STM JOURNALS

Research & Reviews: Journal of
Veterinary Science and Technology

ISSN: 2319-3441 (Online)
ISSN: 2349-3690 (Print)
Volume 14, Issue 2, 2025
May–August
DOI (Journal): 10.37591/RRJoVST

https://journals.stmjournals.com/rrjovst

Research RRJoVST

Balancing Welfare-Productivity Trade-Offs: Logical Frameworks and Strategic Approaches for Sustainable Dairy Development

Md. Emran Hossain[1,*], Shilpi Islam[2]

Abstract

Balancing animal welfare and productivity remains a critical challenge in modern dairy farming. This study explores diverse frameworks for evaluating the welfare-productivity trade-offs essential for achieving sustainable dairy systems. Key approaches are categorized into six thematic areas: animal-centric frameworks, management-oriented models, environmental assessments, economic and policy perspectives, technological innovations, and holistic methodologies. Each framework offers unique metrics and evaluation tools, including behavioral assessments, physiological indicators, precision livestock farming, cost-benefit analyses, and lifecycle approaches. The integration of these frameworks provides a multi-dimensional understanding of how management practices, environmental factors, and technological advancements influence both welfare and productivity. By bridging knowledge gaps and fostering interdisciplinary collaboration, this study highlights the need for adaptive, region-specific solutions that prioritize animal well-being without compromising economic and environmental sustainability. The findings aim to guide policymakers, researchers, and stakeholders in designing dairy systems that harmonize welfare, productivity, and sustainability goals for sustainable dairy development.

Keywords: Animal welfare, dairy farming, economic viability, genetic selection, health, housing systems, precision farming, productivity trade-offs, sustainability metrics

INTRODUCTION

The increasing demand for dairy products has placed significant pressure on modern dairy systems to maximize productivity. This intensification has often come at the expense of animal welfare, creating a challenging welfare-productivity dilemma. While high milk yields remain a primary goal for dairy producers, evidence suggests that intensive management practices can negatively impact the physical and psychological well-being of dairy cows [1]. Striking a balance between productivity and welfare is therefore critical for developing sustainable dairy systems that simultaneously address economic viability, ethical considerations, and environmental sustainability.

***Author for Correspondence**
Md. Emran Hossain
E-mail: emran@cvasu.ac.bd

[1]Professor, Department of Animal Science and Nutrition, Chattogram Veterinary and Animal Sciences University, Khulshi, Chattogram, Bangladesh
[2]Professor, Department of Animal Science and Nutrition, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur, Bangladesh

Received Date: February 05, 2025
Accepted Date: February 24, 2025
Published Date: February 27, 2025

Citation: Md. Emran Hussain, Shilpi Islam. Balancing Welfare-Productivity Trade-Offs: Logical Frameworks and Strategic Approaches for Sustainable Dairy Development. Research and Reviews: Journal of Veterinary Science and Technology. 2025; 14(2): 16–24p.

The welfare-productivity trade-off is a multifaceted issue shaped by various factors, including genetic selection, housing conditions, nutritional strategies, milking practices, and health management. For instance, while genetic selection for high-yielding cows has improved productivity, it has also increased the prevalence of metabolic disorders, lameness, and reproductive inefficiencies [2, 3]. Likewise, intensive housing systems and frequent milking schedules, although effective for maximizing milk production, often result in stress,

injury, and behavioral restrictions [4]. These challenges necessitate a nuanced understanding of how different management and environmental factors interact to influence both welfare and productivity.

To address this dilemma, researchers and stakeholders have developed diverse frameworks for evaluation. These include animal-centric approaches, such as behavioral and physiological assessments, and broader systems-based models, such as precision livestock farming (PLF) technologies and sustainability metrics. This study contributes novelty by offering a comprehensive categorization and analysis of logical frameworks that integrate animal, environmental, economic, and technological perspectives. By identifying methodological gaps and proposing innovative solutions, it provides a practical roadmap for achieving sustainable dairy systems, prioritizing animal welfare while maintaining productivity and ensuring economic viability.

ANIMAL-CENTRIC FRAMEWORKS

Behavioral Assessments

Behavioral assessments focus on observing dairy cow activities, such as feeding, resting, and social interactions to evaluate their welfare. Using ethograms, which are standardized behavioral catalogues, helps quantify these activities [5]. These data provide insights into how management practices impact animal well-being, offering a direct link to welfare-productivity dynamics.

Physiological Indicators

Physiological assessments evaluate stress biomarkers, including cortisol levels and heart rate variability, to measure welfare [6]. Milk composition, such as somatic cell count or fat-to-protein ratios, offers additional physiological insights, reflecting both animal health and productivity outcomes [7]. These indicators serve as reliable measures of the welfare-productivity trade-off.

Health Monitoring

Health monitoring frameworks focus on the prevalence of diseases, like mastitis or lameness, which directly impact both welfare and productivity [8]. Pain scoring and injury prevalence assessments provide actionable data, enabling the identification of management or environmental changes required to improve welfare outcomes.

Reproductive Metrics

Reproductive metrics evaluate fertility indicators, such as calving intervals and postpartum recovery [9]. They also include the assessment of conditions, like dystocia, providing critical insights into how reproductive health influences both welfare and productivity, with direct implications for sustainable management.

Productivity Adjusted for Welfare

Frameworks adjusting productivity for welfare analyzing milk yield relative to welfare indicators, such as a welfare-adjusted productivity index [10]. This approach incorporates metrics, like lactation curves, accounting for health and welfare impacts, providing a balanced view of dairy system efficiency.

MANAGEMENT-ORIENTED FRAMEWORKS

Housing Systems

Housing systems compare setups, like free-stalls and tie-stalls, examining their impact on cow comfort, mobility, and welfare. Factors, such as bedding quality, ventilation, and space allowance significantly influence stress levels and productivity, helping to identify optimal housing practices for sustainable dairy operations [11].

Feeding Strategies

Feeding strategies assess the welfare effects of precision feeding, focusing on balanced diets that meet nutritional needs while minimizing stress [12]. Evaluating the role of forages versus concentrates

highlights their impact on rumen health, stress reduction, and productivity, ensuring long-term sustainability.

Milking Practices

Milking practices compare robotic and conventional systems, focusing on their effects on stress, labor efficiency, and milk yield [13]. Milking frequency is also analyzed to understand its influence on stress levels, udder health, and overall productivity in varying farm contexts.

Calf Rearing Practices

Calf rearing practices explore early weaning versus dam-rearing systems, focusing on behavioral and health impacts [14, 15]. Group housing versus individual housing is examined to assess their effects on calf socialization, welfare, and growth rates, contributing to sustainable productivity improvements [16].

Transition Cow Management

Transition cow management evaluates prepartum and postpartum care protocols to minimize metabolic disorders and stress [17]. Optimizing dry period length is critical for maintaining cow health, welfare, and productivity during lactation cycles, ensuring better long-term outcomes.

ENVIRONMENTAL FRAMEWORKS

Climate-Specific Models

Climate-specific models address heat and cold stress management, evaluating strategies, like shade, sprinklers, and ventilation in hot climates, and insulation or barn heating in colder regions [18]. These frameworks aim to mitigate environmental stressors that affect both cow welfare and productivity, ensuring optimal conditions throughout varying weather conditions.

Environmental Enrichment

Environmental enrichment frameworks examine the impact of stimuli, such as brushes and play areas, on cow welfare and productivity. Enrichment has been shown to reduce stress, encourage natural behaviors, and improve milk yield, particularly when comparing grazing systems to confinement setups, thus enhancing both welfare and performance [19].

Lighting and Photoperiod

Lighting and photoperiod frameworks focus on optimizing lighting regimens to enhance cow welfare and milk production. Proper light cycles can regulate circadian rhythms, improve sleep quality, and increase milk yield, while also mitigating stress, making lighting strategies an important tool for improving overall farm productivity [20].

Noise and Handling

Noise and handling frameworks assess how low-stress handling techniques and reduced noise levels can positively impact cow behavior and welfare [21, 22]. By minimizing stress during handling, these frameworks promote a better welfare-productivity balance, reducing injuries and increasing efficiency and milk production.

Sustainability Assessments

Sustainability assessment frameworks integrate environmental footprint analysis with welfare-productivity metrics. By considering factors, like energy use, water consumption, and waste management, these frameworks evaluate the broader environmental impacts of dairy systems, ensuring that both sustainability and animal welfare are prioritized alongside productivity goals [23].

ECONOMIC AND POLICY FRAMEWORKS

Cost-Benefit Analysis

Cost-benefit analysis frameworks compare the costs of welfare interventions with potential productivity gains [24]. These analyses help determine the financial viability of implementing welfare-

enhancing practices, considering factors, such as reduced veterinary costs, improved cow longevity, and higher milk yield, thereby justifying investment in welfare-friendly technologies.

Regulatory Frameworks

Regulatory frameworks focus on compliance with welfare standards set by governing bodies like the EU or USDA. These frameworks evaluate how adherence to regulations impacts farm operations and assess incentives provided to producers who adopt welfare-enhancing systems, ensuring industry-wide welfare improvements.

Farm Sustainability Index

Farm sustainability index frameworks use composite metrics to assess welfare, productivity, and economic viability [25]. By integrating these factors, the index enables farmers and policymakers to evaluate farm sustainability in a holistic manner, balancing economic profitability with animal welfare and environmental sustainability goals.

Market Demand Assessments

Market demand assessments focus on consumer preferences for welfare-compliant dairy products. These frameworks evaluate how certification schemes, such as organic or animal welfare certifications, influence consumer choices and their impact on productivity, offering valuable insights into market-driven incentives for welfare improvements [26].

Subsidy and Support Mechanisms

Subsidy and support mechanisms frameworks examine the role of financial support from government or industry programs in promoting welfare-centric practices [27]. These frameworks assess the effectiveness of subsidies, grants, and other financial incentives in encouraging producers to adopt practices that enhance both welfare and productivity.

TECHNOLOGICAL FRAMEWORKS

Precision Livestock Farming

PLF frameworks utilize real-time monitoring technologies, such as sensors, to track cow health, welfare, and productivity. These systems enable continuous data collection on vital signs, behaviors, and environmental conditions, facilitating predictive analytics to optimize welfare-productivity trade-offs and enhance farm management [28].

Automated Welfare Assessment Tools

Automated welfare assessment tools use wearable technologies, like collars or ear tags, to monitor stress, health, and behavioral indicators in cows [29]. These tools provide objective, real-time data, allowing farmers to detect health issues or welfare concerns early, reducing stress and improving overall productivity.

Data Integration Platforms

Data integration platforms leverage big data analytics to correlate welfare and productivity metrics. These frameworks consolidate data from multiple sources, such as PLF systems and health records, providing a comprehensive overview that helps identify trends and optimize management practices for better welfare-productivity outcomes [30].

Artificial Intelligence Models

AI models, particularly machine learning algorithms, are used to analyze large datasets and identify patterns in welfare-productivity trade-offs. These frameworks help predict potential welfare issues, optimize productivity strategies, and offer insights for balancing the two, ultimately enhancing decision-making in dairy farming [31].

Remote Sensing Systems

Remote sensing systems, including drones and satellite-based technologies, assess grazing conditions, environmental factors, and pasture health [32]. These frameworks provide valuable data on environmental impacts and grazing efficiency, offering insights for improving welfare while optimizing productivity through better land and resource management.

HOLISTIC FRAMEWORKS

Lifecycle Analysis

Lifecycle analysis (LCA) frameworks provide end-to-end evaluations of dairy systems, assessing the environmental, economic, and welfare impacts throughout the production cycle [33]. These frameworks integrate welfare metrics into carbon footprint calculations, enabling a comprehensive understanding of sustainability that balances productivity with animal welfare considerations.

One Health Approach

The one health approach connects animal welfare, environmental health, and human health in a unified framework [34]. It emphasizes the interconnectedness of these domains and seeks solutions that promote holistic well-being, ensuring that practices that benefit animal welfare also contribute to environmental and human health outcomes.

Sustainability Metrics Models

Sustainability metrics models develop multi-dimensional indices that combine welfare, productivity, and sustainability indicators. These frameworks enable a more integrated assessment of dairy farm sustainability, balancing economic, ethical, and environmental factors to support long-term sustainable practices and improvements in both animal welfare and productivity [35].

Ethical and Welfare Indices

Ethical and welfare indices offer frameworks for scoring the ethical impact of management decisions on animal welfare [36]. These indices assess various welfare aspects, such as comfort, health, and behavior, and provide welfare-adjusted quality of life metrics to guide farm management practices that prioritize ethical considerations alongside productivity goals.

Resilience Frameworks

Resilience frameworks evaluate the ability of dairy systems to withstand and adapt to welfare-productivity stressors. These frameworks assess the robustness of farming systems in maintaining both welfare and productivity under fluctuating environmental, economic, and management conditions, offering valuable insights for building more resilient, sustainable dairy operations [37].

CASE STUDIES APPLICATIONS

Successful Framework Implementations

This section presents examples where frameworks for balancing welfare and productivity have been successfully applied in dairy systems. Case studies from diverse regions demonstrate the practical use of these frameworks to improve animal welfare while maintaining productivity. These examples highlight the adoption of technologies, management strategies, and welfare measures that have been effective in real-world dairy operations. By showcasing these successes, the study emphasizes the potential for frameworks to achieve sustainable dairy farming, providing valuable lessons for others in the industry.

Analysis of Dairy System Outcomes

Detailed analysis of dairy systems that implemented welfare-productivity frameworks reveals important outcomes, such as improved animal health, milk yield, and reproductive performance. The outcomes of these systems provide insight into how specific management practices, such as housing conditions, feeding strategies, and genetic selection, affect both welfare and productivity. These examples also demonstrate the adaptability of frameworks to different farming systems, such as organic

and intensive farms, allowing for customized solutions. Comparing these results across various systems helps identify effective strategies and practices that can be replicated or adapted in other regions or settings.

Lessons and Future Implications

The case studies offer key lessons learned, such as the importance of region-specific adaptations and the challenges of integrating emerging technologies. These lessons can guide future research to refine and improve existing frameworks, making them more applicable and effective across different dairy operations. The findings also provide practical implications for the dairy industry, suggesting that frameworks can be adopted or modified to optimize both welfare and productivity. By focusing on the long-term benefits of these systems, the study emphasizes the need for continued innovation to achieve sustainable dairy farming practices.

CRITICAL ANALYSIS AND COMPARISON

Strengths and Weaknesses of Each Framework

Each framework for balancing welfare and productivity in dairy systems has unique strengths and weaknesses. Animal-centric frameworks, for example, provide valuable insights into animal health and behavior but may lack broader system integration [38]. Management-oriented frameworks excel at operational optimization but might overlook animal welfare nuances. Technological frameworks offer real-time data and efficiency but can be expensive and require high technical expertise [39]. Critically assessing these frameworks helps identify their limitations, ensuring that future implementations can address these gaps to create more holistic and effective solutions for sustainable dairy development.

Areas of Overlap and Integration Opportunities

Many frameworks share common elements, such as the need for efficient management practices or the integration of animal welfare metrics into production systems. Recognizing areas of overlap provides opportunities for integration. For instance, combining precision livestock farming (PLF) tools with animal-centric health assessments could offer a more comprehensive approach to welfare-productivity optimization. By merging the strengths of different frameworks, dairy systems can be improved in a way that balances productivity with enhanced animal welfare [40]. Such integration could also streamline the application of these frameworks in real-world dairy operations, maximizing benefits across various aspects.

Regional and Context-Specific Applicability

Frameworks for welfare-productivity trade-offs must be adaptable to the specific conditions of dairy systems, which vary widely by region. For example, housing and feeding strategies that work in temperate climates may not be effective in tropical regions due to different environmental stressors [41]. The social, economic, and cultural context also influences the applicability of these frameworks. Therefore, frameworks should be flexible and customizable to meet the unique needs of diverse dairy systems. Understanding regional variations in resources, climate, and farm management practices is key to optimizing the relevance and effectiveness of these frameworks.

Addressing Current Research Gaps

Although significant progress has been made in developing frameworks for welfare-productivity balance, there remain notable research gaps. One key area is the need for longitudinal studies to assess the long-term impacts of various management practices and technologies on both animal welfare and productivity. Additionally, more research is needed to quantify the economic implications of welfare-friendly practices, especially for small-scale dairy farmers. Addressing these gaps will improve the accuracy and applicability of frameworks, ensuring that they are both scientifically sound and practically feasible in real-world dairy farming.

CONCLUSIONS

Balancing welfare and productivity in dairy systems is vital for achieving sustainable livestock development. Addressing this trade-off requires a nuanced understanding of the interconnected factors

influencing animal well-being and productivity, including genetic selection, management practices, and environmental conditions. This study highlights the importance of integrating diverse frameworks ranging from animal-centric assessments to advanced technological and systems-based approaches for evaluating welfare-productivity dynamics. Future efforts must focus on region-specific solutions, leveraging precision livestock farming tools and sustainable feeding strategies to optimize outcomes. Collaboration among researchers, policymakers, and industry stakeholders will be critical to translating insights into practical applications. By prioritizing animal welfare alongside economic and environmental considerations, the dairy industry can advance toward sustainable, ethical, and resilient farming systems in the future.

Limitations

This study is limited by the availability and variability of data across different dairy systems, which may affect the generalizability of the findings. The frameworks analyzed may not be applicable to all regions or farming conditions, especially those with limited technological access or resources. Additionally, the integration of diverse frameworks poses challenges in ensuring consistency and comparability of results. The rapid evolution of technologies, such as AI and PLF tools may outpace the scope of the study, limiting the applicability of some findings in the future. Furthermore, the focus on existing frameworks may overlook novel, emerging approaches.

Future Directions

Future research on welfare-productivity trade-offs in dairy systems should adopt a multidisciplinary approach to balance animal welfare and production efficiency effectively. Region-specific frameworks are essential to address the diverse socio-economic and environmental conditions of dairy farming across geographies. Longitudinal studies are needed to capture the sustained effects of management practices, housing systems, and genetic selection on welfare and productivity outcomes. Additionally, the integration of emerging technologies, such as precision livestock farming tools and artificial intelligence, holds potential for real-time monitoring and proactive interventions. However, these tools must be validated across varying farming conditions to ensure their scalability, reliability, and cost-effectiveness.

Efforts should also focus on sustainable feeding strategies, emphasizing alternative feed resources, like agricultural by-products, to reduce costs without compromising nutrition or welfare. Understanding the interplay between environmental stressors, such as heat, and welfare-productivity dynamics is increasingly critical in the context of climate change. Adaptive management practices, climate-resilient housing, and environmental enrichment techniques merit further exploration. Collaboration among researchers, policymakers, and stakeholders is vital to translate findings into practical solutions, including standardized welfare protocols and economic models that quantify the benefits of welfare-friendly practices. Advances in genetics and breeding programs targeting resilient, high-performing animals will play a pivotal role in ensuring sustainable dairy development.

REFERENCES

1. Costa JHC, Hötzel MJ, Longo C, Balcão LF. A survey of management practices that influence production and welfare of dairy cattle on family farms in southern Brazil. J Dairy Sci. 2013;96(1):307–317.
2. Oltenacu PA, Broom DM. The impact of genetic selection for increased milk yield on the welfare of dairy cows. Anim Welf. 2010;19(Suppl 1):39–49.
3. Brito LF, et al. Genetic selection of high-yielding dairy cattle toward sustainable farming systems in a rapidly changing world. Animal. 2021;15:100292.
4. Phillips CJC, et al. A review of the impact of housing on dairy cow behaviour, health and welfare. Livest Hous Mod Manag to Ensure Optim Heal Welf Farm Anim. 2013;37–54. doi:10.3920/978-90-8686-771-4_02.
5. Banks EM. Behavioral research to answer questions about animal welfare. J Anim Sci. 1982;54(2):434–446.

6. Grelet C, et al. Identification of chronic stress biomarkers in dairy cows. Animal. 2022;16(5):100502.
7. Giannuzzi D, et al. Milk phenomics: leveraging biological bonds with blood and infrared technologies for evaluating animal nutritional and health status. Ital J Anim Sci. 2024;23(1):780–801.
8. Silva SR, Araujo JP, Guedes C, Silva F, Almeida M, Cerqueira JL. Precision technologies to address dairy cattle welfare: Focus on lameness, mastitis and body condition. Animals. 2021;11(8):2253.
9. Pinedo P, et al. Associations of reproductive indices with fertility outcomes, milk yield, and survival in Holstein cows. J Dairy Sci. 2020;103(7):6647–6660.
10. Stygar AH, et al. Measuring dairy cow welfare with real-time sensor-based data and farm records: a concept study. Animal. 2023;17(12):101023.
11. Bewley JM, Robertson LM, Eckelkamp EA. A 100-Year Review: Lactating dairy cattle housing management. J Dairy Sci. 2017;100(12):10418–10431. doi:10.3168/jds.2017-13251.
12. Gaillard C, Abarnou J. Responses of dairy cows to weekly individualized feeding strategies regarding their metabolic status. J Dairy Sci. 2024;107(12):10776–10786.
13. Hopster H, et al. Stress responses during milking; comparing conventional and automatic milking in primiparous dairy cows. J Dairy Sci. 2002;85(12):3206–3216.
14. Johnsen JF, et al. Is rearing calves with the dam a feasible option for dairy farms?—Current and future research. Appl Anim Behav Sci. 2016;181:1–11.
15. Cantor MC, Neave HW, Costa JHC. Current perspectives on the short-and long-term effects of conventional dairy calf raising systems: a comparison with the natural environment. Transl Anim Sci. 2019;3(1):549–563.
16. Liu S, et al. Effects of pair versus individual housing on performance, health, and behavior of dairy calves. Animals. 2019;10(1):50.
17. Cook JG, Pepler PT, Viora L, Hill DL. Assessing transition cow management in dairy cows for improved health, milk production, pregnancy, and culling outcomes. J Dairy Sci. 2024;107(12):11381–11397.
18. Tobin D, Janowiak M, Hollinger DY, Skinner RH, Steele R, Radhakrishna R. Northeast regional climate hub assessment of climate change vulnerability and adaptation and mitigation strategies. 2015.
19. Mandel R, Whay HR, Klement E, Nicol CJ. Invited review: Environmental enrichment of dairy cows and calves in indoor housing. J Dairy Sci. 2016;99(3):1695–1715. doi:10.3168/jds.2015-9875.
20. Ahmmad SR. Daylighting and electric lighting for sustainable cattle buildings. Introd Pap Fac Landsc Archit Hortic Crop Prod Sci. 2024;(3).
21. Grandin T. Behavioral principles of livestock handling. Prof Anim Sci. 1989;5(2):1–11.
22. Dimov D, Penev T, Marinov I. Importance of Noise Hygiene in Dairy Cattle Farming—A Review. Acoustics. 2023;5(4):1036–1045. doi:10.3390/acoustics5040059.
23. Ivana B, Puvača N. Economic and Ecological Sustainability of Dairy Production. J Agron Technol Eng Manag. 2024;7(3):1088–1084. doi:10.55817/tqxu2115.
24. Martins SB, Rushton J. Cost-effectiveness analysis: adding value to assessment of animal health, welfare and production. Rev Sci Tech. 2014;33(3):681–689.
25. Brennan M, Hennessy T, Dillon E, Meredith D. Putting social into agricultural sustainability: Integrating assessments of quality of life and wellbeing into farm sustainability indicators. Sociol Ruralis. 2023;63(3):629–660.
26. Christensen T, Denver S, Sandøe P. How best to improve farm animal welfare? Four main approaches viewed from an economic perspective. Anim Welf. 2019;28(1):95–106.
27. Choden D, Timsina MP, Rai DB, Tamang NB. Effects of government subsidy support on livelihood of dairy farmers in Bhutan. Bhutan J Anim Sci. 2017;1(1):1–4.
28. Papakonstantinou GI, Voulgarakis N, Terzidou G, Fotos L, Giamouri E, Papatsiros VG. Precision Livestock Farming Technology: Applications and Challenges of Animal Welfare and Climate Change. Agriculture. 2024;14(4):620.

29. Alipio M, Villena ML. Intelligent wearable devices and biosensors for monitoring cattle health conditions: A review and classification. Smart Heal. 2023;27:100369.
30. Neethirajan S, Kemp B. Digital Livestock Farming. Sens Bio-Sensing Res. 2021;32:100408. doi:10.1016/j.sbsr.2021.100408.
31. Neethirajan S. Artificial intelligence and sensor innovations: enhancing livestock welfare with a human-centric approach. Human-Centric Intell Syst. 2024;4(1):77–92.
32. Gargiulo JI, et al. Comparison of ground-based, unmanned aerial vehicles and satellite remote sensing Technologies for Monitoring Pasture Biomass on dairy farms. Remote Sens. 2023;15(11):2752.
33. Mediboyina MK, O'Neill S, Holden NM, Murphy F. Prospective life cycle assessment of an integrated biorefinery for production of lactic acid from dairy side streams. Sustain Prod Consum. 2024;50:376–390.
34. Pregowski MP. One Welfare: A Framework to Improve Animal Welfare and Human Well-being. CAB Int. 2019;32(6). doi:10.1080/08927936.2019.1673070.
35. Shamsuddoha M, Nasir T, Hossain NUI. A sustainable supply chain framework for dairy farming operations: a system dynamics approach. Sustainability. 2023;15(10):8417.
36. Veissier I, Jensen KK, Botreau R, Sandøe P. Highlighting ethical decisions underlying the scoring of animal welfare in the Welfare Quality® scheme. Anim Welf. 2011;20(1):89–101.
37. Meuwissen MPM, et al. A framework to assess the resilience of farming systems. Agric Syst. 2019;176:102656.
38. Webber S, Cobb ML, Coe J. Welfare through competence: a framework for animal-centric technology design. Front Vet Sci. 2022;9:885973.
39. Cabrera VE, Barrientos-Blanco JA, Delgado H, Fadul-Pacheco L. Symposium review: Real-time continuous decision making using big data on dairy farms. J Dairy Sci. 2020;103(4):3856–3866.
40. Mee JF, Boyle LA. Assessing whether dairy cow welfare is 'better' in pasture-based than in confinement-based management systems. N Z Vet J. 2020;68(3):168–177.
41. Chauhan SS, et al. Impact of heat stress on ruminant livestock production and meat quality, and strategies for amelioration. Anim Front. 2023;13(5):60–68.

