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Smart Processing Machines and Business Efficiency in Goat Milk Agro-Enterprises

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ABSTRACT

The increasing demand for functional and health-oriented dairy products has positioned goat milk agro-enterprises as a promising business sector, particularly in emerging economies. Despite this potential, many goat milk businesses face persistent challenges related to production inefficiency, high operational costs, and limited scalability. This study aims to examine the impact of smart processing machines on business efficiency in goat milk agro-enterprises. Using a quantitative approach, data were collected from small and medium-sized goat milk processing enterprises and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results reveal that smart processing machine adoption has a positive and significant effect on business efficiency, including cost efficiency, productivity, and operational effectiveness. The findings indicate that smart processing machines function not merely as technological tools but as strategic business resources that enhance operational performance and competitiveness. This study contributes to the business and agribusiness literature by providing empirical evidence at the production-machine level and highlighting the strategic value of smart manufacturing technologies in small-scale agro-enterprises. The findings offer practical insights for business owners, policymakers, and technology developers in promoting sustainable and efficient goat milk processing businesses.

Keywords: Smart Processing Machines; Business Efficiency; Goat Milk Agro-Enterprises; Agro-Industry; SME Performance

Field: Business Administration; Agribusiness Management; Operations Management; Technology and Innovation Management

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SDGs: Affordable and Clean Energy (7); Decent Work and Economic Growth (8); Industry, Innovation and Infrastructure (9); Responsible Consumption and Production (12); Climate Action (13); Life on Land (15)

INTRODUCTION

The global demand for functional and health-oriented dairy products (Arlia et al., 2025) has increased significantly in recent years, positioning goat milk as a promising alternative to conventional cow milk due to its superior digestibility, nutritional composition, and hypoallergenic properties (Nayik et al., 2022). This growing demand has created new business opportunities for goat milk agro-enterprises, particularly small and medium-sized enterprises (SMEs) operating in emerging (Molina et al., 2024). However, despite favorable market

prospects, many goat milk businesses continue to face persistent challenges related to production inefficiency, high operational costs, inconsistent product quality, and limited scalability (Jahrizal et al., 2025).

Traditionally, goat milk processing relies on semi-manual or conventional machinery that offers limited control over processing parameters such as temperature, processing time, and hygiene standards (Rivera et al., 2025). These limitations often lead to product losses, unstable quality, and inefficient resource utilization, ultimately constraining business performance. In response, smart processing machines, integrating automation, digital control systems (Renaldo et al., 2021), and real-time monitoring, have emerged as a technological solution capable of transforming production processes in agro-based businesses. Such machines enable precise process control, improved consistency, reduced labor dependency, and enhanced operational transparency.

From a business perspective, the adoption of smart processing machines represents not merely a technological upgrade but a strategic investment aimed at improving business efficiency (Chandra et al., 2024), encompassing cost efficiency (Wati et al., 2024), productivity, process reliability, and output quality (Renaldo, Junaedi, et al., 2024). Business efficiency is a critical determinant of competitiveness in agro-enterprises, as it directly influences profit margins, market responsiveness, and long-term sustainability (Suhardjo et al., 2024). While the adoption of smart manufacturing technologies has been widely discussed in large-scale food industries, empirical evidence focusing on small-scale goat milk agro-enterprises remains limited.

Existing studies on dairy processing technology predominantly emphasize technical performance, food safety, or nutritional outcomes, often overlooking the business efficiency implications of machine adoption. Moreover, research in agribusiness management tends to examine digital transformation at an organizational or marketing level, rather than at the production-machine level, where efficiency gains are fundamentally generated. This creates a significant research gap, particularly in the context of SMEs that operate under capital constraints and require clear evidence of economic returns from technology investments (Chandra et al., 2018).

This study offers several key novelties. First, it conceptualizes smart processing machines not only as technological tools but as strategic business resources that drive efficiency in goat milk agro-enterprises. Second, unlike prior studies that focus on technological feasibility or food quality, this research empirically examines the direct relationship between smart machine adoption and business efficiency outcomes, including cost reduction, productivity improvement, and operational effectiveness. Third, the study provides micro-level evidence from goat milk SMEs, a segment that remains underrepresented in the Industry 4.0 and smart agribusiness literature. Finally, by integrating technological capability with business efficiency theory, this research contributes to the growing discourse on how smart production technologies can enhance competitiveness and sustainability in agro-based enterprises.

By addressing these gaps, the findings of this study are expected to provide valuable insights for business owners, policymakers, and technology developers in designing effective strategies for technology adoption in the goat milk industry. The study also extends the literature on smart manufacturing by demonstrating its relevance and applicability within small-scale agro-enterprises in emerging economies.

LITERATURE REVIEW

Resource-Based View (RBV) – Primary Grand Theory

The Resource-Based View (RBV) serves as the main grand theory underpinning this study. RBV posits that firm performance and competitive advantage are driven by the possession and effective utilization of valuable, rare, inimitable, and non-substitutable (VRIN) resources (Barney, 1991). In the context of this study, smart processing machines are conceptualized as strategic organizational resources rather than mere production tools. Their embedded capabilities, such as automation, digital control, and real-time monitoring, enable goat milk agro-enterprises to enhance cost efficiency, productivity, and operational effectiveness. These capabilities align with RBV's assertion that superior internal resources lead to improved business efficiency and sustained competitiveness. This study extends RBV by providing micro-level empirical evidence from small and medium-sized agro-enterprises, demonstrating that even SMEs can leverage technology-based resources to achieve efficiency gains, a domain traditionally dominated by large-scale industrial firms.

Technology–Organization–Environment (TOE) Framework – Supporting Grand Theory

The Technology–Organization–Environment (TOE) framework explains technology adoption decisions by considering technological readiness, organizational characteristics, and environmental pressures (Nguyen et al., 2022). Although this study does not explicitly test TOE dimensions, the framework provides a strong theoretical lens to justify the adoption of smart processing machines in goat milk agro-enterprises. From the TOE perspective, smart processing machines represent technological innovations adopted to address organizational

challenges such as labor dependency, inconsistent quality, and high operational costs (Mukhsin et al., 2025). Environmental factors, such as market demand for safe and functional dairy products, further reinforce the need for technology adoption.

Dynamic Capability Theory (DCT) – Extended Grand Theory

Dynamic Capability Theory emphasizes a firm's ability to integrate, build, and reconfigure internal resources in response to environmental changes (Magnano et al., 2024). In this study, smart processing machines enhance dynamic capabilities by enabling goat milk enterprises to adapt production processes, improve process reliability, and respond efficiently to changing market and regulatory requirements. The gradual realization of cost efficiency observed in the results aligns with DCT, which suggests that performance improvements often emerge over time as firms learn to optimize new capabilities.

Operations Management Theory – Foundational Theory

From an operations management perspective, business efficiency is achieved through optimized production processes, reduced variability, and improved resource utilization (Handoyo et al., 2023). Smart processing machines directly support these objectives by standardizing processing parameters and minimizing human error. This theory provides the operational foundation for linking machine capabilities to measurable efficiency outcomes.

Goat Milk Agro-Enterprises and Business Challenges

Goat milk agro-enterprises have gained increasing attention due to rising consumer demand for functional and health-oriented dairy products (Clark & Mora García, 2017). Compared to conventional dairy businesses, goat milk enterprises often operate on a smaller scale and face unique structural challenges, including limited capital, labor dependency, fluctuating raw material supply, and inconsistent production quality. These constraints frequently result in low operational efficiency and limited competitiveness, particularly in emerging market contexts where technological diffusion remains uneven.

Prior studies in agribusiness management highlight that production inefficiency is one of the main barriers to value creation in small-scale dairy enterprises (Renaldo et al., 2025). Inefficient processing methods increase unit production costs, reduce product consistency, and limit firms' ability to meet market standards. Consequently, improving processing efficiency has become a strategic priority for goat milk agro-enterprises seeking sustainable business growth.

Smart Processing Machines in Agro-Industrial Production

Smart processing machines refer to production equipment embedded with automation features, digital control systems, and real-time monitoring capabilities that enable precise management of processing parameters (Soori et al., 2023). In agro-industrial contexts, these machines are designed to optimize production processes by reducing human error, enhancing consistency, and improving resource utilization.

The adoption of smart machines has been widely studied in large-scale food manufacturing and industrial dairy processing, where automation has been shown to improve productivity and operational reliability. However, in small and medium-sized agro-enterprises, the diffusion of smart processing technology remains relatively limited. Existing literature tends to focus on technical aspects such as temperature control accuracy, processing time optimization, or hygiene compliance, while the broader business implications of machine adoption receive less empirical attention.

In the context of goat milk processing, smart machines, such as automated pasteurizers, digitally controlled fermenters, and sensor-based cooling systems, have the potential to transform traditional production methods (Nyoto et al., 2023). These technologies allow enterprises to standardize processes, reduce wastage, and minimize dependence on skilled labor, which is particularly valuable for small-scale businesses operating under resource constraints.

Business Efficiency in Agro-Enterprises

Business efficiency is commonly defined as a firm's ability to achieve optimal output with minimal input, encompassing cost efficiency, productivity, and operational effectiveness (Renaldo et al., 2022). In agro-enterprises, efficiency is closely linked to production processes, as processing activities account for a substantial proportion of total operating costs.

Previous research indicates that improvements in processing efficiency directly affect financial performance by reducing variable costs, increasing output consistency, and enhancing throughput. Efficient production systems also support better inventory management and enable firms to respond more effectively to

market demand. Despite its importance, business efficiency in small agro-enterprises is often constrained by outdated equipment, manual processes, and limited access to advanced technology.

The literature further suggests that technology adoption plays a crucial role in enhancing efficiency, particularly when technologies are aligned with firm capabilities and operational needs. However, empirical evidence on how specific production technologies—such as smart processing machines, contribute to efficiency outcomes in small-scale goat milk enterprises remains scarce.

Smart Processing Machines as Strategic Business Resources

From a strategic management perspective, production machines can be viewed as valuable organizational resources that support competitive advantage (Rahman et al., 2025). Smart processing machines, in particular, offer capabilities that extend beyond mechanical functions by enabling data-driven decision-making and process optimization.

Studies on manufacturing strategy suggest that automation and digitalization enhance operational capabilities by improving process reliability and reducing variability. In agro-enterprises, smart machines can serve as enablers of operational excellence by integrating technology with daily production activities. Nevertheless, most existing studies focus on large firms or industrial-scale operations, limiting the generalizability of findings to small goat milk enterprises.

Moreover, while prior research acknowledges the potential of smart technologies to improve performance, few studies empirically examine their impact on business efficiency as a multidimensional construct. This gap is especially evident in the goat milk sector, where technological adoption is still emerging and empirical business-oriented evaluations are limited.

Research Gap and Conceptual Positioning

Based on the reviewed literature, several gaps can be identified. First, research on goat milk agro-enterprises has predominantly focused on product quality, nutrition, and food safety, rather than on business efficiency outcomes. Second, studies on smart processing machines tend to emphasize technical performance instead of their strategic business value. Third, there is a lack of empirical evidence examining how smart processing machines influence efficiency in small-scale agro-enterprises within emerging markets.

This study addresses these gaps by integrating smart processing machine adoption with business efficiency analysis in goat milk agro-enterprises. By focusing on cost efficiency, productivity, and operational effectiveness, the study provides a comprehensive business-oriented evaluation of smart processing machines. This approach contributes to the literature by bridging technology adoption and business efficiency theories, offering new insights into how smart production technologies can enhance competitiveness and sustainability in goat milk agro-enterprises.

METHODOLOGY

Research Design

This study adopts a quantitative research design to examine the relationship between smart processing machines and business efficiency in goat milk agro-enterprises (Sekaran & Bougie, 2016). A cross-sectional approach is employed to capture firm-level data at a single point in time, allowing for empirical analysis of technology adoption and efficiency outcomes. The quantitative design is appropriate for testing hypothesized relationships and generating generalizable insights within the context of small and medium-sized agro-enterprises.

Population and Sample

The population of this study consists of goat milk agro-enterprises, primarily small and medium-sized enterprises (SMEs) engaged in milk processing activities. The sample includes enterprises that have adopted either conventional processing machines or smart processing machines, enabling comparative analysis.

A purposive sampling technique is used to select enterprises that meet the following criteria:

- Actively engaged in goat milk processing and commercialization.
- Utilized processing machines in their production activities for at least one year.
- Operated at a small or medium scale.

Data are collected from business owners or production managers, as they possess comprehensive knowledge of both operational and business performance aspects.

Variables and Measurement

Smart Processing Machines (Independent Variable)

Smart processing machines are defined as production equipment incorporating automation, digital control, and real-time monitoring features. This variable is measured using multiple indicators adapted from prior technology adoption and manufacturing innovation studies, including:

- Level of automation in processing operations
- Digital control of processing parameters (e.g., temperature, time)
- Real-time monitoring and data recording capabilities
- Machine integration with production workflows

Responses are measured using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Business Efficiency (Dependent Variable)

Business efficiency refers to the firm's ability to optimize outputs while minimizing resource inputs. This construct is measured as a multidimensional variable encompassing:

- Cost efficiency (reduction in processing and labor costs)
- Productivity (output volume relative to input usage)
- Operational effectiveness (process reliability and consistency)

Indicators are adapted from operational performance and business efficiency literature and measured using a five-point Likert scale.

Data Collection Method

Primary data are collected through a structured questionnaire administered directly to respondents. To ensure clarity and relevance, the questionnaire is pre-tested with a small group of goat milk business owners prior to full-scale data collection. Feedback from the pre-test is used to refine item wording and structure. The data collection process is conducted through on-site visits and online surveys, depending on respondent availability. Participation is voluntary, and confidentiality of responses is assured.

Data Analysis Technique

Data analysis is performed using Partial Least Squares Structural Equation Modeling (PLS-SEM), which is suitable for exploratory research and complex models involving latent constructs. PLS-SEM is particularly appropriate for SME-based studies with relatively small sample sizes and non-normal data distributions.

The analysis follows a two-step procedure:

- Measurement model evaluation, including assessment of indicator reliability, internal consistency, convergent validity, and discriminant validity.
- Structural model evaluation, including path coefficient estimation, coefficient of determination (R^2), effect size (f^2), and predictive relevance (Q^2).

Bootstrapping techniques are applied to test the statistical significance of the hypothesized relationships.

Reliability and Validity

Construct reliability is assessed using Cronbach's alpha and composite reliability values, with thresholds exceeding 0.70 indicating acceptable reliability. Convergent validity is evaluated through average variance extracted (AVE), while discriminant validity is examined using the Fornell–Larcker criterion and heterotrait–monotrait (HTMT) ratio.

Ethical Considerations

This study adheres to ethical research principles (Renaldo, Fransisca, et al., 2024). Respondents are informed about the purpose of the study and their right to withdraw at any time. All data are used solely for academic purposes, and individual business identities are kept confidential.

Methodological Contribution

Methodologically, this study contributes by empirically operationalizing smart processing machines as a business-relevant construct rather than a purely technical variable. By integrating production-level technology indicators with business efficiency outcomes, the methodology provides a replicable framework for future research (Renaldo & Murwaningsari, 2023) on smart manufacturing adoption in agro-enterprises.

RESULTS AND DISCUSSION

Descriptive Statistics

The descriptive analysis indicates that most goat milk agro-enterprises in the sample operate at a small to medium scale, with processing activities largely concentrated on pasteurized milk and derivative products. Respondents reported varying levels of technology adoption, ranging from semi-automated machines to fully smart processing machines equipped with digital control and monitoring features. Overall, the mean scores for smart processing machine indicators suggest a moderate level of adoption, indicating that smart technology integration in goat milk processing remains in an early growth stage (Renaldo & Veronica, 2024).

Business efficiency indicators show relatively higher mean values for operational effectiveness compared to cost efficiency, suggesting that enterprises perceive immediate improvements in process consistency and reliability before realizing full cost reductions.

Measurement Model Results

The measurement model evaluation confirms that all constructs meet the required reliability and validity criteria. Indicator loadings exceed the recommended threshold of 0.70, demonstrating strong indicator reliability. Composite reliability and Cronbach's alpha values are above 0.70, indicating satisfactory internal consistency.

Convergent validity is established as the average variance extracted (AVE) for each construct exceeds 0.50. Discriminant validity is confirmed using both the Fornell–Larcker criterion and the heterotrait–monotrait (HTMT) ratio, suggesting that smart processing machines and business efficiency are empirically distinct constructs.

These results validate the robustness of the measurement instruments and support subsequent structural model analysis.

Structural Model Results

The structural model analysis reveals a positive and statistically significant relationship between smart processing machines and business efficiency. The path coefficient indicates that higher levels of smart machine adoption led to improved efficiency outcomes, including cost efficiency, productivity, and operational effectiveness. The coefficient of determination (R^2) shows that smart processing machines explain a substantial proportion of variance in business efficiency, highlighting their strategic importance in goat milk agro-enterprises.

Effect size (f^2) analysis indicates a medium to large effect, suggesting that smart processing machines are a meaningful driver of efficiency rather than a marginal technological enhancement. The predictive relevance (Q^2) value further confirms the model's ability to predict business efficiency outcomes.

These findings empirically support the hypothesis that smart processing machine adoption contributes significantly to business efficiency in goat milk agro-enterprises.

Discussion

The results demonstrate that smart processing machines play a critical role in enhancing business efficiency in goat milk agro-enterprises. This finding aligns with prior research in industrial manufacturing, which emphasizes the efficiency gains derived from automation and digital control. However, this study extends existing knowledge by providing empirical evidence from small-scale agro-enterprises, a context that has received limited attention in smart manufacturing literature.

The positive impact of smart machines on operational effectiveness suggests that enterprises benefit from improved process stability, reduced human error, and greater consistency in product quality. These improvements are particularly important in goat milk processing, where temperature sensitivity and hygiene standards directly affect product safety and shelf life. From a business perspective, enhanced operational reliability strengthens customer trust and market competitiveness.

Furthermore, the observed improvement in productivity indicates that smart processing machines enable enterprises to increase output without proportionally increasing labor or resource inputs. This finding supports the view that smart machines function as strategic resources, enhancing firms' operational capabilities and contributing to competitive advantage. The results are consistent with resource-based theory, which posits that valuable and rare resources can improve firm performance.

Interestingly, cost efficiency improvements, while significant, appear to materialize more gradually compared to operational effectiveness. This suggests that the financial benefits of smart machine adoption may

be realized over time as enterprises optimize machine utilization and amortize investment costs. This insight is particularly relevant for SME decision-makers who often hesitate to adopt advanced machinery due to perceived financial risks.

Discussion of Novelty

The novelty of this study lies in its business-oriented evaluation of smart processing machines within goat milk agro-enterprises. Unlike prior studies that focus on food technology or large-scale manufacturing, this research demonstrates that smart machines generate measurable efficiency gains at the SME level. By empirically validating smart processing machines as strategic business assets, this study bridges the gap between smart manufacturing theory and agro-enterprise business practice.

CONCLUSION

Conclusion

This study examines the role of smart processing machines in enhancing business efficiency within goat milk agro-enterprises. The empirical findings demonstrate that the adoption of smart processing machines has a positive and significant impact on business efficiency, encompassing cost efficiency, productivity, and operational effectiveness. These results confirm that smart processing machines function not merely as technological tools but as strategic business resources capable of improving operational performance and competitiveness in small and medium-sized agro-enterprises.

By providing micro-level empirical evidence from goat milk businesses, this study extends the smart manufacturing and agribusiness literature, which has traditionally focused on large-scale industrial contexts. The findings highlight that even at the SME level, smart processing machines can generate measurable efficiency gains, thereby supporting sustainable business growth and value creation in the goat milk industry.

Implications

From a theoretical standpoint, this study contributes to the business and innovation literature (Zulkifli et al., 2023) by empirically linking smart processing machine adoption to business efficiency outcomes in agro-enterprises. It advances prior research by shifting the focus from technical feasibility to business value creation, thereby enriching the understanding of technology adoption at the production-machine level.

Practically, the findings provide important implications for goat milk business owners and policymakers. For business owners, the results suggest that investing in smart processing machines can enhance efficiency and competitiveness, even at a small scale. For policymakers and development agencies, the findings highlight the need to support technology diffusion through training programs, financing schemes, and technology transfer initiatives tailored to agro-based SMEs.

Limitations

Despite its contributions, this study has several limitations that should be acknowledged. First, the research adopts a cross-sectional design, which limits the ability to capture long-term efficiency improvements and learning effects associated with smart machine adoption. Second, the data rely on self-reported measures from business owners and managers, which may be subject to perceptual bias. Third, the study focuses on goat milk agro-enterprises within a specific regional context, potentially limiting the generalizability of the findings to other agro-industrial settings or geographic regions. Additionally, the study does not explicitly differentiate between types of smart processing machines, such as pasteurization, fermentation, or cooling systems, which may have varying impacts on efficiency outcomes.

Recommendations

Based on the findings, several practical recommendations can be proposed. Goat milk business owners are encouraged to view smart processing machines as long-term strategic investments rather than short-term cost burdens. Gradual adoption, starting with critical processing stages such as pasteurization or cooling, may help enterprises manage financial risks while realizing operational benefits. Policymakers and industry support institutions should facilitate technology adoption by providing targeted financial incentives, technical training, and capacity-building programs for agro-based SMEs. Collaborative initiatives involving machine manufacturers, research institutions, and farmer cooperatives can further accelerate the diffusion of smart processing technologies in the goat milk sector. Technology developers are also encouraged to design smart processing machines that are affordable, modular, and tailored to the operational scale of small agro-enterprises, ensuring practical usability and scalability.

Future Research

Future research may extend this study in several directions. Longitudinal studies are recommended to examine the dynamic effects of smart processing machine adoption on business efficiency over time. Comparative studies across different dairy sectors or agro-industrial products could further enhance the generalizability of findings. Moreover, future research could incorporate objective performance indicators, such as financial records or production data, to complement perceptual measures. Exploring moderating variables, such as firm size, managerial capability, digital culture (Junaedi et al., 2024), or access to financing, may provide deeper insights into the conditions under which smart processing machines yield optimal business outcomes. Finally, integrating sustainability and environmental performance indicators would offer a more comprehensive understanding of how smart processing machines contribute to both economic and environmental value creation in agro-enterprises (Sudarno et al., 2022).

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