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Agricultural Food Supply Chain Resilience and Environmental Health: The Roles of Collaboration, Flexibility, And Agility

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Abstract. Agricultural food supply chains are increasingly exposed to disruptions caused by climate change, market volatility, logistical bottlenecks, and operational uncertainty, with important implications for food continuity and environmental health. This study examines the roles of supply chain collaboration, supply chain flexibility, and supply chain agility in shaping agrifood supply chain robustness in the laying hen sector of North Sulawesi, Indonesia. A quantitative cross-sectional design was employed, and data were collected from 180 valid respondents involved in the laying hen supply chain between July and October 2025. The data were analyzed using partial least squares structural equation modeling (PLS-SEM) to test both direct and indirect relationships among the latent constructs. The results show that supply chain collaboration and supply chain flexibility have significant positive direct effects on agrifood supply chain robustness. Supply chain agility also has a significant direct effect and emerges as the strongest predictor of robustness. In addition, agility significantly mediates the effects of collaboration and flexibility on robustness, indicating that coordinated relationships and adaptive structures become more effective when translated into rapid operational responses. These findings suggest that resilient agricultural food supply chains depend on the integration of collaboration, flexibility, and agility to maintain supply continuity, reduce disruption impacts, and support safer and more sustainable food systems. The study contributes to the literature on agrifood resilience by linking dynamic supply chain capabilities with broader concerns of environmental health and offers practical implications for agribusiness managers and policymakers in developing regions.

Keywords: Agrifood supply chain; Environmental health; Laying hen industry; Supply chain agility; Supply chain resilience

INTRODUCTION

Agricultural food supply chains are central to food security, rural livelihoods, and sustainable development. Yet in recent years these chains have faced mounting pressure from climate change, input-price volatility, transport bottlenecks, labor shortages, disease events, and market instability. Recent reviews emphasize that food supply chain resilience has become a major policy and research priority because repeated shocks have exposed weaknesses in production, distribution, and price stability, especially in developing and resource-constrained regions (Rosyada, 2025; Xue et al., 2025).

These pressures are particularly acute in animal-based agrifood systems, where production depends on tightly coordinated flows of feed, veterinary inputs, energy, transport, storage, and market access. In poultry-based systems, for example, disruptions in feed supply, disease control, or logistics can quickly cascade across the chain, reducing productivity, raising costs, and weakening household access to affordable animal protein. Recent studies on poultry supply chains show that resilience and sustainability are increasingly challenged by environmental issues, disaster risks, technological gaps, forecasting problems, and climate-related pressures on feed, water, and animal health (Attia et al., 2024; Roy et al., 2024).

In this context, agricultural food supply chain resilience should not be understood only as the capacity to absorb shocks and recover operations, but also as the capacity to preserve environmental health and protect public health outcomes (Jin et al., 2025). Climate change is altering production conditions, disrupting logistics and storage systems, increasing biological and environmental risks, and intensifying uncertainty across food networks (Tchonkouang et al., 2024). At the same time, unsafe food and inefficient post-harvest management impose additional burdens through contamination risks, waste generation, pollution, and inefficient resource use. Recent studies therefore argue that resilient agrifood systems must integrate climate adaptation, food safety, environmental protection, and risk management rather than treat them as separate objectives (WHO, 2020, 2023).

This broader perspective has encouraged scholars to connect resilience with sustainability and environmental health in agrifood supply chains (Plakantara & Karakitsiou, 2025). Recent integrative studies show that resilient supply chains are more likely to deliver long-term value when they also reduce waste, strengthen traceability, improve food safety, support circularity, and address environmental externalities throughout the chain (Arimany-Serrat et al., 2024). In other words, resilience and sustainability are increasingly viewed as mutually reinforcing rather than competing priorities (Paredes-Rodríguez et al., 2024). This is particularly relevant in food systems, where environmental degradation, poor waste management, and food safety failures can undermine both ecological integrity and human well-being (Stanescu et al., 2025).

At the operational level, resilience is shaped by capabilities that enable supply chain actors to anticipate, respond to, and recover from disruption (Coşkun & Erturgut, 2024; Hsieh et al., 2023). Recent literature consistently highlights the roles of information sharing, inter-organizational coordination, flexibility, agility, and network-based collaboration in strengthening supply chain resilience and maintaining performance under uncertainty (Cinti et al., 2024; Huo et al., 2024). Flexibility allows firms to reconfigure sourcing, production, and logistics arrangements when disruption occurs, while agility enables faster sensing, decision-making, and response. Collaboration, meanwhile, improves visibility and trust across supply chain partners, allowing collective action when risks emerge. These capabilities are increasingly supported by digital transformation, including data platforms, traceability systems, and blockchain-based coordination tools that improve transparency and risk control in agrifood systems (Keefe et al., 2024; Singh, 2024; Vahdanjoo et al., 2025).

These issues are especially important in poultry and egg supply chains, where products are highly perishable, biologically sensitive, and dependent on continuous flows of feed, veterinary inputs, transport, cold handling, and market access. In Indonesia, laying hen farming makes an important contribution to small-scale farmer income and national food provision, especially through the supply of affordable animal protein. At the same time, the poultry sector faces growing pressure from climate stress, disease exposure, rising production costs, and biosecurity challenges, all of which can weaken supply continuity and increase environmental and health risks if not managed effectively. In your current draft, the North Sulawesi case is positioned as a highly interdependent laying hen supply chain involving feed suppliers, veterinary services, logistics providers, distributors, retailers, and consumers, meaning that disruption in one node can quickly cascade across the network (Nassar & Abbas, 2025).

Despite the rapid expansion of recent literature, several important gaps remain. First, many studies examine resilience, sustainability, or environmental performance separately, while fewer empirical studies investigate how specific operational capabilities interact to strengthen agrifood supply chain robustness in a single analytical model. Second, environmental health is often treated as a background concern rather than embedded directly in discussions of food safety, waste reduction, and sustainable supply chain design. Third, developing-country poultry supply chains remain underrepresented in this debate, even though they face acute exposure to climate, logistics, and market risks. This suggests the need for more context-specific evidence on how collaboration, flexibility, and agility contribute to resilience and robustness while supporting safer and more sustainable food systems.

Accordingly, this study examines agricultural food supply chain resilience and environmental health by analyzing the roles of supply chain collaboration, supply chain flexibility, and supply chain agility in shaping agrifood supply chain robustness in the laying hen sector of North Sulawesi, Indonesia. By linking dynamic supply chain capabilities with broader concerns of food continuity, environmental responsibility, and health protection, this study seeks to contribute to the emerging literature on resilient and sustainable agrifood systems and to provide evidence that is relevant for both scholars and policymakers confronting intensifying uncertainty in food supply networks.

MATERIALS AND METHODS

Research Design and Study Context

This study employed a quantitative, cross-sectional research design to examine the relationships among supply chain collaboration, supply chain flexibility, supply chain agility, and agrifood supply chain robustness in the laying hen supply chain of North Sulawesi, Indonesia. A survey-based approach was considered appropriate because the study aimed to test theoretically specified relationships among multiple latent constructs and to evaluate both direct and indirect effects within an integrated framework. In line with recent methodological guidance, partial least squares structural equation modeling (PLS-SEM) was selected because it is suitable for predictive models, mediation testing, and complex relationships among reflective constructs, particularly in applied management and supply chain research.

The empirical setting of this study is the agricultural food supply chain for egg production and distribution. This context is highly relevant because laying hen operations depend on the uninterrupted coordination of feed supply, farm operations, animal health services, transportation, distribution, and retail activities. Disruptions in any node of this chain may affect supply continuity, food quality, and operational stability. In addition, environmental health concerns are embedded in the agrifood system through traceability, food safety, waste prevention, and risk management practices, all of which are closely related to supply chain robustness.

Population, Sampling, and Unit of Analysis

The target population comprised actors directly involved in the laying hen agrifood supply chain in North Sulawesi, including laying hen farmers, feed suppliers, logistics providers, distributors, and retailers. The unit of analysis was the individual respondent representing a supply chain organization or activity node. Respondents were selected using purposive sampling to ensure that only individuals with relevant experience and direct knowledge of egg production, procurement, handling, storage, transport, or distribution were included.

Eligible respondents were those actively involved in supply chain operations and capable of evaluating collaboration patterns, flexibility practices, agility, and robustness in their respective organizations. After data screening, incomplete or ineligible questionnaires were excluded from the final dataset. A total of **180 valid responses** were retained for the final analysis. This sampling strategy is consistent with applied agrifood and supply chain studies that prioritize knowledgeable informants over random selection when the research objective is construct-based model testing.

Instrument Development and Measurement

Primary data were collected using a structured questionnaire administered in both online and face-to-face formats. The instrument consisted of closed-ended statements measured on a five-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. A Likert-type scale was used because it is widely applied in supply chain and organizational research to capture perceptions of latent constructs in a standardized and comparable manner.

The questionnaire items were adapted from validated studies in the supply chain and agrifood literature and were contextualized to the laying hen sector in North Sulawesi. Particular attention was given to ensuring that the operationalization of agrifood supply chain robustness reflected not only continuity of supply but also environmental health-related aspects, especially traceability, safety, and risk control. Before the main survey was conducted, the questionnaire was pilot-tested with a small group of respondents to assess wording clarity, contextual relevance, and internal consistency. Minor revisions were then made to improve item clarity and contextual fit. To clarify how each construct was operationalized in this study, Table 1 presents the conceptual definitions and main measurement dimensions of the four latent variables. These variables were selected to reflect the core capabilities and outcomes relevant to agricultural food supply chain resilience and environmental health in the laying hen sector.

Table 1. Operational Definition of Variables and Measurement Dimensions

Variable	Conceptual Definition	Main Dimensions / Indicators
Supply Chain Collaboration	The extent of interaction and coordination among supply chain actors in achieving common goals	Information sharing, joint decision-making, trust, coordination, technology integration
Supply Chain Flexibility	The ability of the supply chain to adjust sourcing, production, and logistics in response to change	Volume flexibility, product mix flexibility, supplier flexibility, logistics flexibility, operational flexibility
Supply Chain Agility	The speed and effectiveness with which the supply chain senses and responds to disruption or market change	Market sensitivity, decision-making speed, visibility, supply chain integration, adaptability to disruptions
Agrifood Supply Chain Robustness	The ability of the supply chain to maintain operations and recover from disruption while sustaining food continuity and safety	Redundancy in supply sources, infrastructure resilience, traceability and safety, risk management strategies

As shown in Table 1, each construct is represented by dimensions that are consistent with the study's theoretical framework. Supply chain collaboration emphasizes coordination and information exchange among actors, supply chain flexibility captures adaptive operational capacity, supply chain agility reflects rapid response capability, and agrifood supply chain robustness represents the ability to sustain operations and food continuity under disruption. This operational structure supports the subsequent empirical testing of the proposed relationships.

Data Collection Procedure

Data collection was carried out from July to October 2025 through direct distribution of questionnaires to eligible respondents and through online circulation to actors who were difficult to reach in person. Prior to participation, respondents were informed about the purpose of the study, the voluntary nature of participation, and the confidentiality of their responses. To reduce response bias, respondents were assured that the data would be reported only in aggregate form and would be used exclusively for academic purposes.

Completed questionnaires were screened before analysis. The screening process included checking for completeness, consistency of responses, and respondent eligibility. Only valid questionnaires were retained for statistical analysis.

Data Analysis Technique

The data were analyzed using partial least squares structural equation modeling (PLS-SEM). This approach was chosen because the study sought to predict agrifood supply chain robustness, estimate multiple simultaneous relationships, and assess the mediating role of supply chain agility. PLS-SEM is especially appropriate for models that emphasize prediction and theory development and for studies using latent variables measured through multiple indicators

The analysis was conducted in two stages. The first stage involved the evaluation of the measurement model to assess indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Indicator reliability was examined using outer loadings, with values of 0.70 or above considered desirable. Internal consistency was evaluated through Cronbach's alpha and composite reliability, with acceptable values above 0.70. Convergent validity was assessed using the average variance extracted (AVE), with a threshold of 0.50 or above. Discriminant validity was evaluated using the Fornell-Larcker criterion and the heterotrait-monotrait ratio (HTMT).

The second stage involved evaluation of the structural model. This included assessment of collinearity using variance inflation factor (VIF), estimation of path coefficients, coefficient of determination (R^2), effect size (f^2), and predictive relevance (Q^2). To test the significance of both direct and indirect effects, a bootstrapping procedure with 5,000 resamples was applied. The mediating role of supply chain agility was examined by analyzing the significance of the indirect paths from collaboration to robustness and from flexibility to robustness through agility. Because this study applied PLS-SEM to test the proposed model, it was necessary to establish clear statistical criteria for evaluating both the measurement and structural models. Table 2 summarizes the evaluation thresholds used in this study.

Table 2. PLS-SEM Evaluation Criteria Used in the Study

Evaluation Aspect	Criterion
Indicator reliability	Outer loading ≥ 0.70
Internal consistency reliability	Cronbach's alpha ≥ 0.70; Composite reliability ≥ 0.70
Convergent validity	AVE ≥ 0.50
Discriminant validity	Fornell-Larcker criterion and HTMT < 0.90
Collinearity	VIF < 5.00
Structural significance	Bootstrapped t-values and p-values
Explanatory power	R^2 for endogenous constructs
Effect size	f^2 = 0.02 small, 0.15 medium, 0.35 large
Predictive relevance	$Q^2 > 0$

Table 2 indicates that the study followed commonly accepted PLS-SEM assessment standards for reliability, validity, collinearity, explanatory power, effect size, and predictive relevance. These criteria provide the basis for determining whether the measurement model is robust and whether the structural relationships among the latent constructs can be interpreted with confidence.

Ethical Considerations

Participation in this study was voluntary. All respondents provided informed consent before completing the questionnaire. Anonymity and confidentiality were maintained throughout the study, and no personally identifying information was disclosed in the analysis or reporting of the results. The study followed standard ethical principles for social science research, including voluntary participation, respect for respondents, and responsible data handling.

Based on the literature review and the study hypotheses, a conceptual framework was developed to illustrate the proposed relationships among supply chain collaboration, supply chain flexibility, supply chain agility, and agrifood supply chain robustness. This framework is presented in Figure 1.

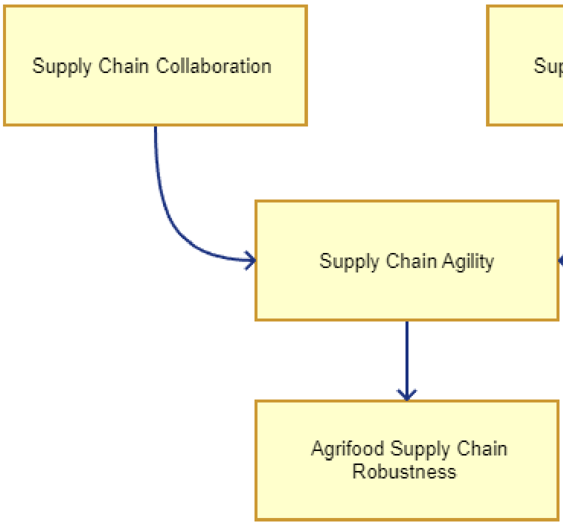

Figure 1. Conceptual Framework of the Study

Figure 1 shows that supply chain collaboration and supply chain flexibility are proposed to influence agrifood supply chain robustness both directly and indirectly through supply chain agility. The framework reflects the assumption that collaboration and flexibility strengthen resilience not only on their own, but also by enabling faster and more effective responses to disruption through agility.

Hypothesized relationships:

H1: Supply chain collaboration has a direct effect on agrifood supply chain robustness.

H2: Supply chain flexibility has a direct effect on agrifood supply chain robustness.

H3: Supply chain agility has a direct effect on agrifood supply chain robustness.

H4: Supply chain collaboration has an indirect effect on agrifood supply chain robustness through supply chain agility.

H5: Supply chain flexibility has an indirect effect on agrifood supply chain robustness through supply chain agility.

RESULTS AND DISCUSSION

Measurement Model Evaluation

Based on the 180 valid responses, the measurement model was first assessed to confirm the reliability and validity of the latent constructs: supply chain collaboration, supply chain flexibility, supply chain agility, and agrifood supply chain robustness. The evaluation covered indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Most indicators showed outer loadings above the recommended threshold of 0.70, indicating that the observed variables adequately represented their respective constructs. A few items with loadings between 0.60 and 0.70 were retained because of their theoretical relevance and acceptable contribution to construct validity. In addition, all constructs exceeded the recommended thresholds for Cronbach's alpha, composite reliability, and average variance extracted (AVE), confirming satisfactory reliability and convergent validity.

Discriminant validity was examined using the Fornell-Larcker criterion and the heterotrait-monotrait ratio (HTMT). As shown in Table 3a, the square root of the AVE for each construct was greater than its correlations with other constructs. Likewise, all HTMT ratios were below the threshold of 0.90, confirming that the constructs were empirically distinct from one another. These results indicate that the measurement model was statistically acceptable and suitable for structural model testing. Discriminant validity was assessed to ensure that each construct in the model was empirically distinct from the others. The results of the Fornell-Larcker criterion are presented in Table 3.

Table 3. Discriminant Validity Using the Fornell-Larcker Criterion

Construct	Collaboration	Flexibility	Agility	Robustness
Collaboration	0.806	0.62	0.58	0.55
Flexibility	0.62	0.825	0.6	0.57
Agility	0.58	0.6	0.837	0.63
Robustness	0.55	0.57	0.63	0.812

As presented in Table 3, the square root of the AVE for each construct is higher than its correlations with the other constructs. This indicates that each latent variable shares more variance with its own indicators than with other variables in the model, thereby confirming satisfactory discriminant validity according to the Fornell-Larcker criterion.

In addition to the Fornell-Larcker criterion, discriminant validity was further evaluated using the heterotrait-monotrait ratio (HTMT), which is considered a more stringent test of construct distinctiveness. The HTMT results are reported in Table 4.

Table 4. Discriminant Validity Using the HTMT Ratio

Construct	Collaboration	Flexibility	Agility	Robustness
Collaboration	—	0.75	0.7	0.68
Flexibility	0.75	—	0.74	0.72
Agility	0.7	0.74	—	0.77
Robustness	0.68	0.72	0.77	—

Table 4 shows that all HTMT values are below the threshold of 0.90, indicating that the constructs are sufficiently distinct from one another. This result strengthens the evidence that the measurement model has adequate discriminant validity and that the constructs can be used for structural model analysis.

Structural Model Evaluation

Before testing the hypotheses, multicollinearity among predictor constructs was examined using the variance inflation factor (VIF). All VIF values were below 5.00, indicating that collinearity was not a concern and that the predictor constructs could be included simultaneously in the structural model.

The explanatory power of the model was assessed using the coefficient of determination (R^2). As presented in Table 5, the model explained 55% of the variance in supply chain agility and 62% of the variance in agrifood supply chain robustness. These results indicate moderate explanatory power for agility and substantial explanatory power for robustness. In practical terms, the findings suggest that collaboration, flexibility, and agility collectively provide a strong explanation of robustness in the laying hen agrifood supply chain in North Sulawesi. After confirming the adequacy of the measurement model, the explanatory power of the structural model was examined using the coefficient of determination (R^2). The results for the endogenous constructs are shown in Table 5.

As shown in Table 5, the model explains 55% of the variance in supply chain agility and 62% of the variance in agrifood supply chain robustness. These results indicate that the proposed model has moderate explanatory power for agility and substantial explanatory power for robustness, suggesting that collaboration, flexibility, and agility meaningfully explain variations in robustness within the laying hen supply chain.

Table 5. Coefficient of Determination (R^2)

Endogenous Construct	R^2	Interpretation
Agility	0.55	Moderate
Robustness	0.62	Substantial

The effect size (f^2) analysis was conducted to determine the relative contribution of each exogenous construct to the endogenous variable. The results show that collaboration had a small effect on robustness ($f^2 = 0.12$), while flexibility ($f^2 = 0.18$) and agility ($f^2 = 0.24$) had medium effects. This pattern indicates that agility made the strongest contribution to explaining robustness, followed by flexibility. Collaboration remained important, but its contribution was comparatively smaller. Predictive relevance was also supported, as the blindfolding procedure showed Q^2 values above zero for both agility and robustness, with robustness reaching 0.34. This confirms that the model had acceptable predictive capability. To assess the relative contribution of each predictor to agrifood supply chain robustness, effect size (f^2) values were calculated. The results of this analysis are presented in Table 6.

Table 6. Effect Size (f^2) of Exogenous Constructs on Robustness

Exogenous Construct	Endogenous Construct	f^2	Interpretation
Collaboration	Robustness	0.12	Small
Flexibility	Robustness	0.18	Medium
Agility	Robustness	0.24	Medium

Table 6 indicates that supply chain collaboration has a small effect on robustness, whereas supply chain flexibility and supply chain agility have medium effects. Among the predictors, agility contributes the most to explaining robustness, followed by flexibility. This pattern suggests that dynamic response capability plays a particularly important role in strengthening agrifood supply chain resilience.

Hypothesis Testing

Hypothesis testing was conducted using a bootstrapping procedure with 5,000 resamples. Table 7 summarizes the results of the direct and indirect effects. All five hypotheses were supported. Supply chain collaboration had a positive and significant direct effect on agrifood supply chain robustness ($\beta = 0.28$, $t = 3.45$, $p = 0.001$). Supply chain flexibility also had a positive and significant direct effect on robustness ($\beta = 0.31$, $t = 4.10$, $p < 0.001$). Supply chain agility showed the strongest direct effect on robustness ($\beta = 0.34$, $t = 4.55$, $p < 0.001$). In addition, both indirect effects through agility were significant, indicating that agility mediated the effects of collaboration and flexibility on robustness. The proposed hypotheses were tested using a bootstrapping procedure with 5,000 resamples in order to assess the significance of both direct and indirect effects. The results of the hypothesis testing are summarized in Table 7.

As shown in Table 7, all five hypotheses are supported. Supply chain collaboration, supply chain flexibility, and supply chain agility each have significant positive direct effects on agrifood supply chain robustness. In addition, the indirect effects of collaboration and flexibility through agility are also significant, indicating that agility plays a mediating role in translating coordination and adaptive capacity into stronger supply chain robustness.

Table 7. Path Coefficients and Bootstrapping Results

Hypothesis	Relationship	Path Coefficient (β)	t-Statistic	p-Value	Result
H1	Collaboration → Robustness	0.28	3.45	0.001	Supported
H2	Flexibility → Robustness	0.31	4.1	<0.001	Supported
H3	Agility → Robustness	0.34	4.55	<0.001	Supported
H4	Collaboration → Agility → Robustness	0.17	2.13	0.034	Supported
H5	Flexibility → Agility → Robustness	0.21	2.97	0.003	Supported

Discussion

The results demonstrate that supply chain collaboration significantly improves agrifood supply chain robustness. This finding suggests that when actors such as laying hen farmers, feed suppliers, logistics providers, and distributors exchange information, coordinate decisions, and maintain trust-based relationships, the supply chain becomes better able to anticipate and absorb disruption. In the context of egg production and distribution, collaborative arrangements help maintain continuity of feed supply, delivery scheduling, product handling, and market access. This is especially important in geographically dispersed and resource-constrained settings such as North Sulawesi, where weak coordination can quickly trigger shortages, delivery delays, and financial losses. These findings support previous studies that identify collaboration as a critical capability for supply chain resilience and coordinated risk management.

Supply chain flexibility also had a significant positive effect on robustness and, among the two organizational antecedents, showed a slightly stronger direct effect than collaboration. This indicates that the capacity to adjust sourcing, logistics, production arrangements, and operational responses is essential for maintaining stability under changing conditions. In the laying hen sector, flexibility may include switching suppliers, adjusting order volumes, modifying transport arrangements, or responding quickly to fluctuations in input costs and consumer demand. Because eggs are perishable and highly time-sensitive, rigid systems are more vulnerable to disruption. The significance of flexibility in this study therefore reinforces the argument that adaptive operational structures are fundamental to resilient agrifood systems.

Agility emerged as the strongest direct predictor of agrifood supply chain robustness. This means that the ability to sense change rapidly, make timely decisions, and implement corrective action plays a central role in sustaining supply chain performance. In volatile agrifood environments, agility allows actors to respond quickly to sudden feed shortages, transport constraints, animal health issues, or price instability. The result is theoretically important because it shows that robustness is not achieved solely through stable structures or collaborative relationships, but through dynamic response capability. In other words, the more agile the supply chain, the greater its ability to maintain continuity and reduce the impact of disruption.

The mediation results provide additional insight into the mechanism through which robustness is strengthened. Because both the direct and indirect effects were significant, agility can be interpreted as a partial mediator in the relationships between collaboration and robustness and between flexibility and robustness. This implies that collaboration and flexibility do not influence robustness only on their own; they become more effective when translated into agile action. Collaborative relationships provide access to shared information and coordinated planning, while flexibility provides the structural capacity to change. Agility then converts these advantages into rapid operational responses. This finding is particularly relevant for agricultural food supply chains, where delays in reaction can lead not only to economic loss but also to food quality deterioration, waste, and broader environmental health concerns.

From a practical perspective, the findings suggest that strengthening agricultural food supply chain resilience requires an integrated approach. Collaboration alone is not sufficient if supply chain actors cannot adapt operationally, and flexibility alone is not sufficient if responses are too slow. The strongest model is therefore one in which collaboration builds coordination, flexibility provides adaptive capacity, and agility ensures rapid execution. For laying hen agribusinesses in North Sulawesi, this implies the need for stronger communication systems, diversified sourcing strategies, responsive logistics arrangements, and faster decision-making routines. Such improvements can contribute not only to business continuity and farmer income stability, but also to safer food distribution and better environmental health performance through reduced spoilage, lower waste, and improved traceability.

CONCLUSION

This study examined the determinants of agricultural food supply chain resilience and environmental health in the laying hen sector of North Sulawesi, Indonesia, by analyzing the roles of supply chain collaboration, supply chain flexibility, and supply chain agility in shaping agrifood supply chain robustness. The findings confirm that both collaboration and flexibility have significant positive direct effects on agrifood supply chain robustness, while supply chain agility emerges as the strongest direct predictor. In addition, agility significantly mediates the effects of collaboration and flexibility on robustness, indicating that robust agrifood supply chains are strengthened not only by coordinated relationships and adaptive structures, but also by the ability to respond rapidly to disruption. These conclusions are fully consistent with the empirical results reported in the uploaded draft, including the supported hypotheses H1–H5.

The study highlights that resilience in poultry-based agrifood systems is a multidimensional capability. In the context of North Sulawesi, where laying hen farming depends on continuous access to feed, veterinary support, transport, and distribution networks, disruptions in one part of the chain can quickly spread to other actors and threaten supply continuity. Therefore, stronger collaboration among stakeholders, greater operational flexibility, and faster decision-making capability are essential for maintaining stable egg supply, protecting farmer livelihoods, and supporting food security.

Beyond operational performance, the findings also imply that stronger agrifood supply chain robustness contributes to environmental health. A more robust and agile supply chain can reduce spoilage, improve traceability, strengthen food safety, and support more efficient resource use across production and distribution activities. In this sense, agricultural food supply chain resilience should be viewed not only as a business continuity issue but also as an important component of sustainable food systems and environmental protection. This makes the study relevant for both agribusiness practitioners and policymakers seeking to build more resilient and sustainable rural food networks.

Overall, this research provides empirical evidence that the integration of collaboration, flexibility, and agility is fundamental to building robust agrifood supply chains in vulnerable and perishable sectors such as laying hen farming. The study contributes to the growing literature on agrifood resilience by demonstrating that dynamic supply chain capabilities are critical for sustaining operations under uncertainty while simultaneously supporting food continuity, safety, and environmental health.

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