



## SUSTAINABLE LIVESTOCK PRODUCT PROCESSING AND FOOD SAFETY: THE MEDIATING ROLE OF SMART QUALITY MONITORING SYSTEMS

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### **Abstract**

*The livestock industry is a vital component of global food systems, providing essential nutrition, employment, and economic benefits. However, ensuring the sustainability of livestock product processing and maintaining food safety remains a significant challenge due to microbial contamination, chemical residues, and inefficiencies in production processes. The adoption of sustainable livestock processing practices—including improved handling, waste management, and energy-efficient operations—can reduce environmental impacts, enhance product quality, and mitigate health risks. Smart quality monitoring systems (SQMS), integrating sensors, Internet of Things (IoT) devices, real-time data analytics, and automated control systems, provide innovative solutions for ensuring product quality and safety. These systems enable continuous monitoring of temperature, humidity, microbial load, and chemical composition during processing, storage, and distribution, allowing for early detection of deviations and preventive interventions. This study investigates the impact of sustainable livestock product processing practices on food safety, emphasizing the mediating role of smart quality monitoring systems. Sustainable practices alone may not guarantee food safety without effective monitoring mechanisms; SQMS ensure adherence to safety standards, traceability, and compliance with regulatory frameworks. A quantitative research design was employed, targeting livestock processing plants, quality control managers, and regulatory officers. Structured questionnaires assessed sustainable processing practices, the implementation of smart quality monitoring systems, and food safety outcomes. Data were analyzed using Smart PLS structural equation modeling to evaluate direct and mediated effects. Results indicate that sustainable livestock processing positively influences food safety. Smart quality monitoring systems significantly mediate this relationship, highlighting that real-time monitoring and automated quality control enhance the effectiveness of sustainable practices. Findings underscore the importance of integrating technological solutions with environmentally responsible practices to achieve safe, high-quality livestock products. Policymakers, industry managers, and technology developers can leverage these insights to strengthen food safety protocols, improve operational efficiency, and promote sustainable livestock production.*

**Keywords:** *Sustainable Livestock Processing, Food Safety, Smart Quality Monitoring Systems, Iot In Food Processing, Sustainable Food Systems*

### **Introduction**

Livestock product processing is a critical component of food supply chains, encompassing slaughter, processing, packaging, storage, and distribution. The global demand for safe, high-quality livestock products has increased due to population growth, urbanization, and rising consumer awareness regarding nutrition and food safety. However, conventional livestock processing practices often face challenges, including microbial contamination, improper handling, chemical residues, and inefficient use of resources. These challenges can compromise product safety, reduce shelf life, and lead to significant economic and public health consequences (Grace, 2015).

Sustainable livestock processing practices aim to minimize environmental impacts while ensuring product



quality and safety. Practices such as waste recycling, energy-efficient processing, water conservation, improved sanitation, and responsible chemical use not only enhance operational efficiency but also reduce contamination risks and promote environmentally friendly production (FAO, 2020). Despite the adoption of these sustainable practices, ensuring food safety remains a complex task due to the dynamic nature of microbial growth, chemical reactions, and storage conditions throughout the supply chain.

Smart quality monitoring systems (SQMS) provide a technological solution by enabling real-time, continuous tracking of critical parameters during livestock product processing. These systems leverage sensors, IoT devices, and advanced data analytics to monitor temperature, humidity, microbial contamination, pH, and chemical residues, allowing immediate corrective actions and preventive interventions (Li et al., 2019). SQMS also support traceability, ensuring that every product can be traced back to its source, which is critical for regulatory compliance, consumer trust, and rapid response in case of contamination events.

Theoretical frameworks, including the Resource-Based View (RBV) and Technology Acceptance Model (TAM), inform this study. RBV posits that technological capabilities, such as SQMS, are valuable resources that enhance operational efficiency, product quality, and competitive advantage (Grant, 1996). TAM emphasizes that perceived usefulness and ease of use influence the adoption of technological innovations in production processes (Davis, 1989). By integrating sustainable practices with SQMS, livestock processing facilities can achieve superior food safety outcomes while maintaining environmentally responsible operations.

Empirical evidence suggests that sustainable processing practices alone may be insufficient for ensuring food safety. Grace (2015) reported that improper monitoring of temperature and microbial loads in livestock processing can lead to foodborne outbreaks despite environmentally sustainable operations. Li et al. (2019) demonstrated that implementing IoT-based monitoring systems significantly reduces contamination risk and enhances compliance with safety standards. These findings highlight the mediating role of SQMS in translating sustainable practices into effective food safety outcomes.

This study investigates the direct effect of sustainable livestock product processing on food safety and the mediating influence of smart quality monitoring systems. Using Smart PLS structural equation modeling, the study provides empirical insights into how integrating sustainable practices with advanced monitoring technologies improves operational efficiency, ensures compliance with regulatory frameworks, and strengthens consumer confidence in livestock products. The results are intended to guide policymakers, industry managers, and technology developers in optimizing livestock processing for both sustainability and food safety.

## Literature Review

Sustainable livestock processing encompasses practices that reduce environmental impacts, enhance resource efficiency, and ensure product quality. Key practices include waste management and recycling, water and energy conservation, proper sanitation, responsible chemical use, and adherence to environmental and safety regulations (FAO, 2020). These practices not only reduce pollution and resource consumption but also create a safer and more consistent production environment, which is essential for maintaining food safety.

Despite the implementation of sustainable practices, food safety challenges persist due to microbial contamination, chemical residues, temperature deviations, and improper storage conditions. Studies show



that up to 20–30% of livestock products can be affected by microbial or chemical contamination during processing and storage if monitoring is inadequate (Grace, 2015). To mitigate these risks, technological solutions such as smart quality monitoring systems (SQMS) are critical.

SQMS integrate sensors, IoT devices, automated control systems, and advanced analytics to continuously monitor critical parameters, enabling real-time detection of deviations and immediate corrective action. For example, temperature and humidity sensors can alert operators to storage conditions that may favor microbial growth. Chemical sensors can detect residues exceeding safety thresholds, and automated alerts can prevent contaminated products from reaching the market (Li et al., 2019). This continuous monitoring enhances compliance with food safety standards, improves traceability, and reduces the likelihood of foodborne outbreaks.

The Resource-Based View (RBV) provides a theoretical lens, suggesting that technological resources like SQMS create a competitive advantage by enhancing operational efficiency and food safety (Grant, 1996). The Technology Acceptance Model (TAM) further explains adoption dynamics, highlighting that perceived usefulness and ease of use influence facility managers' willingness to implement advanced monitoring systems (Davis, 1989). Empirical studies demonstrate that facilities adopting SQMS report higher compliance with safety regulations, reduced contamination events, and improved product quality metrics (Zhang et al., 2020).

Research also emphasizes the mediating role of SQMS in linking sustainable livestock processing practices to food safety. Sustainable practices improve the operational environment, but without real-time monitoring, deviations may go undetected, leading to contamination or quality deterioration. By acting as a mediating mechanism, SQMS ensure that sustainable practices translate into tangible food safety improvements. Studies by Li et al. (2019) and Zhang et al. (2020) confirm that combining sustainable practices with smart monitoring systems leads to superior outcomes compared to relying solely on sustainability initiatives.

Challenges in implementation include the high cost of SQMS, technical expertise requirements, and integration with existing processing workflows. Addressing these challenges requires training programs, policy support, and incentives to encourage adoption. Integrating SQMS with sustainable practices ensures a holistic approach to food safety, operational efficiency, and environmental responsibility, which is essential for modern livestock production systems.

## Conceptual Model and Theoretical Framework

### Conceptual Model:

- Sustainable Livestock Product Processing (SLPP) → Food Safety (FS)
- Mediator: Smart Quality Monitoring Systems (SQMS)

### Theoretical Framework:

- Resource-Based View (RBV)
- Technology Acceptance Model (TAM)

### Hypotheses:

H1: SLPP positively influences food safety

H2: SQMS mediates the relationship between SLPP and food safety



## Methodology

A quantitative research design was employed to assess the impact of sustainable livestock processing practices on food safety, with smart quality monitoring systems as a mediator. The target population included livestock processing plants, quality control managers, and regulatory officers. A structured questionnaire measured sustainable practices, SQMS implementation, and food safety outcomes on a five-point Likert scale.

Data collection involved field visits, online surveys, and collaboration with regulatory bodies and industry associations. Out of 400 distributed questionnaires, 368 valid responses were obtained. Demographic and operational variables, including plant size, production volume, and experience with digital monitoring, were recorded.

Data analysis was conducted using Smart PLS structural equation modeling. Reliability and validity of constructs were confirmed through Cronbach alpha, composite reliability, and average variance extracted. The structural model assessed direct effects of sustainable livestock processing on food safety and indirect effects through smart quality monitoring systems. Bootstrapping with 5000 resamples was used to evaluate statistical significance.

## Results

### Measurement Model Results

Construct	Cronbach Alpha	Composite Reliability	AVE
Sustainable Livestock Processing	0.91	0.93	0.72
Smart Quality Monitoring Systems	0.89	0.91	0.70
Food Safety	0.92	0.94	0.74

### Structural Model Results

Hypothesis	Relationship	Path Coefficient	T value	P value	Result
H1	SLPP → FS	0.57	9.25	0.000	Supported
H2	SLPP → SQMS → FS	0.36	7.10	0.000	Supported

## Interpretation

The results indicate that sustainable livestock processing practices significantly improve food safety (H1, 0.57). Practices such as proper waste management, energy-efficient operations, sanitation, and responsible chemical use create a safer production environment. Smart quality monitoring systems significantly mediate this relationship (H2, 0.36), demonstrating that continuous monitoring, automated alerts, and data-driven interventions are critical for translating sustainability efforts into measurable food safety outcomes. Facilities implementing SQMS can detect deviations in microbial load, temperature, humidity, and chemical residues in real time, preventing contamination and ensuring compliance with regulatory standards.

The findings emphasize that sustainability alone cannot guarantee food safety. SQMS act as a bridging mechanism, ensuring that environmentally responsible practices lead to high-quality, safe products. Integration of technological monitoring with sustainable operations enhances operational efficiency, reduces risk, and builds consumer trust. Policy support, investment in smart monitoring technologies, and training for facility managers are essential for scaling these practices across the livestock industry.



## Conclusion and Discussion

This study demonstrates that sustainable livestock processing practices positively impact food safety, with smart quality monitoring systems serving as a critical mediator. The integration of environmentally responsible practices with real-time monitoring ensures compliance with safety standards, reduces contamination risks, and enhances overall product quality.

Policy implications include promoting the adoption of SQMS in processing facilities, providing incentives for sustainable practices, and offering training programs to enhance technical expertise. Industry managers should adopt integrated strategies combining sustainability and technological monitoring to improve operational efficiency and meet regulatory requirements.

## Future Recommendations

Future research should explore the long-term impact of SQMS on operational efficiency, cost-benefit analyses of smart monitoring adoption, and consumer perceptions of quality and safety. Comparative studies across different livestock products, facility sizes, and regions can inform best practices for integrating sustainability and technology. Further research could also assess the role of AI and predictive analytics in enhancing smart quality monitoring systems.

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