Research Raina *et al*. (2023) shows that there has been a significant increase in the neutralizing antibody response to FMDV serotypes O and Asia 1. Systematic vaccination of cattle and buffalo has been successful in Brazil, resulting in the country's declaration as FMD-free by the OIE since 2018 (Robattini *et al*., 2020). This attribute reflects adaptability, which is the ability of farmers to adjust livestock health strategies in response to disease threats and maintain production sustainability.

Overall, the technology dimension enchances robustness through preventive measures (such as sanitation) and adaptability through vaccine, drug, and vitamin-based livestock health management. The consistent application of simple health technologies helps small-scale farmers maintain their productivity, making it an important aspect in building a dairy farming system that is more resilient to shocks such as FMD.

The MDS results indicate that the status of technological resilience falls into the "fair" category. This condition suggests that technology plays an important role, but in reality, its implementation is not yet uniform. Field interviews revealed that some farmers have implemented sanitation and vaccination practices, but others are limited by capital, access to drugs/vaccines, and technical knowledge. The robustness and adaptability capacities that should be strengthened by sanitation and livestock health management have not been collectively developed, but only among some farmers. This is a factor that hinders an increase in the resilience score in the technology dimension, even though both attributes are analytically sensitive.

Institutional dimension

The institutional dimension relates to the role of institutions in supporting dairy business resilience. Based on the leverage analysis results (Figure 5), two attributes in the institutional dimension show the highest sensitivity to dairy business resilience, namely the role of farmer groups and the role of livestock services.

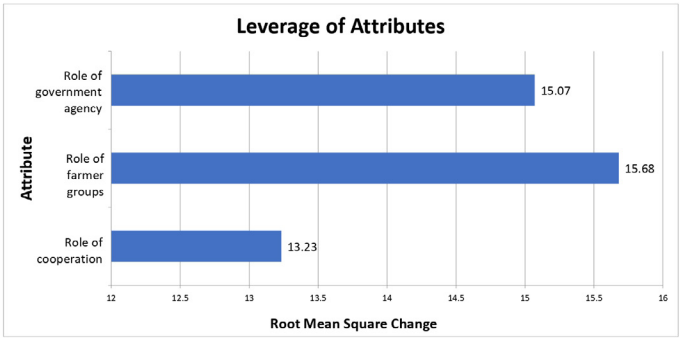

Figure 5: Results of the institutional dimension leverage analysis. A higher RMS value indicates that removing this attribute from the analysis causes a larger shift in the resilience score meaning it is a more influential lever.

The role of farmer groups is a sensitive attribute because it functions as a medium for coordination, a forum for

Links Researchers

learning, a source of information, and an advocate for farmers' rights regarding policies that affect them (Yunasaf *et al*., 2008). These functions reflect robustness capacity, which is the ability to maintain basic business functions through rapid community-based actions, as well as adaptability capacity, because groups help farmers adjust their business management when there are changes in the milk handling system, restrictions on livestock traffic, or the need for access to medicines. This is in line with the institutional principle according to Regulation of the Minister of Agriculture of the Republic of Indonesia Number 67 of 2016 that institutions grow from, by, and for farmers to strengthen their position in risky situations.

The second sensitive attribute is the role of the livestock service, which demonstrates the importance of regulation and technical assistance in building the resilience of smallholder farms in the context of FMD. Through the service, the government plays a role in formulating disease control policies, vaccination, regional quarantine, case tracing, and conditional culling if necessary (Fathurrohman and Dewi, 2023). The effectiveness of the agency's role determines how quickly farmers access vaccines and understand biosecurity SOPs in dealing with FMD so that they can reduce the risk of FMD transmission. This support strengthens robustness through standardized preventive measures, while also supporting transformability, as government policies open up space for structural changes, such as the implementation of sustainable vaccination programs or the formation of FMD task forces at the local level.

However, the MDS results show that farmers' assessments of the institutional dimension are evenly distributed between high, medium, and low categories. This variation indicates that the effectiveness of institutional support is not felt equally by all farmers. Based on interviews, some farmers said that information from groups or agencies did not always reach them directly, some farmers were not active in group activities, and others felt that they did not receive concrete benefits from government programs. This low perception does not mean that institutions are not important, but rather indicates asymmetry in access, participation, and information flow among farmers. This explains why the institutional dimension simultaneously shows the highest average resilience score yet contains the most sensitive attributes: institutions are highly effective where they function well, but their benefits are unevenly distributed, creating "patchiness" in institutional coverage. In areas or groups where support is strong, resilience increases sharply; where support is weak, resilience declines just as sharply, making the attributes extremely sensitive. Prasetyo *et al*. (2018) stated that the inhibiting factors in dairy cooperative partnerships include personal barriers at the member level and organizational barriers such as misaligned visions between partners and stakeholders, as well as funding constraints. Febrianti *et al*. (2025) added that common issues within cooperative membership include low member participation, limited access to capital, and insufficient continuous guidance and support. These constraints may lead to uneven institutional support.

Dairy farming in Indonesia, which is still dominated by small-scale businesses, is in dire need of cooperatives that provide various services such as milk collection and distribution, feed supply such as concentrates, artificial insemination and animal health, as well as savings and loan services and credit guarantees (Salsabilah *et al*., 2024). Basically, dairy farmers are structurally dependent on cooperatives, but if the institutional role is considered insignificant by some farmers, this condition can threaten the sustainability of the system, for example, if farmers lose trust in or access to the functions of cooperatives.

Cases of threats to the sustainability of cooperatives have occurred at the KUD Sinar Jaya cooperative in Bandung Regency and CV Lembang Kamuning in West Bandung Regency, which lost members due to a loss of trust in the cooperative, causing them to switch to selling their milk production to collectors even though the price offered was the same. This poses a serious threat to the long-term sustainability of dairy farming. When farmers switch to collectors, they lose access to essential services such as livestock health support, feed access, technical assistance, and price advocacy services that collectors do not provide but which have been the main function of cooperatives. These services are crucial for maintaining productivity and reducing disease risk, so their absence places small-scale farmers at significantly greater economic and biosecurity risk (Salsabilah *et al*., 2024).

CONCLUSIONS AND RECCOMENDATIONS

Based on the results of the study, it is known that the resilience status of most dairy farms in TPK Pojok KPSBU West Java is in the unsustainable category, especially in the ecological, economic, and socio-cultural dimensions. The leverage analysis results show the attributes that most influence the level of business resilience. The attributes with the highest leverage indicate critical points that need to be the focus of intervention because changes in these attributes have the greatest impact on improving resilience:

1. Ecological dimension: Barn location (9.59), forage land (7.77), and waste management (7.60).
2. Economic dimension: Number of livestock (10.49), milk price (9.25), and savings (5.42)
3. Socio-cultural dimension: Farming experience (9.69), other jobs (9.68), and extension worker participation

(9.31)
4. Technological dimension: Sanitation (15.36) and vitamins/medicine (8.34)
5. Institutional dimension: Role of groups (15.68) and role of government agencies (15.07)

The following are strategic recommendations that can be implemented according to priority based on the highest leverage value.

1. Strengthening the technological aspect by improving barn sanitation as a quick and affordable measure, such as providing subsidized disinfection packages supported by government programs, with collective procurement and distribution through cooperatives, implementing a standardized sanitation schedule, and applying simple biosecurity measures that are easy for farmers to implement. Cooperatives can also assist farmers by ensuring the availability of basic medicines and vitamins at affordable prices through collective procurement and cooperative cross-subsidies.
2. Improving institutional aspects by strengthening cooperative and farmer-group governance through mandatory transparency of milk pricing and service fees, performance-based service guarantees (timely payment, assured access to feed and veterinary services), and participatory decision-making. Relevant agencies should reinforce this by implementing region-based disease monitoring, simplifying FMD assistance procedures, and establishing a permanent local FMD task force.
3. Improving economic aspects by strengthening milk price stabilization through long-term purchase contracts, incentives for high-quality milk production, and establishing micro-savings schemes, for instance by deducting IDR 1,000-2,000 per liter of milk sold, to be allocated to farmers' savings, which does not burden small farmers but builds long-term reserves. Implementing a gradual increase in livestock ownership through the rearing of female calves, while income from the sale of male calves can be allocated for expanding forage land or improving barns, ensuring that business expansion is accompanied by increased maintenance capacity.
4. Strengthening socio-cultural aspects through various tiered extension activities, including training in biosecurity, feed management, and animal health.
5. Strengthening ecological aspects through gradual and feasible arrangement of barn locations, such as minimum sanitation zones, creation of barn entry and exit paths, and simple barn modifications, utilization of feed land together with other farmers, and distribution of superior grass seeds by cooperatives/agencies.

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NOVELTY STATEMENT

This research integrates various dimensions to evaluate the resilience of smallholder farming cooperatives in facing endemic diseases and to identify sensitive attributes that shape the adaptive and institutional capacity of farmers in dealing with FMD outbreaks. The findings of this study provide new empirical evidence from the case of TPK Pojok KPSBU West Java, which can be used as a replicable evaluation framework to measure the resilience of other agribusiness systems under the pressure of disease outbreaks.

AUTHORS CONTRIBUTION

LN: Writing original draft, data analysis, editing, resources, review, supervision. KNS: Writing original draft, data analysis, resources, editing. SA: Conceptualization, supervision, validation, review, data analysis, writing original draft. MAM: Conceptualization, supervision, validation, review, data analysis. MS: Conceptualization, supervision, validation, review. UY: Conceptualization, supervision, validation, review.

Generative AI and AI-assisted technology statement

The authors declare that no generative AI or AI-assisted technologies were used to generate, analyze, or interpret the research data. Generative AI tools were used only to assist in checking grammar, language clarity, and readability of the manuscript during the revision process. All scientific content, interpretations, and conclusions remain the full responsibility of the authors.

Conflict of interest

The authors have declared no conflict of interest.

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