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Integrated Risk and Biosecurity Optimization in Poultry Production: A Lean and Credit-Risk Approach to Strengthen U.S. Agricultural Resilience

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Abstract: Amidst the increasing pressures and escalating biological, operational, and financial threats, the poultry industry of the United States, it is necessary to rethink strategies and embrace an integrated approach to risk management. The main thrust of this paper is the proposition of a novel framework that combines biosecurity, Lean management principles, and credit risk assessment to strengthen agricultural resilience. The study highlights existing gaps in the use of financial risk models, operational efficiency tools, and disease preventive protocols by drawing on an extensive analysis of academic research, government publications, and industry case studies. Undeniably, each domain has advanced independently in scope and sophistication. But that independence creates conflicting practices and missed synergies. For example, cost-saving Lean strategies may inadvertently compromise biosecurity standards, while traditional credit models frequently overlook operational and health-related risk indicators. By synthesizing findings across these disciplines, the study argues for a systems-level approach in which biosecurity compliance and Lean maturity are integrated into creditworthiness assessments and policy frameworks. The paper concludes with actionable recommendations for producers, policymakers, and researchers to support a holistic and scalable model of resilience in poultry production systems.

Keywords: *Poultry Biosecurity, Lean Agriculture, Credit Risk Assessment, Agricultural Resilience, Supply Chain Risk, Highly Pathogenic Avian Influenza (HPAI), Financial Risk Modeling, Integrated Risk Management, U.S. Poultry Industry, Climate-Related Agricultural Risk, Farm-Level Operations, Supply Chain Finance.*

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I. INTRODUCTION

In 2025, the poultry farming sector in the United States is facing significant risks that threaten productivity, profitability, and more importantly, public health. The main risk factors that have been identified include large-scale disease outbreaks, continuous biosecurity challenges, and persistent supply chain fragility. According to Avinews.com (2025), ongoing avian influenza (HPAI) in the United States has cut down export projections for 2025 by 3.7% YoY, affecting both local profitability and global market dominance. The pressure is amplified by supply chain strains from labor shortages, traffic jams, and increasing logistics expenses, which make timely distribution more challenging.

While the CDC and USDA continue to monitor new outbreaks and caution about further supply disruptions, Salmonella outbreaks remain a key issue. Recent research (Anna Duerr, 2024; Adeyeye et al, 2025; Angelique Fischer, 2016) continues to emphasize how biosecurity lapses such as inadequate perimeter control, insufficient cleaning protocols, and the presence of wild animals and birds near poultry houses continue to facilitate disease introduction. Past incidents have shown how rodent infestations, manure management failures, and personnel transfer between flocks without changing protective gear can contribute to outbreak risks (Graziosi et al, 2024). Mouss, Hammouche, and Meziane (2025) report how rising temperatures have a direct, negative impact on poultry welfare and productivity, showing how every 1°C increase in temperature can decrease production by 3–5%, and recurring droughts and water shortages are projected to reduce production by up to 12% by 2050.

The vulnerability is vividly highlighted by the continuous shortages of eggs and price spikes brought on by HPAI outbreaks. Farmers experience financial losses, production interruptions, and a sluggish recovery in spite of indemnity payments (Ayebare et al., 2025). These recurrent problems highlight how inadequate reactive tactics are and

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how urgently integrated, proactive solutions are needed. In addition to disease containment, the industry needs to work towards systemic biosecurity improvements, strengthen regulatory enforcement, boost investment in diagnostics and vaccinations, and integrate climate-aware catastrophe planning (Prajapati et al., 2025). Since poultry and feed systems are at risk from flooding, hurricanes, and increasingly unpredictable weather, the scope of risk has grown to include structural, ecological, and financial aspects.

When combined, these elements create a more unstable environment for poultry production in the United States, one that necessitates a cross-disciplinary, systems-level response. Agricultural biosecurity has become essential to the resilience of the global food system as biological threats to livestock, food safety, and human health increase in the twenty-first century (Adeyeye et al., 2025). In this paper, we argue that combining lean management with credit-risk assessment creates a resilience-enhancing framework for poultry production. The methodology used is a policy/framework content analysis. We analyze how well public guidelines and programs such as USDA, APHIS, and FDA integrate lean or financial resilience ideas, while cross-referencing them with academic proposals or critiques.

II. LITERATURE REVIEW

- *Current Risks in U.S. Poultry Production: An Integrated Perspective*

There are a number of major risks that pose a significant threat to the production, processing, and distribution systems of the poultry industry in the United States. According to reports from the US Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) (2025), more than 169 million birds were affected by fresh outbreaks of the HPAI, resulting in massive depopulation and extraordinary financial costs exceeding $1.4 billion for control, indemnity, and compensation. This situation is compounded by the fact that recent strains are highly infectious, making prediction and containment more complex (CDC, 2025). The overuse of antibiotics has also led to treatment-resistant pathogens, increasing mortality rates, and complicating disease management. The growing frequency of global supply chain disruptions, which are made worse by pandemics, geopolitical conflicts, climate-related catastrophes, and economic volatility, has also revealed serious weaknesses in U.S. food trade policy, as Alawode and Chiamaka (2025) methodically point out. The COVID-19 pandemic revealed weaknesses in the supply chains for meat and poultry, such as a lack of workers, sporadic factory closures, and changes in customer demand. The price and availability of feed (corn, soybeans) have fluctuated due to global economic uncertainty and climate-related disruptions, further taxing margins and operational predictability.

- *Biosecurity in Poultry Production*

A key tactic in contemporary poultry production is biosecurity, which aims to stop viruses from entering, spreading, and remaining on farms. From daily operations (e.g., wearing farm-specific clothes and using farm-specific equipment) to structural designs (e.g., compartmentalized facility layouts) and sanitation protocols (e.g., cleaning and disinfection routines) that are continuously implemented at the farm level, it covers a wide range of measures (Delpont et al., 2023). Given the geographical concentration and operational interdependence of farms in the integrated commercial poultry system, these steps are essential to reducing the high risk of disease transmission (Thompson et al., 2025).

Despite the existence of extensive biosecurity guidelines, empirical studies have shown a wide variance in implementation across different farming contexts and geographies. For instance, a survey conducted among poultry growers in Georgia revealed uneven adherence to recommended biosecurity protocols. While most growers reported implementing visitor-focused practices such as requiring shoe covers, more systemic measures (like restricted vehicle access or tire disinfection) were less consistently applied. Compliance tended to increase in areas with higher farm density and during active disease outbreaks, underscoring the reactive rather than preventive posture of many operations (Dorea et al., 2010).

Several structural flaws continue to undermine the efficacy of biosecurity in poultry farming. These include compliance gaps, in which farms may apparently implement required standards but fail to enforce them fully or consistently (Aderemi, Ayandiji, & Adeleke 2023). Resource constraints, particularly among small-scale or backyard farmers, may culminate in underinvestment in biosecurity infrastructure, increasing risk across the production chain. Furthermore, monitoring and data gaps persist: biosecurity evaluations lack worldwide standardization, and fragmented data sharing across regions and agencies impedes coordinated disease response. On a technical level, concerns such as biofilm buildup, which can shield germs from disinfectants, are routinely disregarded in standard cleaning processes, lowering sanitation efficacy (Mohammed, 2024).

The degree of biosecurity implementation often correlates with farm size and structure. Large-scale operations tend to follow stricter protocols compared to smallholders or backyard farms, due to better access to resources and regulatory oversight (Morris et al., 2023). However, even well-resourced operations face challenges related to the cost and complexity of biosecurity investments. These investments, ranging from restricted farm access and mortality disposal systems to water treatment and air filtration, can be capital-intensive, making them less accessible to smaller producers (Delpont et al., 2021).

Beyond farm-level implications, inadequate biosecurity carries significant public and economic consequences. The 2014–2015 highly pathogenic avian influenza (HPAI) H5N1 outbreak in the U.S. led to nearly a billion dollars in response-related costs, including depopulation, virus containment, and indemnity payments (USDA-APHIS, 2016). Moreover, the outbreak caused substantial disruptions in poultry exports, with estimated losses of 145,000 tons in chicken meat and $177 million in turkey exports (MacLachlan et al., 2022). The ripple effects were particularly damaging to seasonal markets

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like Thanksgiving, where missed production cycles due to flock depopulation coincided with peak consumer demand (Çakır et al., 2018).

To address these issues, federal and state organizations have established official biosecurity systems. USDA's Animal and Plant Health Inspection Service (APHIS) mandates that biosecurity protocols be in place for both conventional and organic farms, including restrictions on outdoor access during high-risk periods. In early 2025, USDA-APHIS made biosecurity audits mandatory for receiving HPAI indemnity payments. Before restocking previously infected sites or releasing hens into quarantine buffer zones, these audits must be carried out every six months until state authorities have cleared the area (Federal Register, 2024). These efforts are supported by the "Defend the Flock" program, which provides training and educational resources to improve on-farm biosecurity compliance.

Meanwhile, the Centers for Disease Control and Prevention (CDC) contributes biosecurity guidance emphasizing personal protective equipment (PPE), zoonotic risk mitigation, and farmworker safety—particularly during outbreaks involving novel or high-risk pathogens such as COVID-19 or H5N1. At the state level, departments of agriculture supplement federal mandates with localized protocols during outbreaks, enforcing movement controls and quarantine zones. These agencies also extend guidance to small-scale producers, focusing on basic hygiene, controlled farm access, and the physical separation of poultry from wild and domestic animals.

Collectively, these findings emphasize that biosecurity is not merely a technical protocol but a multilevel, public-private responsibility (Mato-Amboage et al., 2018). It is central to national agricultural resilience, with implications for public health, global trade, and food security. Strengthening biosecurity thus requires both behavioral change on farms and system-wide coordination—including policy innovation, financial incentives, and continued investment in science-based interventions.

- *Lean Management in Agribusiness*

Originally created in the manufacturing industry, lean management is becoming more and more popular as a strategic framework in agribusiness, especially in the US. Fundamentally, Lean emphasizes removing inefficiencies, streamlining workflows, and encouraging a continuous improvement culture at all organizational levels. Its core ideas (standardization, just-in-time manufacturing, waste reduction, and employee-driven innovation) provide a useful prism through which agricultural operations can raise sustainability, quality, and productivity.

An academic summary of the main Lean principles and methods that have shown a remarkable ability to adjust to the complexity of agricultural systems was published by Carrijo and Batalha in 2024. They demonstrated how operational redundancies that are typical of conventional farm models may be decreased by removing non-value-adding activities (categorized under the TIMWOOD framework: Transportation, Inventory, Motion, Waiting, Overproduction, Over-processing, and Defects). Additionally, it was explained that 5S protocols (Sort, Set in order, Shine, Standardize, Sustain) facilitate the development of safer and more organized work environments, while Value Stream Mapping (VSM) allows producers to visualize and improve their processes from beginning to end. Kaizen, or continuous, incremental improvement, is a philosophy that promotes long-term, inclusive involvement with creativity, efficiency, and problem-solving.

Empirical studies and case-based evidence reveal a growing body of success stories. Lean implementation has led to tangible operational benefits such as reduced search times for tools and inputs, enhanced workflow efficiency, and improved utilization of labor and material resources. In poultry production specifically, Lean interventions have improved egg quality and overall production efficiency, even among producers with limited prior exposure to Lean frameworks. These results suggest that the Lean approach holds particular promise for labor- and input-intensive sectors, such as poultry, where consistent routines and clear visual systems can have significant downstream effects (Ologbon and Adekunle, 2024; Satolo et al., 2016).

Importantly, Lean thinking in agriculture is increasingly integrated with technological innovations such as precision agriculture and digital quality management systems (Toruan et al., 2025). This convergence enables data-informed decision-making and enhances supply chain responsiveness, making Lean not only a tool for internal efficiency but also for external resilience in the face of demand fluctuations or supply disruptions.

Despite its promise, Lean implementation in agribusiness is not without challenges. Resistance to change among employees, lack of technical training, and difficulties in adapting industrial tools to biologically and environmentally variable farm systems have posed notable obstacles. However, research consistently shows that successful Lean adoption is more likely when preceded by structured onboarding phases, coach-facilitated workshops, and strong leadership commitment from farm owners or managers (Zargun and Al-Ashaab, 2013).

Overall, Lean management offers a powerful framework for enhancing operational performance in U.S. agribusiness. When appropriately adapted and supported, it can reduce waste, improve quality, and help producers navigate the competing pressures of economic efficiency, environmental responsibility, and food safety compliance.

- *Credit Risk and Financial Resilience*

Credit risk assessment in U.S. agricultural systems is undergoing a substantive transformation, driven by advances in supply chain finance (SCF), hybrid risk modeling, and climate-integrated risk evaluation. These developments reflect a broader shift toward financial strategies that enhance the resilience of farm operations, especially in sectors like poultry production, where both biological volatility and market instability pose persistent financial threats.

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Integrating Supply Chain Finance (SCF) frameworks into credit risk assessments is a significant advancement in agriculture finance. Instead of treating the borrower as an isolated risk entity, SCF considers the stability and organization of the whole agricultural value chain. The ability of producers' connections to major processors, cooperatives, or institutional customers to lower risk is being evaluated by U.S. financial institutions more and more. By implicitly ensuring input continuity and payment stability, these relationships can reduce overall credit risk. Furthermore, SCF makes it easier to incorporate non-traditional credit information, such long-standing connections with suppliers or processors, enabling underprivileged or up-and-coming farmers to obtain funding even in the face of weak or unofficial credit records (Zhang & Zhao, 2025; Villalba, Venus, & Sauer, 2023; Walvaren & Barry, 2003).

Parallel to these structural changes is the growing use of advanced and hybrid risk scoring models. Traditional financial metrics such as solvency, liquidity, repayment capacity, and financial efficiency remain central, particularly in commodity-focused sectors like U.S. dairy and poultry farming. However, these are increasingly augmented by qualitative and predictive variables, including management experience, market exposure, and farm-level adaptability. Notably, artificial intelligence (AI) and ensemble learning techniques—such as explainable machine learning models and hybrid long short-term memory (LSTM) networks—are being adopted for their superior accuracy in modeling nonlinear risks inherent in agricultural production. These tools enhance the predictive capacity of credit risk assessments, especially in dynamic and climate-sensitive production systems (Chai et al., 2025; Wolf & Karszes, 2023; Gao, Yang, & Zhao, 2023).

Several researchers (Liu, Ren, & Jin 2025; Ceu & Gasper, 2024; Wolf & Karszes, 2023) also emphasize how climate-related risks now play a pivotal role in shaping creditworthiness in agriculture. Environmental risk integration is becoming a standard feature in modern credit risk models, as lenders seek to account for temperature variability, drought incidence, and extreme weather events in loan decisions and portfolio stress testing. This reflects a growing recognition that climate shocks are not only agronomic but also financial, with implications for repayment risk, collateral degradation, and loan recovery timelines. As a result, credit risk models are evolving to include climate exposure indices and scenario-based simulations to better prepare lending institutions and borrowers for future disruptions.

Lastly, improving financial resilience in agriculture requires customized loan policies and flexible risk assessment techniques. A financial feedback loop that rewards prudent management and offsets increased lending risk is offered via risk-based loan pricing, in which interest rates are tier-based depending on risk ratings (Goodwin and Mishra, 2000). A significant shift from static lending models is represented by adaptive credit scoring systems, which adjust their calculations based on operational, market, and climate signals in real time. For chicken producers, whose operations could be suddenly affected by disease outbreaks, trade restrictions, or seasonal demand swings, such dynamism is essential.

Together, these developments mark a convergence of financial innovation and agricultural risk management. By embedding credit risk assessment more deeply into the structural and operational realities of agricultural production, lenders and policymakers can help build a more resilient and inclusive financial ecosystem for U.S. agribusiness.

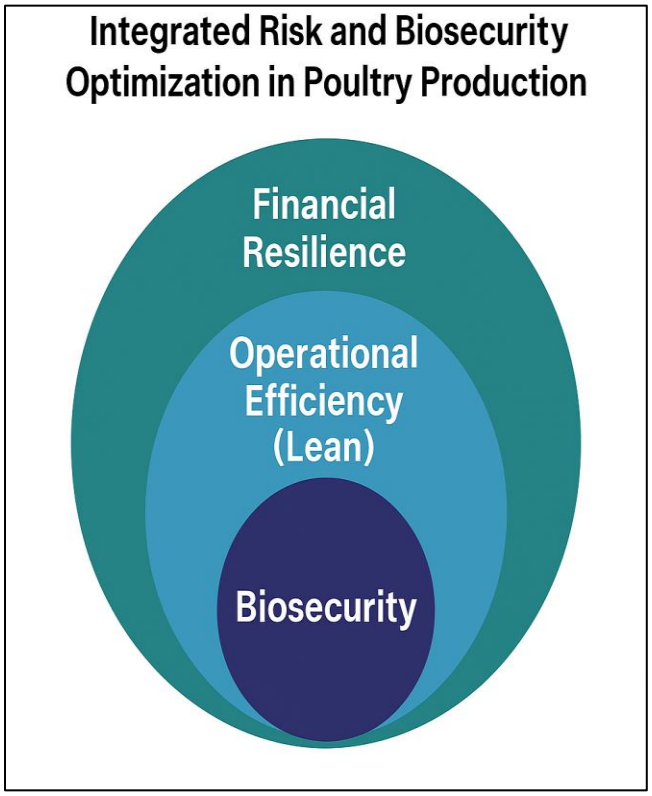

Fig 1 Integrated Risk and Biosecurity Optimization in Poultry Production.

➢ *Existing Models and Frameworks (Brief Overview)*

We use well-established models from the banking and agriculture industries to contextualize our methodology. First, there are systematic approaches to thinking about absorptive, adaptive, and transformative capacities at the household and farm levels thanks to resilience measurement frameworks like the Sustainable Livelihoods Framework (SLF) and the FAO's Resilience Index Measurement and Analysis (RIMA). We utilize these to explain how resilience outcomes (such as improved cash flow, risk sharing, and adaptive investment) are influenced by financial literacy and credit-risk awareness. Secondly, the Basel family of parameters, probability of default (PD), loss given default (LGD), and exposure at default (EAD), is cited by credit risk management as a clear means of expressing farm credit risk and customizing borrower education around factors that influence repayment capability. An thirdly, for poultry biosecurity, WOAH/OIE "compartmentalization" illustrates how standardized risk segmentation and documented controls can maintain market access during disease events. Our recommendations align with this logic by pairing biosecurity controls with financial risk buffers.

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- *Gaps in Integration: Bridging Operational, Financial, and Biosecurity Silos*

Despite significant advancements in Lean management, biosecurity, and agricultural credit risk modeling, these domains largely operate in silos. Operational efficiency efforts are rarely aligned with disease prevention protocols, and financial risk assessments seldom incorporate real-time indicators of biosecurity or process performance. As a result, interventions designed to strengthen one dimension of resilience may unintentionally undermine another, for example, lean practices that reduce redundancy can conflict with biosecurity measures requiring isolation and controlled access.

This lack of cross-disciplinary integration limits the effectiveness of risk management in poultry production. Few existing models actively link operational metrics with financial risk scoring or health safety compliance, and those that do often remain narrow in scope or insufficiently validated. The absence of such integrated frameworks makes it difficult for producers, lenders, and policymakers to holistically assess farm vulnerability or to design interventions that strengthen resilience across multiple domains simultaneously.

III. METHODOLOGY

This study is a narrative literature review supplemented by conceptual synthesis. We searched Google Scholar and Science Direct, and Scopus (2000 - 2025) and screened multilateral/policy reports like the FAO, World Bank, and OECD, using keywords combining agriculture/livestock/poultry, resilience, financial literacy/financial capability, credit risk, and biosecurity. We included sources that (i) address financial capability or credit-risk management for smallholders or agri-SMEs, and/or (ii)assess resilience outcomes in livestock or mixed-farming systems. We excluded purely laboratory or non-agricultural finance studies. No primary data were collected. The findings we present are a synthesis of published articles and reports.

A thematic analysis approach was used to extract key concepts, practices, and gaps from each domain. These findings were then compared and synthesized to identify points of overlap, divergence, and potential integration. Emphasis was placed on identifying frameworks, case studies, and empirical findings relevant to U.S. commercial poultry systems. This methodology allows for a conceptual mapping of risk management practices without relying on simulation, econometrics, or primary fieldwork, providing a grounded yet accessible foundation for proposing an integrated risk framework. This approach was chosen due to the scarcity of integrate models, and the need to synthesize multi-disciplinary literature as a foundation for future empirical testing.

IV. RESULTS AND DISCUSSION

The various articles and reports found, especially those cited in the literature review, reveals strong but compartmentalized advances in risk management across poultry biosecurity, Lean operations, and agricultural finance. Each domain contributes distinct and valuable tools: biosecurity measures help prevent disease transmission; Lean principles streamline processes and improve resource use; and credit risk models assess financial solvency and adaptability. However, these tools are largely applied in isolation, leading to missed opportunities for synergistic resilience.

In the domain of biosecurity, U.S. poultry systems have established comprehensive practices focused on disease prevention and control. Nonetheless, implementation varies significantly based on farm size, geography, and available resources, and is often reactive rather than proactive. Similarly, Lean practices have delivered operational gains (such as reduced waste, improved workflow, and enhanced product quality), but their uptake in agriculture, particularly among smaller operations, is inconsistent and frequently constrained by training gaps and organizational inertia.

Financial resilience tools, particularly credit risk models, are becoming increasingly sophisticated. Modern approaches now incorporate environmental variables, supply chain linkages, and machine learning-based risk scoring. Yet, these models rarely factor in operational indicators such as biosecurity compliance or Lean process maturity. As a result, lending assessments may fail to capture the full scope of risk exposure or resilience capacity at the farm level.

Crucially, the analysis identifies a persistent lack of integrative frameworks; models that simultaneously consider animal health, operational efficiency, and financial risk. The absence of such cross-disciplinary tools means that interventions in one domain may undermine others: for example, cost-cutting measures under Lean may conflict with biosecurity protocols that require redundancy or downtime. Similarly, farms with high biosecurity standards but poor financial documentation may be penalized in credit risk assessments.

This fragmentation underscores the need for an integrated approach that reflects the interdependencies among biological, operational, and financial systems in poultry production. A unified risk management framework could, for instance, embed biosecurity scores into credit evaluations or align Lean efficiency metrics with health and safety benchmarks. Such integration would enable policymakers, lenders, and producers to make decisions that enhance overall system resilience, rather than optimizing one dimension at the expense of another.

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Disciplinary Focus Matrix

Risk Category	Biosecurity	Lean Management	Credit Risk Assessment
Health & Safety	Core focus: Pathogen control	Indirect: through cleaner processes	Not typically included
Operational Efficiency	Secondary: via compliance routines	Core focus: Process optimization	Occasionally assessed (cost impact)
Financial Resilience	Public health spending implications	Reduces waste, but rarely quantified	Core focus: default risk, loan exposure
Climate/ Environmental	Via disease vectors, waste mgmt	Indirect (e.g., resource efficiency)	Increasingly included in modern models
Integration Readiness	Limited with other domains	Some tech integration (e.g. sensors)	Weakly connected to farm-level ops

Fig 2 Disciplinary Focus Matrix Showing Integration Opportunity.

RECOMMENDATIONS

➢ *For Practitioners*

It is recommended that poultry producers adopt integrated risk management systems that balance sound biosecurity, financial planning, and operational efficiency. Using Lean techniques like value stream mapping and 5S in ways that strengthen biosecurity protocols is part of this. Additionally, since health and safety regulations can be used to improve credit profiles in the context of changing risk-based financing models, producers are urged to record and share their adherence to these regulations.

➢ *For Policymakers*

The creation of cross-functional standards that link operational procedures, financial resilience, and animal health should be encouraged by financing and regulatory organizations. This can entail providing incentives for farms to undertake certified biosecurity and Lean evaluations, as well as incorporating these metrics into federal agricultural financing schemes or insurance policies. For small and medium-sized farms looking to implement integrated systems, public-private partnerships may also be utilized to lower entrance barriers.

➢ *For Researchers*

Future studies should build on the conceptual insights in this paper by conducting empirical analyses that test the effectiveness of integrated financial and biosecurity interventions. A valid example is that researchers could pilot-test an integrated credit scoring model that incorporates both financial literacy indicators and biosecurity compliance data among a selected size of poultry farmers or livestock farmers (probably small or mid-size, for a start). This would allow for the assessment of how combined interventions influence access to credit, loan repayment performance, and resilience to disease outbreaks. Additionally, comparative research across different farm sizes, regions, and production systems could identify scaling factors and adaptation needs, contributing to the broader applicability of these approaches.

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