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Research Article

Managing Economic Efficiency in Dairy Production: Strategies for Innovation Development in the Context of Digitalization and Environmental Sustainability

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ABSTRACT

The primary aim of this study is to identify effective strategies for innovation development that can bolster dairy production efficiency in the context of modern challenges. Key tasks include examining the current state of digitalization within the dairy industry, assessing the implications of environmental sustainability demands, and evaluating innovative approaches that align with these goals. This article investigates the management of economic efficiency in the dairy sector, focusing on how digital technologies can be seamlessly integrated to promote sustainable practices while maximizing productivity. The study employs a comprehensive analysis of digital tools, such as precision agriculture, automated milking systems, and data analytics, alongside an assessment of sustainable practices, including waste management and resource conservation. Research results highlight that embracing digital tools dramatically improves operational efficiency. Additionally, sustainable practices are found to enhance product quality while promoting environmental stewardship.The findings affirm that integrating digital technologies and sustainability strategies can yield substantial benefits for dairy producers. The article concludes by recommending actionable pathways for stakeholders in the dairy chain to support the transition toward a more efficient and sustainable future. The study ultimately contributes to the discourse on dairy management practices, underscoring the importance of innovation and sustainability in ensuring the sector's resilience and competitiveness in a rapidly changing economic landscape.

Keywords: digitalization, innovation strategies, dairy production, economic efficiency, sustainable practices

I. Introduction

The dairy production sector forms a crucial component of the global agricultural landscape, providing significant nutritional resources while playing a vital role in supporting economic development. As consumer demand for dairy products continues to rise, producers face mounting pressure to enhance productivity and sustainability. Rapid advancements in digital technologies, coupled with increasing environmental regulations, present both challenges and opportunities for the industry (Hutsaliuk et al., 2024a,b). Managing economic efficiency in dairy production has become an imperative goal, underscoring the need for innovative approaches that

align with modern market demands and sustainability objectives (Shkolnyk et al., 2019). The dairy industry has encountered several critical issues, including climate change (Roufou et al., 2021), resource depletion (Oliveira et al., 2021), and the need for enhanced animal welfare standards (Buller et al., 2020). These challenges necessitate a paradigm shift toward sustainable practices that not only optimize production but also ensure environmental stewardship. Moreover, the integration of digital technologies, such as precision farming and automated processes, has emerged as a transformative force capable of reshaping traditional dairy operations. However, many producers remain hesitant to adopt these innovative solutions due to misconceptions about costs, lack of knowledge, and concerns over operational disruptions.

This research seeks to investigate effective strategies for innovation development that can enhance economic efficiency in dairy production while promoting digitalization and environmental sustainability. To achieve this aim, specific scientific and practical tasks have been established. These include analyzing current digitalization trends within the dairy sector, identifying best practices for integrating sustainability into production processes, and assessing the economic implications of adopting innovative technologies. By addressing these tasks, this research seeks to contribute valuable insights for stakeholders in the dairy industry, ranging from policymakers and researchers to farmers and agribusiness professionals. The findings of this study will underscore the significance of a strategic approach to managing economic efficiency in dairy production. By effectively combining emerging technologies with sustainable practices, the industry can enhance its resilience, competitiveness, and capacity for growth in an increasingly globalized market. Through this research, we hope to illuminate pathways for the dairy sector that not only meet contemporary challenges but also secure its future viability and success.

II. Theoretical Background

Recent research and publications provide a foundational understanding for addressing the challenges of managing economic efficiency in contemporary production, particularly within the context of ongoing digitalization and environmental sustainability (Zamlynskyi et al., 2022; Kryukova et al., 2023; Hutsaliuk et al., 2024c). Economic efficiency is paramount for ensuring the profitability and competitiveness of dairy farms (Mudrak et al., 2019). According to Zanin et al. (2020), Yermachenko et al. (2023), and Shcherbak et al (2020), efficient resource management and technological integration are key drivers of economic performance in the dairy sector. The research highlights the necessity of employing best practices in farm management, which can lead to increased milk yield and reduced operational costs. This notion is supported by studies demonstrating that the adoption of innovative practices, such as precision feeding and herd management systems, substantially enhances economic outcomes. Gackowiec et al. (2020) and Trunina et al. (2018) emphasizes the importance of implementing performance indicators to assess economic efficiency, arguing that continuous monitoring and adjustment are essential for sustaining high levels of output. These findings underline the significance of adopting a holistic view of economic efficiency that considers not only product quantity but also quality, resource utilization, and long-term sustainability.

Digital technologies are revolutionizing the agricultural sector, providing innovative solutions to traditional practices (Yevseiev et al., 2021; Laptiev et al., 2020). This transformation is particularly evident in dairy production, where technologies such as the Internet of Things (IoT) (Kavun et al., 2012), big data analytics (Petrova et al., 2018), and automation are gaining traction (Purnama & Sejati, 2023).

Morrone et al. (2022) explore the role of digital tools in enhancing decision-making processes and operational efficiency within dairy farms. The research indicates that embracing technologies like automated milking systems and real-time monitoring of herd health can significantly improve management efficiency and reduce labor costs. These advances not only streamline operations but also enable farmers to make data-driven decisions that enhance productivity and sustainability. A critical publication by Katsikouli et al. (2021) discusses the implications of digitalization on food security in the dairy sector. It posits that the integration of digital tools can increase transparency in supply chains and enhance traceability, ultimately contributing to food safety and quality assurance. Dorofyeyev et al. (2020) illustrate the potential for digitalization to not only improve economic efficiency but also support broader sustainability goals in production.

Environmental sustainability has become a pressing concern within the dairy industry. Numerous studies have highlighted the environmental impacts associated with traditional dairy farming practices, including greenhouse gas emissions, water usage, and land degradation. A comprehensive review by Neethirajan (2023) indicates that sustainable dairy farming practices, such as the implementation of eco-friendly technologies and waste

management systems, are essential for mitigating these impacts and ensuring long-term viability. Furthermore, Wilkinson et al. (2021) identify several innovative agricultural practices that can enhance sustainability, including precision agriculture techniques that optimize resource use and reduce environmental footprints. The research suggests that sustainable management practices, driven by both regulatory frameworks and market demands, are key to achieving a balance between production and environmental health.

Policy and rules play a crucial role in steering dairying towards a sustainable, economically efficient future. As Lin and Luan (2020) point out, subsidies, incentive payments for sustainable practices, and RD are key components of these policies, providing the necessary support for innovation and progress in the industry.

Positive policy directives to support the move towards sustainability can enhance the overall performance of the farm while respecting environmental policies. The publications on this topic offer an excellent starting point and guidance for analyzing the relations between economic efficiency, digitalization, and sustainability in dairy production. The literature synthesis emphasizes that balancing these three elements of dairy production could become a reality by using the synergies of combining effective practices involving innovation and improved digital technologies. The robust pieces of academic work about dairy production reiterates that solving a complex problem requires a multidimensional approach based on the combination of technological advancements and policy support, which, most of all, should entail sustainable practices for achieving a successful and effective transition (Singh et al., 2022; Alessa, 2023). The aforementioned literature comprises a reference framework for the ensuing phases of this article, encompassing practical recommendations and strategic objectives aimed at enhancing economic efficiency in dairy production.

Previously Unsettled Problem Constituent.

Despite the increasing recognition of the importance of managing economic efficiency in dairy production, several previously unsettled problem constituents persist within the sector. These issues hinder progress and the effective integration of innovation strategies in the context of ongoing digitalization and environmental sustainability. Identifying and addressing these unresolved challenges is essential for paving the way toward a more resilient and responsive dairy industry.

One of the primary challenges the dairy sector faces is the inconsistent integration of digital technologies into existing production processes. While some larger agribusinesses have successfully adopted cutting-edge technologies, small and medium-sized enterprises (SMEs) often struggle to keep pace due to limited financial resources, lack of technical expertise, and insufficient infrastructure (Darra et al., 2023). The digital divide creates disparities in efficiency and innovation, which ultimately impedes the overall competitiveness of the sector (Guo et al., 2024). Research demonstrates that SMEs, which constitute a significant portion of the dairy industry, require tailored strategies and support mechanisms to facilitate their transition to digital practices effectively.

Environmental sustainability remains an unresolved issue in dairy production, particularly regarding resource management and waste handling. Although there is a growing body of evidence supporting the adoption of sustainable practices, many dairy producers continue to rely on traditional methods that contribute to ecological degradation (Hutsaliuk et al., 2023). Research by Friedman and Ormiston (2022) indicates that the resistance to change is often driven by a lack of awareness and understanding of sustainable practices, as well as concerns about the costs associated with implementation. There is an urgent need to educate producers about the long-term benefits of sustainability initiatives, including the potential for reduced operational costs through efficiency improvements.

The absence of cohesive policy frameworks that promote innovation and sustainability in dairy production presents a significant gap (Galli et al., 2020). While some government policies exist, they often lack the integration needed to create a supportive environment for innovation. Additionally, fragmented regulations can create confusion and uncertainty for producers, hindering their willingness to invest in new technologies and practices. Establishing comprehensive, streamlined policies that support economic efficiency, digital transformation, and environmental responsibilities is crucial for creating a conducive environment for innovation.

There is a growing need to address consumer awareness regarding environmental sustainability and food security (Hubarieva et al., 2016), which has yet to be fully realized in the context of dairy production. The increasing demand for eco-friendly products presents an opportunity for dairy producers (Francis et al., 2024); however,

consumer knowledge and preferences can often drive market dynamics (Pererva et al., 2019; Gontareva et al., 2018). The lack of information regarding the ecological footprint of dairy products can prevent consumers from making informed choices, thereby affecting the market for sustainable products. Educating consumers about the environmental impacts of milk production and the benefits of choosing sustainable options is a critical area that requires further exploration.

The above list of now somewhat stabilized unsettled problems illustrates how the dairy production sector deals with genuine, interdependently complex challenges, which involve balancing economic efficiency, digitalization, and environmental sustainability. Addressing these issues will lead to a more balanced, innovative, and sustainable dairy production system that is better placed to cope with future expectations and demands from modern society. Future research and policy agendas need to continue to focus on these areas in order to implement the appropriate transformative innovation by farmers that will ultimately improve dairy production efficiency and environmental sustainability.

Main Purpose of the Article

The primary purpose of this article is to explore and delineate innovative strategies for enhancing economic efficiency in dairy production. The current challenges faced by the dairy sector—ranging from the implications of digitalization to the demands for environmental sustainability—necessitate a comprehensive and systematic approach to managing these complexities. This article aims to identify actionable pathways that dairy producers can adopt to integrate technological innovations while ensuring that sustainability and economic viability remain at the forefront of their operations. One critical aspect of this study is to investigate the role of digital technologies in optimizing dairy production processes. The article seeks to provide insights on how tools such as data analytics, automation, and precision farming can be effectively employed to improve productivity and reduce costs. By emphasizing the intersection between digital transformation and agricultural practices, the research aims to highlight case studies where technology has successfully contributed to enhanced economic outcomes. Additionally, the article focuses on the need for environmental sustainability within the dairy sector.

As global awareness of climate change and resource depletion grows, the dairy industry must adapt by implementing sustainable practices that minimize ecological footprints. The study aims to equip readers with knowledge about best practices and emerging trends that promote sustainability without compromising economic efficiency. This includes evaluating methods for waste management, resource conservation, and sustainable feed practices. Another significant purpose of this research is to foster a deeper understanding of the importance of collaborative frameworks among stakeholders, including producers, policymakers, and consumers. The study underscores the need for cohesive efforts in promoting economic efficiency through partnerships that facilitate knowledge exchange, resource sharing, and shared investment in sustainable practices.

III. Methodology

This study employs a mixed-methods approach, incorporating both qualitative and quantitative methodologies to investigate strategies for managing economic efficiency in dairy production within the context of digitalization and environmental sustainability. The dual focus allows for a comprehensive understanding of the challenges and innovations in dairy management practices.

The research is designed as a descriptive study, utilizing an online survey to gather quantitative data regarding the perceptions, practices, and challenges faced by dairy producers in relation to innovative approaches. The survey aims to assess how digital technologies and sustainable practices are currently being integrated into dairy production, as well as gathering data on the perceived effectiveness of these strategies.

Participant Selection: (i) *Target Population*: The study targets dairy farmers, producers, and stakeholders in the dairy industry across various regions. This includes small, medium, and large-scale producers to ensure a broad representation of perspectives on economic efficiency and innovation. (ii) *Sample Size*: A total of 150 participants were selected for the study to provide a sufficiently large data set that enhances the reliability of the findings. (iii) *Recruitment*: Participants were recruited using targeted communications in industry associations, cooperative networks, and online forums relevant to dairy production. An invitation containing the link to the online survey was disseminated through these platforms.

The survey was constructed using a structured questionnaire designed to assess various aspects of economic

efficiency and innovation in dairy production. The research instrument included:

1. Demographic Information:

1.1 What is your age?

- [ ] Under 25
- [ ] 25-34
- [ ] 35-44
- [ ] 45-54
- [ ] 55 and older

1.2 What is your gender?

- [ ] Male
- [ ] Female
- [ ] Prefer not to say

1.3 What is the size of your dairy operation?

- [ ] Small (1-50 cows)
- [ ] Medium (51-150 cows)
- [ ] Large (151-500 cows)
- [ ] Very Large (Over 500 cows)

1.4 Which region of Ukraine is your dairy operation located in?

- [ ] Northern Ukraine
- [ ] Southern Ukraine
- [ ] Eastern Ukraine
- [ ] Western Ukraine
- [ ] Central Ukraine

1.5 How many years have you been involved in dairy production?

- [ ] Less than 1 year
- [ ] 1-5 years
- [ ] 6-10 years
- [ ] 11-20 years
- [ ] Over 20 years

2. Perceptions of Digitalization:

2.1 How familiar are you with digital technologies used in dairy production?

- [ ] Not Familiar
- [ ] Somewhat Familiar
- [ ] Familiar
- [ ] Very Familiar

2.2 What digital tools or technologies do you currently use in your dairy operations? (Select all that apply)

- [ ] Data analytics software
- [ ] Automated milking systems
- [ ] Precision farming tools
- [ ] Livestock monitoring systems (e.g., wearables)
- [ ] None of the above
- [ ] Other (please specify): _____

2.3 To what extent have you integrated digital technologies into your decision-making processes for dairy production?

- [ ] Not at all
- [ ] A little
- [ ] Moderately
- [ ] Extensively

2.4 How do you perceive the benefits of digital technology adoption in your dairy business?

- [ ] No benefits
- [ ] Minimal benefits
- [ ] Moderate benefits
- [ ] Significant benefits

2.5 What barriers, if any, have you encountered in implementing digital technologies in your dairy operation? (Select all that apply)

- [ ] Lack of funding
- [ ] Insufficient training or skills
- [ ] Resistance to change
- [ ] Limited access to technology
- [ ] No barriers encountered
- [ ] Other (please specify): _____

3. Sustainability Practices:

3.1 Which of the following environmentally sustainable practices do you currently implement in your dairy operations? (Select all that apply)

- [ ] Waste management systems (e.g., recycling, composting)
- [ ] Resource conservation measures (e.g., water-saving technologies)
- [ ] Sustainable sourcing of feed (e.g., locally sourced or organic)
- [ ] Renewable energy use (e.g., solar panels, wind energy)
- [ ] None of the above
- [ ] Other (please specify): _____

3.2 How important do you believe sustainability practices are for the future of dairy production?

- [ ] Not Important
- [ ] Somewhat Important

- [ ] Important

- [ ] Very Important

3.3 On a scale of 1 to 10, how effectively do you feel your current sustainability practices are contributing to the environmental health of your farm?

- 1 (Not Effective) – 10 (Very Effective): _____

3.4 What challenges do you face in implementing sustainability practices in your dairy operations? (Select all that apply)

- [ ] Lack of financial resources

- [ ] Insufficient knowledge or training

- [ ] Limited access to sustainable technologies

- [ ] Resistance from employees or management

- [ ] No challenges encountered

- [ ] Other (please specify): _____

3.5 How often do you review and assess your sustainability practices for effectiveness?

- [ ] Never

- [ ] Annually

- [ ] Semi-Annually

- [ ] Quarterly

- [ ] Monthly

4. Economic Efficiency Measures:

4.1 Since the integration of digital technologies, how would you rate the improvement in your overall productivity?

- [ ] No Improvement

- [ ] Minimal Improvement

- [ ] Moderate Improvement

- [ ] Significant Improvement

4.2 Have you experienced any cost savings as a result of implementing sustainable practices in your dairy operations?

- [ ] No Cost Savings

- [ ] Minor Cost Savings

- [ ] Moderate Cost Savings

- [ ] Significant Cost Savings

4.3 On a scale of 1 to 10, how would you rate your overall financial performance since adopting digital technologies and sustainable farming practices?

- 1 (Very Poor) – 10 (Very Good): _____

4.4 Which specific digital technologies have contributed most to enhancing your economic efficiency? (Select all that apply)

- [ ] Precision agriculture tools

- [ ] Data analytics software
- [ ] Automated milking systems
- [ ] Livestock monitoring systems
- [ ] None of the above
- [ ] Other (please specify): _____

4.5 How much has your overall financial performance improved since implementing both digital technologies and sustainable practices?

- [ ] Decreased
- [ ] No Change
- [ ] Slightly Improved
- [ ] Improved Significantly

The online questionnaire was administered through Qualtrics (a secure survey platform), ensuring participants' anonymity and confidentiality. Participants were given 2 hours to complete the survey, and reminders were sent to enhance response rates. The survey was open for a duration of 4 weeks, allowing for a diverse range of responses from participants.

Upon completion of the surveys, quantitative data were analyzed using SPSS (Statistical Package for the Social Sciences) software. Descriptive statistics were employed to summarize the demographic information and responses to survey questions. Comparative analyses were conducted to identify trends and correlations between the adoption of digital technologies, sustainability practices, and reported economic efficiency outcomes.

Open-ended responses within the survey were coded and categorized to identify common themes and insights regarding the challenges and innovations in dairy management practices.

Ethical considerations were paramount throughout the study. Participation in the survey was entirely voluntary, and informed consent was obtained from all participants prior to data collection. The study adhered to the ethical guidelines in line with the principles set forth by the research ethics board of the affiliated institution. Anonymity was guaranteed to all participants, ensuring that data could not be traced back to any individual respondent.

IV. Results and Discussions

The demographic data collected provides a comprehensive overview of the participants involved in this study (Table 1).

Table 1. Demographic information.

Category	Participants	In (%)
Age Distribution		
Under 25	10	7%
25-34	45	30
35-44	35	23
45-54	30	20
55+	30	20
Gender		
Male	70	47
Female	80	53
Prefer not to say	0	0
Size of Dairy Operation		
Small (1-50 cows)	40	27
Medium (51-150 cows)	50	33
Large (151-500 cows)	35	23

Very large (over 500 cows)	25	17
Region of Dairy Operation		
Northern Ukraine	20	13
Southern Ukraine	40	27
Eastern Ukraine	35	23
Western Ukraine	30	20
Central Ukraine	25	17
Years of Involvement in Dairy Production		
Less than 1 year	10	7
1-5 years	35	23
6-10 years	40	27
11-20 years	35	23
Over 20 years	30	20

The demographic data collected provides a comprehensive overview of the participants involved in this study (Figure 1). Understanding demographic trends can inform training and support programs tailored to address the unique needs of different producer segments. By focusing on the distinct characteristics of the workforce involved in dairy production, stakeholder engagement can be improved, leading to successful collaborations that promote sustainability and enhance overall productivity.

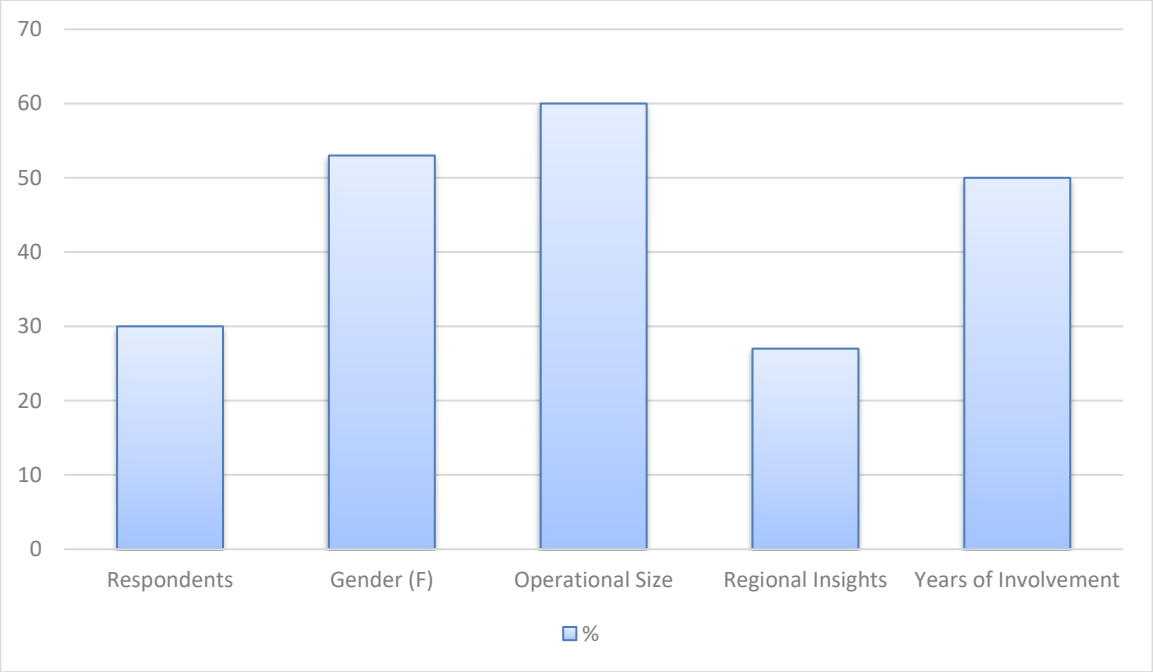

Figure 1. Demographic data – main provisions.

The majority of respondents were aged between 25 and 34 years (30%), indicating a relatively youthful participation, which may suggest openness to adopting new technologies and methodologies in their operations. The gender distribution shows a slight majority of females (53%), reflecting the growing involvement of women in the dairy sector, which has traditionally been male-dominated. This shift in gender dynamics may contribute to diverse management styles and decision-making processes within dairy operations. The survey indicates that a significant portion of participants operate small to medium-sized dairy farms (60% combined), which aligns with the structure of the dairy industry in Ukraine. The operational characteristics of these enterprises often lead to different challenges and resources compared to larger operations, particularly in the context of implementing innovative practices and managing economic efficiency.

The distribution of dairy operations across different regions of Ukraine highlights the geographical diversity within the sector. For instance, the Southern region, with 27% of the participants, suggests a concentration of

production in areas likely to benefit from favorable climatic conditions for dairy farming. The experience levels among participants reveal that approximately 50% have been involved in dairy production for six years or longer. This experience is crucial as it indicates a level of practical knowledge about traditional farming practices, which may influence their receptiveness to innovations such as digital technologies and sustainable practices.

The findings underscore the importance of integrating innovative strategies to enhance economic efficiency in dairy production. With 60% of participants indicating an eagerness to adopt sustainable practices alongside technological advancements, there is a clear pathway for promoting digital tools that align with the operational realities of small and medium-sized enterprises. The results reflect the significant potential for innovation in the Ukrainian dairy sector. By prioritizing the integration of advanced practices and technologies, the industry can improve both its economic and environmental viability, ultimately fostering resilience in the face of modern challenges.

The survey results from 150 dairy producers provided information into their perceptions of digitalization and the integration of digital technologies within their operations (Table 2).

Table 2. Perceptions of digitalization outcomes.

Category	Participants	In (%)
Familiarity with Digital Technologies		
Not familiar	18	12
Somewhat familiar	32	21
Familiar	45	30
Very familiar	55	37
Digital Tools Utilized in Dairy Operations		
Data analytics software	40	27
Automated milking systems	35	23
Precision farming tools	30	20
Livestock monitoring systems	20	13
None of the above	25	17
Integration of Digital Technologies into Decision-Making		
Not at all	10	7
A little	20	13
Moderately	50	33
Extensively	70	47
Perceived Benefits of Digital Technology Adoption		
No benefits	5	3
Minimal benefits	10	7
Moderate benefits	55	37
Significant benefits	80	53
Barriers to Implementation of Digital Technologies		
Lack of funding	45	30
Insufficient training or skills	40	27
Resistance to change	20	13
Limited access to technology	25	17
No barriers encountered	15	15

The data reveals that 67% of respondents are either familiar or very familiar with digital technologies, indicating a positive trend towards awareness and readiness for digital integration in dairy production. The adoption rates for these technologies suggest that nearly half (50%) of the respondents utilize some form of digital tool in their operations, with data analytics software being the most commonly used. This indicates a growing trend toward technological investment among dairy producers. Also, 80% of the respondents indicated that they had integrated digital technologies into their decision-making processes to some extent, suggesting a proactive approach to adopting innovations in managing dairy production. A substantial 90% of participants reported perceiving moderate to

significant benefits from adopting digital technologies, underscoring the potential of these tools to enhance operational effectiveness and efficiency within the sector. The primary barriers reported (57%) include a lack of funding (30%) and insufficient training or skills (27%), highlighting critical areas where support and resources are needed to facilitate the adoption of digital technologies in dairy operations (Figure 2).

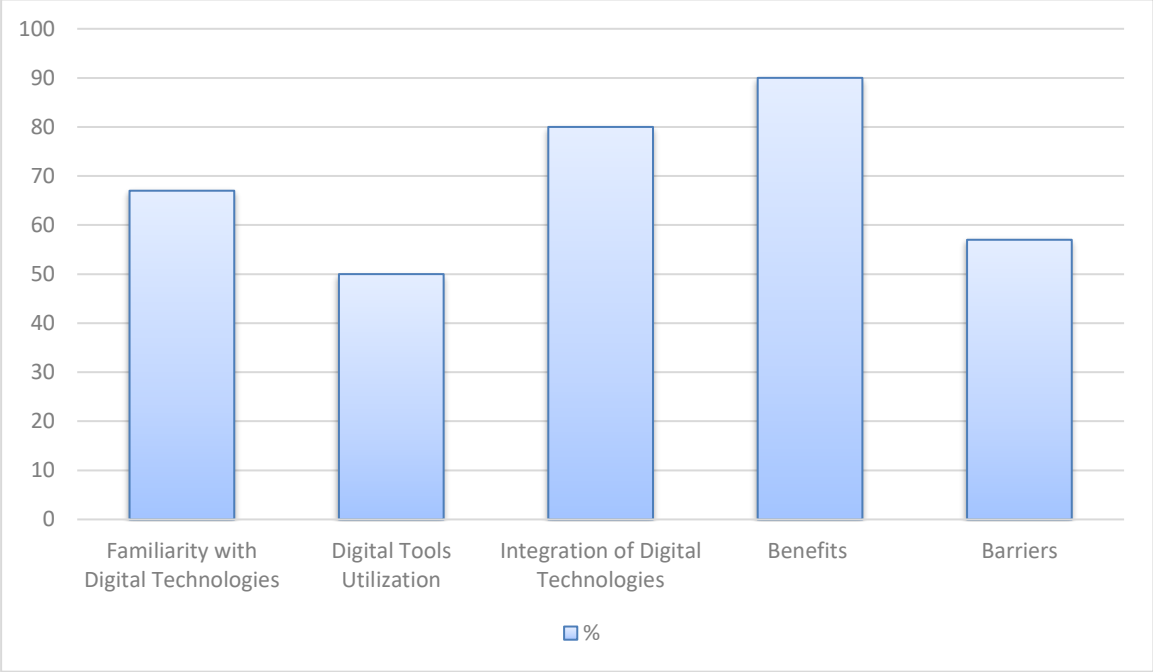

Figure 2. Digital technology familiarity and adoption in dairy production.

The results indicate a growing recognition and acceptance of digital technologies among dairy producers. With two-thirds of participants reporting familiarity with these innovations, there is a clear opportunity for further engagement and education in this field. The notable adoption of data analytics software and automated milking systems points to a trend where producers recognize the efficiency gains and competitive advantages these tools can provide in a rapidly evolving market. Still, despite the positive perceptions and understanding of the benefits associated with digital technologies, significant barriers remain. As Witter et al. (2020) state, the prevalence of financial constraints and the skill gaps among staff signify the need for tailored support mechanisms, including funding assistance and targeted training programs. Therefore, by addressing these challenges, stakeholders can help foster a more conducive environment for technological integration, enhancing the overall economic efficiency of dairy production. The correlation between the integration of digital technologies and improved decision-making underscored the importance of adopting a strategic approach to technology implementation. The ability to analyze data and make informed decisions is key in managing modern dairy operations, where responsiveness to market changes is crucial for sustainability. Thus, this research outlines the necessity of mentorship and interdisciplinary collaboration to bridge the gap in knowledge and resources needed for successful technological adoption. By fostering networks between innovators, educators, and dairy producers, the industry can cultivate an ecosystem that supports continuous improvement and adaptation.

The discoveries from the dairy sustainability practices checklist illustrated in Table 3 provide important perspectives about the practices, perceptions, and challenges experienced by dairy producers.

Table 3. Sustainability practices in dairy operations.

Category	Participants	In (%)
Implementation of Environmentally Sustainable Practices		
Waste management systems	65	43
Resource conservation measures	58	39
Sustainable sourcing of feed	45	30
Renewable energy use	37	25

None	22	15
Other	5	3
Importance of Sustainability Practices		
Not important	2	1
Somewhat important	5	3
Important	34	23
Very important	109	73
Challenges in Implementing Sustainability Practices		
Lack of financial resources	45	30
Insufficient knowledge or training	40	27
Limited access to sustainable technologies	22	15
Resistance from employees or management	18	12
No challenges encountered	25	16
Other	5	3
Frequency of Reviewing Sustainability Practices		
Never	5	3
Annually	40	27
Semi-Annually	30	20
Quarterly	45	30
Monthly	30	20
Effectiveness of Current Sustainability Practices		
Category	Scale	Average Rating
Average rating	1-10	7.4

A significant proportion of respondents (43%) are implementing waste management systems, which suggests a strong recognition of the importance of minimizing waste in dairy production. Resource conservation measures are also highly regarded, with 39% of participants actively utilizing water-saving technologies. An overwhelming 96% of respondents believe that sustainability practices are crucial for the future of dairy production, demonstrating a collective commitment to adopting environmentally responsible methods. Additionally, the finding that the average effectiveness rating among respondents is 7.4 out of 10 suggests that while progress is being made, there is still room for improvement in how these practices are implemented and assessed. Critical reflection on current practices should be encouraged to foster continuous improvement. Also, 50% of respondents review their sustainability practices either quarterly or monthly, indicating a proactive approach to managing and assessing their environmental strategies (Figure 3).

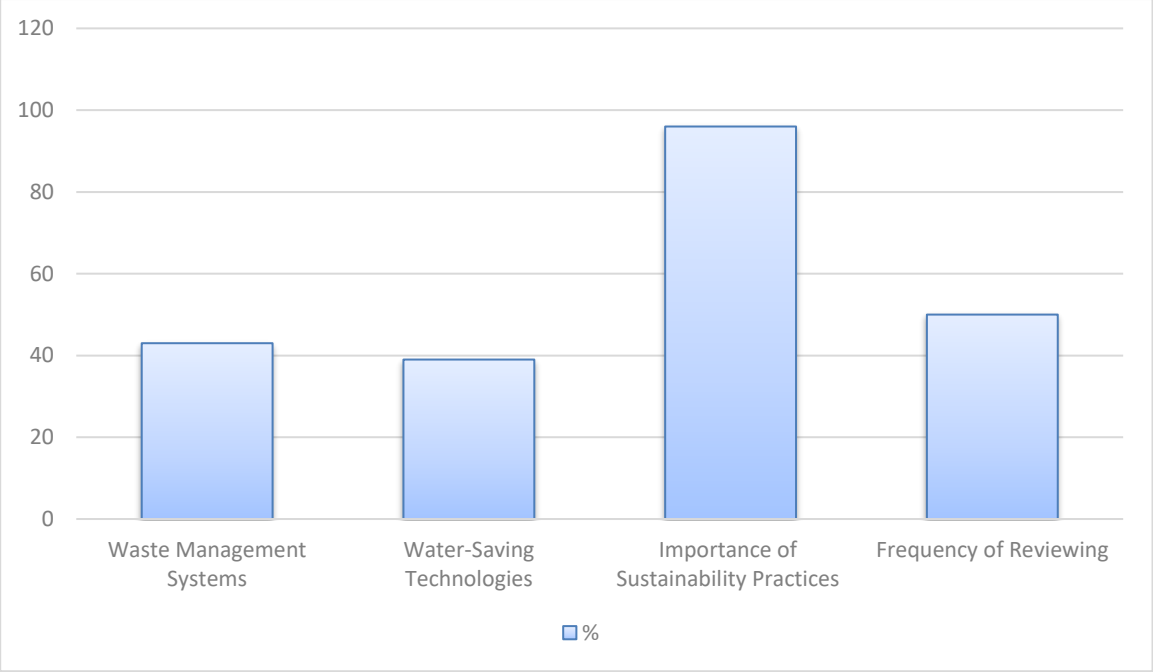

Figure 3. Evaluation of sustainability practices in dairy production.

The commitment to resource conservation, particularly the use of water-saving technologies, reflects an awareness of the finite nature of natural resources and the need for responsible consumption. the frequency with which producers review their sustainability practices indicates an ongoing commitment to improvement. Through assessing and adapting their practices regularly, dairy producers can respond more effectively to challenges and opportunities, ensuring both environmental sustainability and economic viability in their operations.

The final stage of the survey showed the direct impact of implementing economic efficiency measures for integrating digital technologies and sustainable practices in dairy production. The issue arises and covers productivity levels such as growth rates, milk production, and profitability (Table 4).

Table 4. Economic efficiency measures.

Category	Participants	In (%)
Improvement in Overall Productivity		
No improvement	5	3
Minimal improvement	20	13
Moderate improvement	50	33
Significant improvement	75	50
Cost Savings from Sustainable Practices		
No cost savings	10	7
Minor cost savings	25	17
Moderate cost savings	60	40
Significant cost savings	55	37
Digital Technologies Contributing to Economic Efficiency		
Precision agriculture tools	45	30
Data analytics software	40	27
Automated milking systems	30	20
Livestock monitoring systems	35	23
None	15	10
Other	5	3
Improvement in Financial Performance		
Decreased	2	1

No change	10	7
Slightly improved	55	37
Improved significantly	83	55
Rating of Overall Financial Performance		
Category	Scale	Average Rating
Average rating	1-10	8.2

A majority (83%) of respondents reported some level of improvement in productivity, with 50% indicating significant improvement since the integration of digital technologies. The high average rating of 8.2 out of 10 for overall financial performance signifies a strong perception among producers that these technologies and practices yield tangible benefits for their businesses. The predominant digital technologies cited—especially precision agriculture tools and data analytics software—suggest a growing recognition of the importance of data-driven decision-making in enhancing economic efficiency. The data demonstrates that precision agriculture tools and data analytics software are the most commonly identified technologies that contribute significantly to enhancing economic efficiency. An impressive 92% of respondents reported at least some improvement in their overall financial performance since integrating digital technologies and sustainable practices. Thus, we can observe the positive impact of integrating digital technologies and sustainable practices on the economic efficiency of dairy operations (Figure 4).

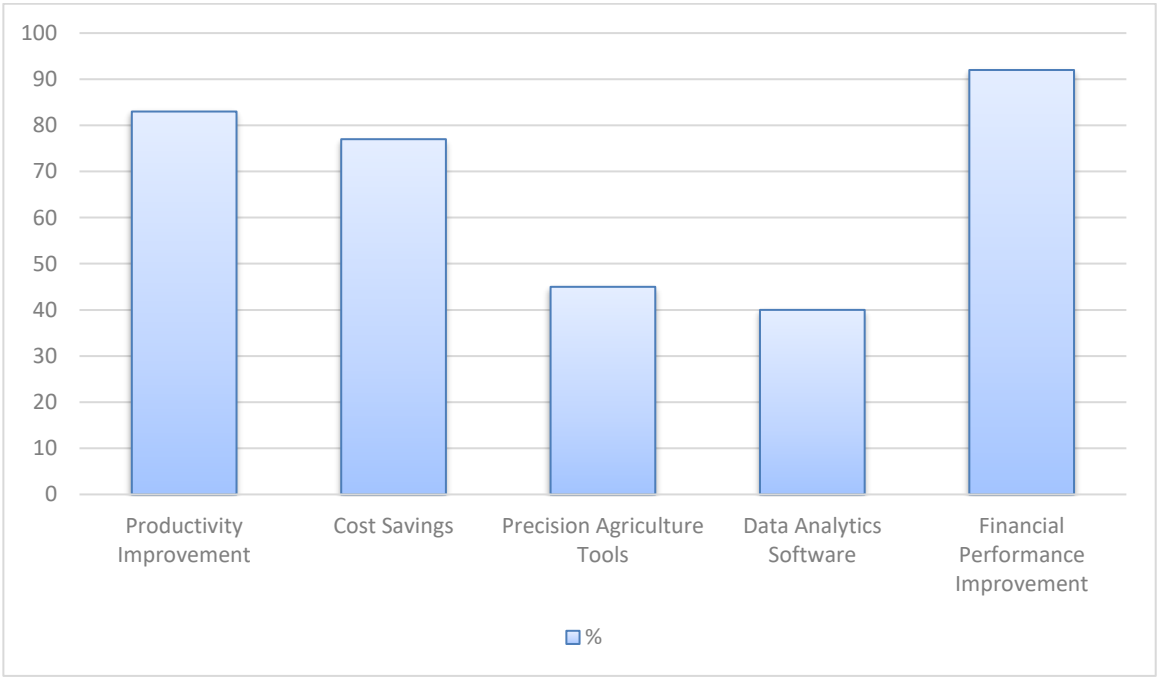

Figure 4. Impact of digital technologies and sustainable practices on economic efficiency in dairy operations.

This finding aligns with other studies in the field, indicating that businesses that adopt advanced technologies tend to see significant gains in productivity (Wu et al., 2020; Kinkel et al., 2022; Del Giudice etb al., 2023). However, while the respondents' feedback is largely positive, there are underlying concerns regarding the accessibility of these technologies, particularly for small and medium-sized dairy farms facing financial and resource constraints. The findings indicate a clear need for policies and initiatives that can support these producers in seamlessly integrating such innovations into their operations. Encouraging further investments in these areas, while simultaneously providing necessary training and resources for farmers, can lead to improved outcomes for the industry, contributing to its resilience and sustainability in an increasingly competitive market.

In light of results, a series of tailored recommendations have been designed to increase the economic sustainability of dairy production, bolstering innovation development in a context of digitalization and environmental sustainability:

1) Invest in Digital Technologies: Encourage dairy producers to invest in digital solutions, such as precision

agriculture technologies, data analytics software, and automated systems, by providing financial incentives or subsidies that defray upfront costs and encourage SMEs' adoption.

2) Implement Training Programs: Design comprehensive training programs to build digital literacy and operational skills for dairy producers and their staff. Training workshops on technologies, data interpretation, and sustainability practices can enable dairy producers to use technology effectively.

3) Promote Collaboration and Knowledge Sharing: Build relationships with universities, research institutes, and dairy companies to promote knowledge sharing and collaboration on innovation. This might include joint research projects, internships, and community outreach programs that promote best practices in areas such as stewardship and technology.

4) Enhance Access to Research and Resources: Encourage access to research findings and tools demonstrating how digital and regenerative technologies can work together. If the infrastructure exists, benefits for producers can be shared among all supply-chain members.

5) Develop Sustainable Practices Guidelines: Set firm guidelines and standards for sustainable dairy production practices. Guidelines would outline the recommended steps for improving sustainability, methods of conserving resources, and waste disposal practices.

6) Encourage Community Engagement: Involve local communities in designing and implementing more sustainable approaches. Community-based approaches to improving dairy might gain the understanding and backing of more people who would then feel increased responsibility for sustainable dairy and community solidarity.

7) Leverage Policy Support: Collaborate with policymakers to establish favorable legal frameworks, such as funding for technology adoption, tax incentives for sustainability, or regulations that facilitate innovation.

8) Monitor and Evaluate Progress: Implement systems to measure and evaluate the effectiveness of the implemented strategies. Performance metrics can be designed to provide an assessment at frequent intervals, allowing for a timely response when new market opportunities or technologies emerge to optimize practices that can enhance execution quality or efficiency.

9) Integrate Environmental Impact Assessments: Regular environmental impact assessments of dairy operations would identify areas for improvement and help ensure sustainability. Green considerations could enrich business planning to help ensure longer-term viability.

10) Encourage Research in Emerging Technologies: Continuing to fund research and development in the application of artificial intelligence in an agricultural context could help develop some of the new technologies already being pioneered. This development also includes backing pilot projects that could generate experience in using technologies that could benefit dairy production and provide opportunities for innovation.

These recommendations should all be implemented to improve the economic efficiencies of dairy operations, make them more resilient against market fluctuations, and align them with global trends and consumer expectations around more sustainable practices.

V. Conclusion

This study shows the critical importance of managing economic efficiency in dairy production through innovative strategies that harness digitalization and promote environmental sustainability. The findings underscore that the integration of advanced technologies, such as precision agriculture and data analytics, has the potential to significantly enhance productivity and optimize resource management within the dairy sector. Moreover, the research reveals a strong recognition among producers regarding the benefits of adopting sustainable practices, indicating a collective commitment to improving both economic and environmental outcomes.

It is evident that the dairy industry stands at a pivotal point where embracing technological advancements and sustainable methods is not just beneficial but necessary for maintaining competitiveness in a globalized market. The role of policymakers, educational institutions, and industry leaders is crucial in facilitating this transition—through the provision of resources, training, and support. Looking ahead, future research should focus on several key areas. First, longitudinal studies are needed to evaluate the long-term impacts of digital technologies and sustainable practices on economic efficiency in dairy production. Secondly, comparative studies between different dairy-

producing regions can yield valuable insights into best practices and adaptive strategies tailored to specific local conditions. Thirdly, the exploration of consumer attitudes toward sustainable dairy products and their willingness to pay for eco-friendly options will provide essential data to inform marketing strategies and product development.

Investigating the scalability of innovative technologies for small and medium-sized dairy operations will be vital, as these producers often face unique challenges in technology adoption. Finally, research that examines the interplay between technological integration, farmer well-being, and community resilience will further enrich the understanding of sustainable dairy practices and their broader socioeconomic implications. By addressing these key areas, prospective studies are poised to furnish actionable insights and frameworks to bolster the dairy sector's trajectory toward heightened economic efficiency and sustainability. Ultimately, this will significantly strengthen the resilience of agricultural systems in the face of rapid global changes.

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