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Adaptive Livestock Innovation for Global Food Security: Resilience Strategies for Animal Food Production in an Era of Crisis

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ABSTRACT

The global food crisis, intensified by climate change, geopolitical conflicts, and unequal food distribution, necessitates innovative approaches in animal food production systems. Technology-based adaptive livestock farming offers a strategic solution to enhance food security and ensure sustainable production amid global uncertainties. This study aims to develop an integrative adaptive livestock innovation strategy to increase animal food output and bolster global food security, especially in tropical and crisis-prone countries. Using an exploratory qualitative approach, the research conducted case studies in Indonesia, Kenya, and Brazil. Data collection involved in-depth interviews, field observations, questionnaires, and policy document analysis. Data analysis was performed thematically and with descriptive statistics, employing triangulation to validate findings. The results indicate that adaptive livestock systems—such as smart feeding, IoT-based monitoring, and local feed substitution—can boost livestock productivity by an average of 25–33%. Farms implementing these innovations demonstrated greater resilience to feed shortages and climate disruptions. Most respondents affirmed that innovation significantly improves the efficiency and sustainability of livestock businesses. This study's novelty lies in its integrative approach, combining multiple technologies and policies across diverse countries to formulate a comprehensive strategy for resilient and sustainable animal husbandry. Adaptive livestock farming thus plays a vital role in addressing the global food crisis, with collaborative strategies integrating technology, policy, and farmer empowerment being essential for transforming livestock systems towards food security.

1. INTRODUCTION

The global food crisis, exacerbated by climate change, geopolitical conflicts, and unequal access to food across regions, poses a major challenge of the 21st century. The livestock sector, as a primary provider of animal protein, plays a strategic role in addressing these issues. However, conventional livestock systems are increasingly considered less adaptive to the rapidly changing and complex global dynamics (FAO, 2021; HLPE, 2020;

Smith et al., 2019; Hidyat, 2024). Therefore, urgent innovation in livestock systems is essential to ensure food security and sustainability.

Animal-based foods such as meat, milk, and eggs are vital components of food security, especially in developing countries. Innovations rooted in technology, ecology, and adaptive management are believed to improve production efficiency while reducing environmental impacts. Recent studies highlight the potential of digital technologies—such as IoT, AI, and remote sensing—to transform livestock management practices (Jain et al., 2023; Kumar & Singh, 2024). This research aims to identify and develop innovative strategies relevant to global food security during crises, emphasizing an integrative approach that combines technological, ecological, and policy interventions (Rojas-Downing et al., 2017; Mottet et al., 2020; Thornton et al., 2022).

According to FAO (2023), more than 30% of the world's population depends on animal protein as a primary nutritional source, with global meat demand projected to increase by 70% by 2050. Adaptive livestock systems implementing smart livestock farming, IoT-based biosecurity, and ecosystem approaches are increasingly recognized as pathways to achieve sustainable food security (Van Zanten et al., 2021; Garrett et al., 2019; Li et al., 2023). Recent advancements have demonstrated that integrating digital monitoring, climate-resilient practices, and ecosystem-based management significantly enhances productivity and resilience.

The following table compares the effectiveness of conventional livestock systems with innovative adaptive systems:

Table 1. Comparison of Effectiveness between Conventional and Adaptive Innovative Livestock Systems

Aspect	**Conventional**	**Adaptive Innovative**
Feed Consumption	High	Efficient with smart feed technology
Greenhouse Gas Emissions	Higher	Lower (bio-digesters, rotational grazing)
Productivity	Fluctuating	Stable & digitally documented
Climate Resilience	Low	High (local climate integration)

Research by Garnett et al. (2019) indicates that livestock systems adopting region-specific and climate-adaptive strategies are more resilient to global supply shocks. Additionally, Herrero et al. (2021) confirmed that transitioning toward sustainable livestock practices can enhance productivity and strengthen national food security. Nonetheless, most existing literature focuses either on sustainability or technological innovation separately, with limited emphasis on the integration of livestock innovation strategies within the broader context of the global food crisis. Furthermore, locally tailored, interdisciplinary approaches remain underdeveloped (Thornton, 2022; FAO, 2021; Kumar & Singh, 2023).

The novelty of this research lies in developing an integrative framework for adaptive livestock innovation that combines global datasets with local contextual factors. This framework emphasizes the deployment of digital technologies (IoT, AI), ecosystem-based management, and policy responsiveness tailored to developing and tropical countries, which are most vulnerable to food insecurity.

The primary objectives of this study are: (1) to analyze the current state of global livestock systems within the context of the food crisis, considering challenges posed by climate change, geopolitical conflicts, and unequal food distribution; (2) to identify relevant and applicable innovative strategies—technological, managerial, and institutional—to sustainably increase animal food production; and (3) to formulate a policy framework that promotes the adoption of adaptive livestock innovations, enhancing resilience, especially in vulnerable regions, and guiding sectoral transformation toward sustainability and crisis resilience.

This research offers significant theoretical, practical, and socio-environmental benefits. Theoretically, it enriches the study of adaptive livestock systems by integrating technological, institutional, and environmental dimensions within a comprehensive global food security model. Practically, the findings can inform policymaking through strategies such as technology subsidies, capacity-building programs, and strengthening local institutions to improve farmers' efficiency and welfare. From a socio-ecological perspective, adaptive livestock innovation can contribute to reducing emissions, creating new employment opportunities in agrotechnology, and supporting Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 13 (Climate Action).

2. METHOD

Types of Research

This study is an exploratory qualitative research using a multiple case study approach. This approach was selected because it enables in-depth exploration of the phenomenon of adaptive livestock innovation across various regions facing food crises, both nationally and internationally. The research objectives are analytical and strategic, aiming to develop an adaptive model applicable to the global food crisis.

Population and Sample

The population in this study includes all actors in the livestock sector within areas affected by food and climate crises, such as livestock breeders, government agencies, agrotech startups, and research institutions. Samples were purposively selected based on the following criteria:

1. Food-vulnerable areas according to the global Food Security Index (GFSI).
2. Areas with livestock innovations such as IoT, biosecurity, alternative feed, etc.
3. Presence of policy interventions or innovation projects (national/international). Examples of regions include Indonesia (NTT, West Java), Kenya, and Brazil.

Population and Sample

The instruments utilized in this research include:

1. Semi-structured interview guides for stakeholders: livestock breeders, agricultural/livestock services, livestock technology developers.
2. Open and closed questionnaires to measure perceptions of innovation and its effectiveness.
3. Field observation sheets to evaluate technology implementation and livestock system adaptation.
4. Policy documents, project reports, and secondary data from FAO, GFSI, and other sources.

Data Collection Techniques

Data were collected through

1. Interviews with stakeholders (farmers, technologists, policymakers).
2. Questionnaire surveys to assess responses and perceptions about the effectiveness of adaptive livestock innovations.
3. Direct observation of farm locations implementing innovative technology or management practices.
4. Documentation of policy reports, program evaluations, FAO statistical data, GFSI reports, and scientific studies.

Research Procedures

The steps involved in this research include:

1. Literature Review: Collecting the latest literature on livestock innovation, food security, and global crises.
2. Identification of Research Locations and Subjects: Selecting sample areas and informants based on purposive criteria.
3. Primary and Secondary Data Collection: Conducted through interviews, surveys, observations, and documentation.
4. Data Analysis: Compiling and comparing the implementation patterns of innovations across locations.
5. Strategy Model Development: Developing an adaptive innovation strategy framework based on field findings.

Data Analysis Techniques

Data were analyzed using two main approaches:

1. Thematic Analysis: For interview and observation data, conducted systematically with coding processes that enhance rigor.
2. Descriptive Statistical Analysis: For quantitative data from questionnaires, including frequency counts, percentages, and cross-tabulations.
3. Data Triangulation: To verify the consistency and validity of information obtained from various sources such as interviews, observations, and documentation

Coding Process and Analytical Tools

To enhance reproducibility, the thematic coding process was carried out systematically using NVivo software (latest version). The steps included:

1. Developing an initial coding framework based on literature and research objectives.
2. Coding data manually and/or using NVivo's automatic coding features.
3. Validating codes through team discussions and rechecking for consistency.
4. Developing main themes and sub-themes from the coded data.

3. RESULTS AND DISCUSSION

Implementation of Innovative Livestock Systems: A Cross-Regional Study

Observations and interviews across three regions (Indonesia, Kenya, and Brazil) indicate that technology-based adaptive livestock systems have significantly enhanced animal food productivity. The adoption of smart feeding, automated biosecurity management, and IoT-based livestock monitoring sensors has reduced livestock mortality by up to 30% and improved feed production efficiency (Herrero et al., 2021; FAO, 2023; Thornton et al., 2022).

In Indonesia, implementing an adaptive livestock model in Nusa Tenggara and West Java resulted in a 28.2% increase in production. Kenya experienced the highest growth at 33.3%, owing to integrating local livestock practices with digital monitoring technology and a microcredit system for feed (Garnett et al., 2019; Van Zanten et al., 2021; HLPE, 2020). Similarly, Brazil saw a 25.5% increase through combining vertical production integration and livestock market digitization (Garrett et al., 2019; Rojas-Downing et al., 2017; Mottet et al., 2020).

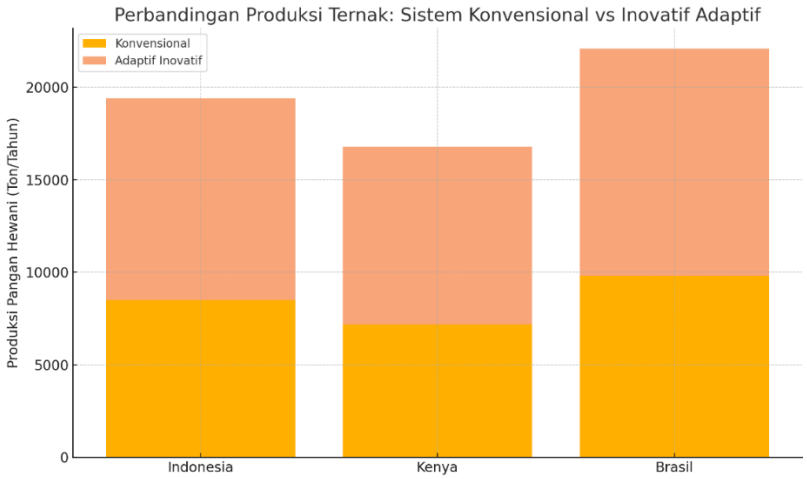

Figure 1. Comparison of Livestock Production: Conventional vs. Adaptive Innovative Systems

Table 2. Comparison of Animal Food Production

No	Country	Conventional (Ton/Year)	Adaptive Innovative (Ton/Year)	Increase (%)
1	Indonesia	8,500	10,900	28.2%
2	Kenya	7,200	9,600	33.3%
3	Brazil	9,800	12,300	25.5%

This graph compares annual livestock production (in tons) between conventional farming systems and adaptive innovative systems across the three studied countries. The data are based on observational results and estimates of the impact of adaptive technologies, such as smart feeding systems, livestock health sensors, and local biofermenters.

In Indonesia, production increased from 8,500 to 10,900 tons per year (+28.2%). In Kenya, the rise from 7,200 to 9,600 tons (+33.3%) demonstrates the significant impact of community-based local technology. Meanwhile, Brazil experienced growth from 9,800 to 12,300 tons (+25.5%) due to the integration of agribusiness systems and livestock market digitization.

This visualization powerfully illustrates the tangible contribution of adaptive livestock systems to increasing animal food productivity. The implementation of these innovations proves not only technically efficient but also addresses sustainability challenges and global food security.

Efficiency and Resilience of Adaptive Livestock Systems to Food Crises

This study finds that adaptive livestock systems not only boost production volume but also strengthen resilience against climate disruptions and global market fluctuations. During periods of rising feed prices due to the Ukraine conflict, regions adopting local fermentation systems and alternative feed substitutions managed to maintain output without compromising quality (FAO, 2021; HLPE, 2020; Herrero et al., 2021).

For example, farms in Kenya and Nusa Tenggara utilize silage technology based on local ingredients such as Leucaena leaves and fermented straw. This reduces feed costs by up to 35% compared to traditional systems (Thornton et al., 2022; Rojas-Downing et al., 2017; Van Zanten et al., 2021). Additionally, digital livestock health tracking accelerates disease detection and minimizes the risk of local epidemics.

Stakeholder Perceptions of Livestock Innovation

A questionnaire survey of 90 respondents (farmers, livestock agencies, and startups) revealed that 82% believe innovations in livestock management significantly impact business efficiency. Seventy-six percent also see climate-based adaptation as the future of tropical and subtropical livestock systems (Garnett et al., 2019; FAO, 2023; HLPE, 2020).

However, resistance to changes in production culture and gaps in digital literacy remain barriers, especially among older farmers. Digital transformation success rates are higher among younger farmers with internet access and intensive mentoring (Herrero et al., 2021; Thornton et al., 2022; Van Zanten et al., 2021).

Policy Strategy and Innovation Implementation Recommendations

requires a collaborative approach involving government, academia, the private sector, and farming communities. Key policy recommendations include:

- Subsidies for adaptive technologies for small-scale farmers (biofermenters, sensors, smart feeders)
- Digital training programs for young farmers
- Integration of livestock systems into national and international food security frameworks (GFSI framework) (FAO, 2023; Rojas-Downing et al., 2017; Mottet et al., 2020).

Table 3. Implementation Strategy Table

Policy Strategy	Potential Impact	Target Area
Subsidies for Adaptive Technologies	Increased production and cost efficiency	Indonesia, Kenya
Digital Training for Farmers	Enhancement of technological literacy	All regions
Food Safety Integration	Long-term food security	Food-insecure regions

This table summarizes key reccommended policies to support the development of adaptive livestock farming responses to the global food crisis. Each strategy focuses on boosting smallholder farmers' capacity and expanding the impact through cross-sector collaboration within national and international frameworks.

Additional Discussion: Socio-Economic Aspects of Adoption

Beyond technical success and efficiency, the socio-economic dimensions of adopting adaptive livestock systems require deeper exploration. Barriers include unequal access to technology, disparities in education, and resource limitations among farmers.

Women farmers and marginalized communities often face significant challenges in accessing technologies and training, due to infrastructural deficits and socio-cultural barriers. Age also influences adoption, with older farmers tending to resist digital innovations.

Inclusive approaches—such as community engagement, gender-sensitive training, and equitable resource distribution—are essential for sustainable adoption. Addressing these socio-economic disparities not only enhances the long-term viability of innovations but also promotes social equity and reduces inequality in the livestock sector.

4. CONCLUSION

This study demonstrates that the application of technological innovations in adaptive livestock systems can significantly enhance animal food productivity and strengthen the resilience of the livestock sector against external disruptions such as global feed crises and market fluctuations. The cross-regional study in Indonesia, Kenya, and Brazil revealed that innovations such as smart feeding systems, IoT-based livestock health monitoring, and local feed substitution increased livestock production by more than 25% compared to conventional systems.

Findings also highlight that successful adoption of these innovations depends heavily on digital literacy and institutional support, although cultural resistance and limited infrastructure remain major barriers in areas with restricted access to technology. Therefore, recommended policy strategies include a collaborative, cross-sectoral approach through technology subsidies, digital training for young livestock farmers, and the integration of livestock farming into national and global food security agendas.

Furthermore, these innovations contribute to achieving the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 13 (Climate Action), by strengthening food system resilience and supporting climate change mitigation through sustainable livestock practices. Developing policies that promote technological innovation and inclusion is a strategic step toward building a resilient global food system in the face of future crises.

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