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Review Article

Factors Affecting Longevity and Reasons for Culling in Dairy Cattle and Buffalo

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Abstract

Dairy cattle and buffalo longevity is critical to economic sustainability and animal welfare in dairy production. This current study embarks on a comprehensive exploration of the multifaceted factors that influence the longevity of these bovine species, subsequently impacting dairy industry profitability and animal selection. This study meticulously dissects the reasons for culling dairy cattle and buffalo, shedding light on the nuanced interplay between genetics, management practices, and emerging technologies. The current analysis delves into the genetic underpinnings of longevity, elucidating the hereditary factors contributing to enhanced lifespan in these valuable dairy animals. Furthermore, it delves into the intricacies of optimal herd management, encompassing nutrition, housing, and healthcare practices, which play a pivotal role in extending the productive lifespan of these animals. Moreover, we examine the dynamic landscape of advancements in biotechnology and genomics, revealing their potential to revolutionize dairy farming by enhancing the longevity and overall productivity of cattle and buffalo. We have amalgamated the latest research findings, presenting a compelling knowledge synthesis understanding the intricate web of factors affecting longevity and culling is paramount as the dairy industry navigates global sustainability and animal welfare challenges. The current study aims to serve as an indispensable resource for scholars, practitioners, and policymakers in the livestock sector, illuminating the path toward a more sustainable and humane dairy sector.

Keywords: Animal production; Culling; Dairy animals; Economic Impact; Genetics; Herd management; Longevity; Selective breeding.

Introduction

A consistent supply of milk and dairy products is provided by the dairy sector, which plays a crucial role in global agriculture to fulfill the growing nutritional needs of the human population. Dairy cattle and buffalo are essential to this business; their contributions go beyond providing food and include animal welfare and sustainable economic practices. The lifespan of these animals is a crucial factor in the quest for

optimal dairy production, as it influences not only the financial success of dairy businesses but also the moral benchmarks by which we evaluate how we treat our cattle (Pinedo *et al.*, 2010).

It starts a thorough investigation into the longevity and intricate mechanisms behind the culling of buffalo and dairy animals. Although the ability to transform feed into valuable dairy products, such as milk and meat, makes these animals highly valued, their productive lifespan is inevitably limited. Therefore, maintaining the dairy industry's long-term survival requires an awareness of the factors that determine lifespan and the rationale behind culling (Galloway *et al.*, 2010).

The longevity of dairy cattle and buffalo is not merely an academic concern but an ethical, economic, and ecological imperative. By understanding and addressing the factors that impact their lifespan, we take a significant step toward achieving a more sustainable, humane, and prosperous future for the dairy industry. The current sections will traverse the domains of genetics, herd management, biotechnology, sustainability and more, uncovering the intricate tapestry of factors that define the longevity and culling practices of dairy cattle and buffalo. As we do so, we invite the reader to join us on this journey of exploration, discovery, and insight into the complex world of bovine longevity and culling (De Haan *et al.*, 2016).

The Imperative of Longevity

Like many other areas of agriculture, the dairy business must simultaneously address the challenges of feeding the world's expanding population and lessening its environmental impact. Due to this issue, we must reconsider our conventional methods and give careful thought to the idea of longevity. Fundamentally, longevity is the capacity of buffalo and dairy cattle to continue producing for a long time, as shown by their years of life as well as their productivity and efficiency (Steinfeld *et al.*, 2006). Longevity is paramount in the context of sustainable agriculture. As global demand for dairy products escalates, the dairy sector faces the need to produce more with less, a demand intensified by the imperative to reduce greenhouse gas emissions, land usage and water consumption. Extending the productive lives of dairy cattle and buffalo inherently contributes to these objectives, as animals that are culled prematurely represent lost potential and resources (Martinez Correal, 2007).

Furthermore, from an ethical standpoint, the welfare of dairy animals must be a central concern. Culling raises profound moral and animal welfare questions. A commitment to enhancing the longevity of these animals aligns with societal expectations for humane treatment and responsible animal husbandry practices. In addition to ethical considerations, there are clear economic incentives for improving the longevity of dairy cattle and buffalo. Replacing culled animals incurs substantial costs related to procurement, acclimatization, and training of replacement stock. Furthermore, older cows and buffalo tend to have higher milk production, offering a compelling economic case for extending their productive lives (Heffernan, 2004).

Their well-being and capacity to contribute to human sustenance and welfare hinge on the decisions of caretakers and stakeholders in the dairy industry. Within this context, the approach examines factors influencing longevity and the practice of culling in dairy cattle and buffalo (De Haan *et al.*, 2001).

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Genetics and the Longevity Conundrum

One of the cornerstones in unraveling the mystery of longevity and culling in dairy cattle and buffalo is the profound influence of genetics. An animal's genetic makeup lays the foundation for its potential lifespan and productivity within a dairy herd. Understanding the intricacies of bovine genetics is pivotal for running breed improvement programs. It offers insights into the inherent variations in longevity among individual animals (Burnett *et al.*, 2015). Genetic diversity within dairy cattle and buffalo populations is vast, encompassing various breeds with unique characteristics. While some species have been selectively bred for high milk production, others may exhibit superior disease resistance or adaptability to specific environmental conditions. These genetic variances extend to longevity factors (Glimp, 1988).

Selective breeding programs have historically focused on improving milk yield and other economically relevant traits. However, there is growing recognition within the dairy industry of the need to incorporate longevity as a primary breeding objective. This shift reflects the acknowledgment that genetic factors significantly impact the length of a cow or buffalo's productive life. Genome-wide association studies and the advent of genomic selection have revolutionized the ability to identify specific genes and genetic markers associated with longevity-related traits. Such markers give dairy producers valuable tools to make informed breeding decisions to enhance longevity. Selecting animals with favorable genetic predispositions makes it possible to create herds with a higher proportion of long-lived and productive individuals (Sutton *et al.*, 2013) as shown in Figure 1.

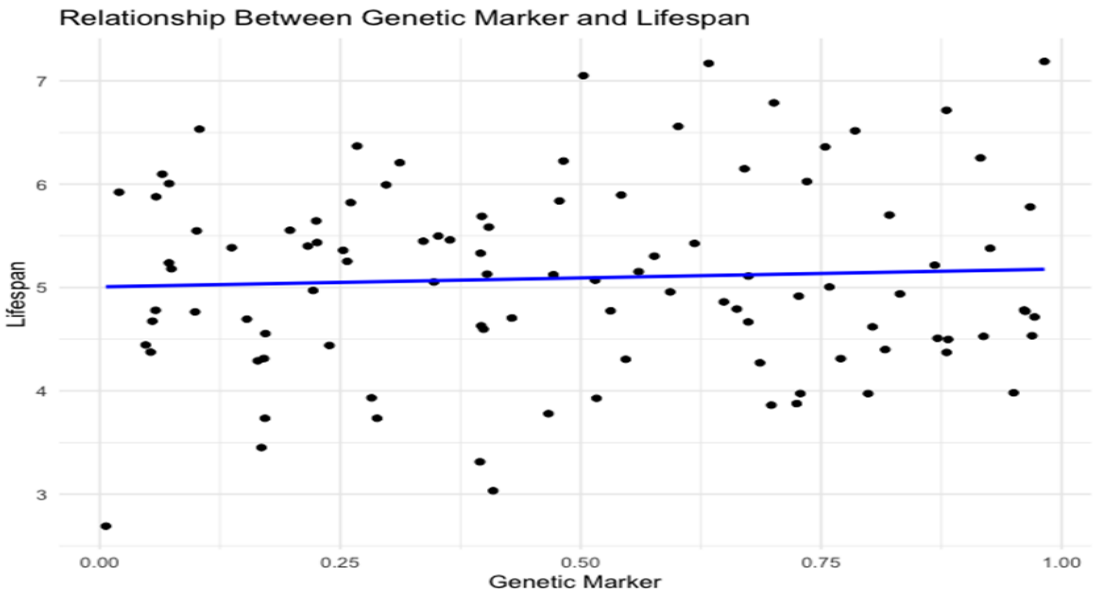

Figure 1. Revolutionizing dairy breeding for longevity and sustained productivity.

This scatterplot with a blue trend line illustrates the correlation between a genetic marker and the lifespan of dairy cattle. The x-axis represents the genetic marker, and the y-axis represents the lifespan in years (Arslan *et al.*, 2018).

This intricate interplay between genes and environment underscores the complexity of the longevity problem. While genetics offer a foundational understanding, they must be considered within the broader context of herd management practices, health protocols and advancements in biotechnology. Genetic determinants of longevity, examining the

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hereditary factors that impact the productive lives of dairy cattle and buffalo (Gerber *et al*., 2013).

Herd Management and the Longevity Equation

Beyond genetics, effective herd management is a linchpin in the quest to extend the productive lives of dairy cattle and buffalo. While genetics provide the potential for longevity, the practical application of sound management practices allows animals to realize this potential (Sere and Steinfeld, 1996).

Nutrition and Feeding

Central to the longevity equation is providing balanced and nutritionally adequate diets. Nutrition impacts the overall health of dairy cattle and buffalo and their ability to produce milk efficiently. Imbalances or deficiencies in essential nutrients can lead to reduced fertility, compromised immune function and higher susceptibility to diseases, all of which can shorten the lifespan of these animals (Katothya, 2017).

Housing and Environment

Living conditions in which dairy cattle and buffalo are kept are equally influential. Proper housing protects animals from harsh weather conditions, minimizes stress, reduces the risk of injuries, and maintains their overall well-being. The design and maintenance of housing facilities play a vital role in ensuring the comfort and health of these animals (Von Keyserlingk *et al*., 2009).

Healthcare and Disease Management

Effective healthcare protocols are imperative for preventing, diagnosing, and treating diseases that can afflict dairy cattle and buffalo. Diseases can be a major cause of culling, and as such, regular veterinary care, vaccinations, and disease prevention strategies are essential components of herd management. Managing the herd's health reduces culling and enhances animal welfare (Savian *et al*., 2021).

Reproductive Management

The reproductive success of dairy cattle and buffalo is inextricably linked to longevity. Fertility issues can lead to prolonged non-productive periods, which are economically detrimental. Implementing efficient reproductive management practices, including timely breeding, artificial insemination, and pregnancy monitoring, is crucial for maintaining the productivity and lifespan of these animals (Hobbs, 2010).

Data-Driven Decision Making

Modern dairy operations increasingly rely on data analytics and technology-driven decision support systems. These tools enable producers to monitor the health and performance of individual animals and the herd. By identifying potential issues early and implementing targeted interventions, dairy farmers can extend the productive lives of their cattle and buffalo (Velado-Alonso *et al*., 2021).

Biotechnology, Genomics, and the Promise of Longevity

The dairy industry, like many others, is experiencing a technological revolution that has the potential to reshape the landscape of animal husbandry and longevity. Biotechnology and genomics have emerged as powerful tools for improving the productivity and lifespan of dairy cattle and buffalo (Bizzuti *et al*., 2021).

Biotechnology

Biotechnological advancements have paved the way for innovative solutions in the dairy

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sector. Notable among these is the use of reproductive technologies such as artificial insemination (AI) and embryo transfer (ET). AI allows for the selective breeding of high-quality sires, enabling genetic progress to be rapidly disseminated within the herd. ET takes this a step further by multiplying the genetic potential of superior females. These technologies boost productivity and preserve and disseminate valuable genetic material, contributing to longevity (Wei *et al.*, 2021).

Genomics

Sequencing the bovine genome has been a transformative development in animal breeding. Genomic selection, a technique that leverages genetic markers to predict an animal's future performance, has revolutionized breeding programs. It allows for identifying animals with a higher likelihood of producing offspring with enhanced longevity and productivity. Genomics also enables the detection of genetic predispositions to diseases, permitting early intervention and disease (Claire *et al.*, 2021).

Precision Livestock Farming

Beyond genetics, precision livestock farming integrates technology and data analytics to optimize the management of dairy cattle and buffalo. Sensors and monitoring systems can track real-time parameters such as feed intake, activity, and health status. This data-driven approach allows for early detection of health issues, timely interventions, and more efficient resource allocation, all of which contribute to extending animal lifespan (Dahl and Connor, 2021).

While these technological advances hold immense promise, their implementation requires a thorough understanding of their potential benefits and limitations. Effective utilization of biotechnology and genomics necessitates the availability of the technology and the expertise to interpret and apply the generated data effectively.

A Path Toward Sustainability and Ethical Farming Practices

The dairy industry operates at the nexus of complex challenges, from feeding a burgeoning global population to mitigating its environmental footprint. Within this context, the longevity and welfare of dairy cattle and buffalo are inextricably linked to broader societal expectations and environmental imperatives (Yunita and Hasibuan, 2021).

The journey that lies ahead in this review paper is one of exploration, inquiry, and discovery. We will navigate the intricate web of genetics, management practices, biotechnology, and genomics, seeking to unravel the complexities of longevity and culling in dairy cattle and buffalo. We will scrutinize industry trends and technological innovations that offer both challenges and opportunities for dairy producers (Terry *et al.*, 2021).

Ultimately, we aspire to provide a holistic understanding of this critical subject that transcends academic boundaries and resonates with those dedicated to the betterment of the dairy industry. Our goal is to elucidate the factors that influence the productive lives of dairy cattle and buffalo and inspire a dialogue on the ethical and environmental dimensions of dairy farming (Díaz *et al.*, 2020).

Genetic Influences on Longevity

Genetic factors have been acknowledged as pivotal in dairy cattle and buffalo longevity. Researchers have delved into the intricate world of bovine genetics, seeking to unveil the hereditary traits that underpin extended productive lives. A landmark study underscored the potential of selective breeding programs in enhancing longevity by identifying specific genetic markers associated with longer lifespans in Holstein cattle.

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Furthermore, the genetic diversity among dairy cattle and buffalo breeds has piqued research interest. Breed-specific variations in lifespan have been documented, emphasizing the significance of breed selection in optimizing longevity within dairy herds (Mapiye *et al.*, 2020) shown in Figure 2.

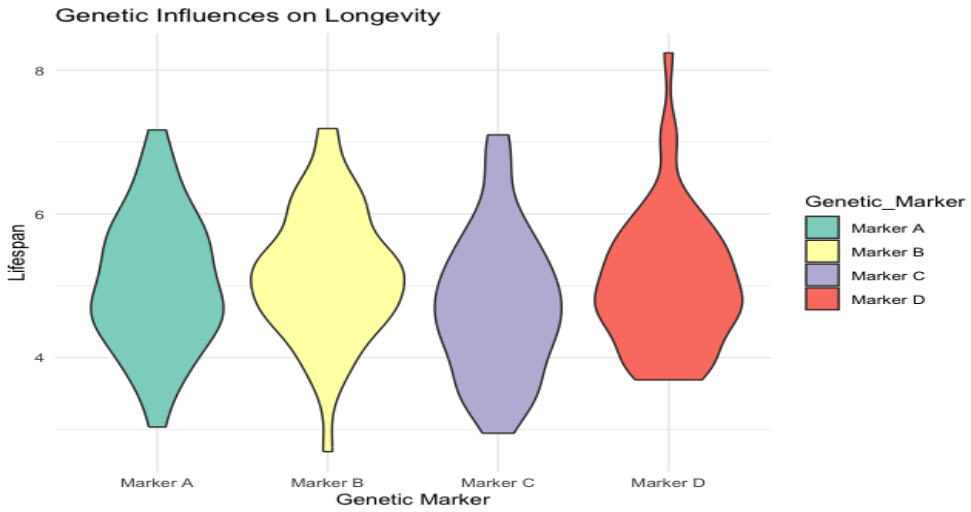

Figure 2. Unveiling genetic markers for enhanced longevity in dairy cattle and buffalo, emphasizing breed-specific variations.

The violin plot illustrates the distribution of lifespan data for multiple genetic markers in dairy cattle. It reveals variations in lifespan patterns, highlighting potential genetic influences on longevity, with Marker D exhibiting the most comprehensive distribution and the most significant variability (Wanapat *et al.*, 2020).

Management Practices and Longevity

Effective herd management practices the cornerstone of extending the productive lives of dairy cattle and buffalo. Nutrition, housing, and healthcare have been scrutinized in numerous studies. A comprehensive analysis of nutrition's impact on longevity revealed that balanced diets minimize health issues and prolong the productive lifespan.

Housing conditions and environmental factors have also received considerable attention. Research highlighted the importance of well-ventilated, stress-free environments in promoting longevity (Ghatak *et al.*, 2020).

Healthcare practices and disease management have been focal points in dairy herd management. Studies have shown that proactive veterinary care can significantly reduce premature culling events, thus emphasizing the pivotal role of healthcare protocols.

Advancements in Biotechnology and Genomics

Recent strides in biotechnology and genomics have revolutionized the dairy industry's approach to enhancing longevity. Genomic selection has gained prominence, allowing for identifying animals with superior genetic predispositions for longevity-related traits.

Biotechnology extends beyond genetics. Artificial insemination and embryo transfer techniques have demonstrated their potential to propagate excellent genetic material, contributing to longer-lived and more productive herds (Leroy *et al.*, 2020).

Precision livestock farming, integrating data analytics and technology-driven decision support systems, offers a promising approach to enhance longevity. Real-time animal health and behavior monitoring enables early intervention and improved longevity outcomes.

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Economic Implications of Longevity and Culling

Understanding the economic dimensions of longevity and culling is vital for dairy producers and the industry. Beyond the genetic and management aspects, the financial considerations associated with these practices have garnered substantial research attention.

Culling Costs

Research has consistently highlighted the considerable costs incurred in culling and replacing animals prematurely. Expenses related to procurement, acclimatization, and training of replacement stock place a significant economic burden on dairy operations. Culling, therefore, represents the loss of a productive animal and a substantial financial setback (Chan *et al.*, 2020).

Productivity and Efficiency

Older dairy cattle and buffalo tend to exhibit higher milk production, offering a compelling economic case for extending their productive lives. Studies have elucidated the correlation between age and productivity, emphasizing the financial benefits of delaying culling. Moreover, longer-lived animals contribute to improved herd efficiency, reducing the need for frequent replacements and, consequently, lowering operational costs (Huang *et al.*, 2020).

Economic Sustainability

The economic sustainability of dairy operations is intrinsically tied to the lifespan of their cattle and buffalo. Extending the productive lifespan of these animals bolsters the economic viability of dairy enterprises, especially in a climate of fluctuating milk prices and operational expenses. It fosters resilience and stability amid economic uncertainties (D'Amato *et al.*, 2020).

Industry Trends and Consumer Preferences

As the dairy industry evolves, consumer preferences and market dynamics are crucial in shaping longevity and culling practices. Consumers increasingly favor products derived from sustainable and ethically managed dairy operations. Understanding these trends is vital for dairy producers seeking to align their practices with evolving consumer demands, thereby ensuring long-term market relevance and profitability (Takiya *et al.*, 2019).

Sustainability and Ethical Considerations

In addition to economic factors, longevity and culling in dairy cattle and buffalo are inextricably tied to broader sustainability and ethical concerns. Dairy farming operates within an evolving global context characterized by increasing awareness of environmental impact and animal welfare (Huang *et al.*, 2019).

Sustainability in Dairy Production

Sustainability has become paramount in modern dairy farming. Extending the productive lives of dairy cattle and buffalo is inherently aligned with sustainable agriculture. Longer-lived animals are more resource-efficient, reducing dairy operations' carbon footprint and environmental impact; minimizing premature culling contributes to conserving resources, including feed, water, and land, aligning with the global pursuit of sustainable food systems (Cassar-Malek *et al.*, 2018).

Environmental Footprint

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Like other livestock industries, dairy farming faces scrutiny for its environmental impact. Culling events result in the replacement of animals, which necessitates the resource-intensive process of raising and acclimatizing new stock. By extending the lifespan of existing animals, the industry can significantly reduce its environmental footprint. Sustainable dairy production practices resonate with environmentally conscious consumers and align with regulatory and sustainability certification requirements (Lal, 2004).

Ethical Considerations and Animal Welfare

Ethical considerations of animal welfare play a pivotal role in discussions surrounding longevity and culling. Premature culling, particularly when driven by avoidable factors, raises ethical concerns. Society increasingly expects dairy producers to adhere to humane treatment standards and responsible animal husbandry practices. Aligning culling decisions with ethical principles is not only a moral imperative but also essential for maintaining public trust and social license to operate.

Regulatory and Certification Standards

Regulatory bodies and certification programs incorporate sustainability and ethical standards into their requirements for dairy operations. Compliance with these standards ensures adherence to ethical and environmental principles and opens access to markets prioritizing sustainability and responsible animal management. Dairy producers that extend the lifespan of their cattle and buffalo are better positioned to meet these evolving standards and access premium markets (Pickering *et al.*, 2015).

In essence, the sustainability and ethical considerations surrounding longevity and culling in dairy cattle and buffalo transcend the boundaries of individual farms. They have become integral to the broader dairy industry's resilience and market relevance in an era defined by ethical consumerism and environmental consciousness.

Factors Influencing Longevity

Longevity, the ability of dairy cattle and buffalo to remain productive over an extended period, is influenced by a complex interplay of genetic, environmental, and management factors. Understanding these factors is critical for optimizing the lifespan of these valuable animals. Below, we explore five key factors:

Genetic Factors

Genetic influences on longevity are profound. An animal's genetic makeup establishes the foundation for its potential lifespan and productivity. Researchers have identified specific genes and genetic markers associated with increased longevity. These markers offer dairy producers' valuable tools for selective breeding programs to enhance the genetic predisposition for longer lifespans. Additionally, the genetic diversity among dairy cattle and buffalo breeds plays a pivotal role in determining longevity, emphasizing the importance of breed selection in herd management (Pritchard, 2010).

Genetic influences on longevity extend into the realm of resilience against environmental stressors. Recent research delves into identifying genes associated with heat tolerance, disease resistance, and adaptability to changing climates.

Nutrition and Feeding

Nutrition is a fundamental factor influencing the longevity of dairy cattle and buffalo. Balanced and nutritionally adequate diets are essential for these animals' overall health

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and productivity. Imbalances or deficiencies in essential nutrients can lead to reduced fertility, compromised immune function, and a higher susceptibility to diseases, all of which can shorten their lifespan. Proper nutrition is about quantity and ensuring the correct balance of nutrients for each stage of an animal's life as shown in Figure 3.

In the context of nutrition, emerging research explores the concept of precision feeding. This approach leverages advanced technology, including sensors and data analytics, to tailor dairy cattle and buffalo individualized diets. Precision feeding optimizes nutrient utilization, reduces waste, and promotes metabolic health by continuously monitoring an animal's nutritional needs and adjusting feed compositions shown in Figure 4. Such precision contributes to longer productive lives and aligns with sustainability goals by minimizing resource wastage by contributing to longer productive lives and aligning with sustainability goals by reducing resource wastage in excess feed (Bouwman *et al.*, 2013).

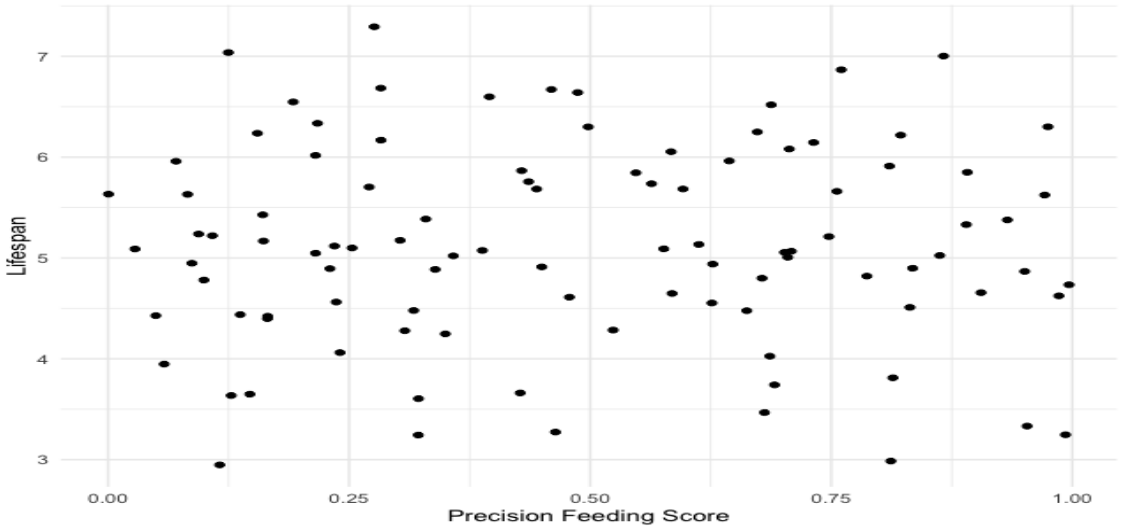

Figure 3. The scatterplot illustrates a potential relationship between precision feeding and cattle longevity (Prendiville *et al.*, 2010).

Housing and Environment

Housing and environmental factors are increasingly linked to animal behavior and welfare. Ethological research investigates how housing design and environmental enrichment can positively influence dairy cattle and buffalo's mental and emotional well-being. Considerations such as access to outdoor spaces, opportunities for social interaction, and comfortable resting areas are being integrated into housing practices to create environments that reduce stress and promote natural behaviors (Allen, 2013).

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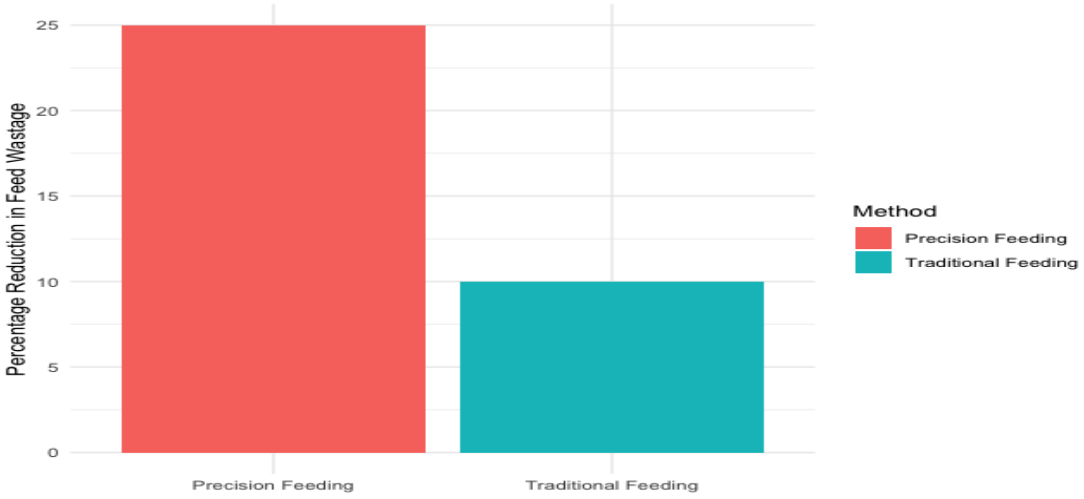

Figure 4. The bar chart showcases the efficiency of precision feeding in reducing resource wastage compared to traditional methods, highlighting sustainability benefits (Murphy and Allen, 2003).

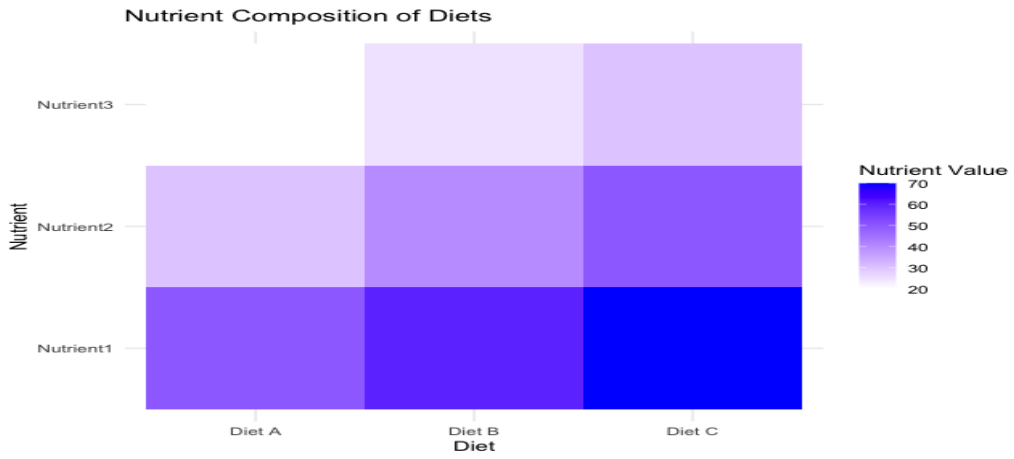

Figure 5. The heat map displays nutrient composition across diets, allowing assessment of nutrient balance (Mottet *et al.*, 2016).

Healthcare and Disease Management

Effective healthcare and disease management imperative for ensuring dairy cattle and buffalo longevity. Diseases can be a major cause of premature culling. Regular veterinary care, vaccinations, and disease prevention strategies are essential for herd management. Timely diagnosis and treatment of illnesses and proactive health monitoring contribute to extending productive lives. Preventative measures like biosecurity protocols and vaccination schedules are integral to minimizing disease incidence (Mason *et al.*, 2013).

Reproductive Management

Reproductive success is intimately linked to the longevity of dairy cattle and buffalo. Fertility issues can lead to prolonged non-productive periods, which are economically detrimental. Implementing efficient reproductive management practices, including timely breeding, artificial insemination, and pregnancy monitoring, is crucial for maintaining productivity and lifespan. Ensuring that animals have optimal conditions for reproduction, such as appropriate nutrition and reduced stress, plays a pivotal role in reproductive success.

These five factors, genetics, nutrition and feeding, housing and environment, healthcare and disease management, and reproductive management, represent critical aspects of dairy cattle and buffalo longevity. By doing so, dairy producers can promote the well-being of their animals, enhance productivity, and contribute to a more sustainable and prosperous dairy industry (Curry, 2013).

Reproductive management is evolving with a focus on sustainability. Researchers are investigating innovative techniques for improving reproductive efficiency while minimizing the environmental footprint. For instance, strategies to reduce the number of non-productive inseminations and increase the use of sexed semen are being explored. These approaches enhance reproductive outcomes and reduce the need for replacement animals, aligning with sustainability goals. Additionally, advancements in reproductive biotechnology, such as in vitro fertilization and embryo transfer, offer opportunities to propagate the genetics of high-performing and longer-lived animals more efficiently (Mottet *et al.*, 2018).

Culling Criteria and Practices

Economic Considerations

Economic considerations are a fundamental driver of culling decisions in the dairy industry. Dairy producers meticulously evaluate the cost-effectiveness of retaining or replacing an animal. Factors such as reduced milk production, high veterinary costs, and prolonged non-productive periods can render an animal economically unviable. Consequently, culling is often considered a pragmatic choice to mitigate financial losses and optimize resource allocation. While economic-driven culling decisions are vital for the financial sustainability of dairy operations, there is an ongoing shift towards holistic economic assessments that also consider the long-term impact of culling on herd genetics, productivity, and overall profitability (Gerber *et al.*, 2015).

Health and Welfare Concerns

Health and welfare concerns are central to ethical culling practices in dairy farming. Dairy producers increasingly prioritize the well-being of their animals, recognizing that humane treatment and responsible stewardship are ethical imperatives and ethical imperatives and essential for maintaining public trust. Culling decisions rooted in health and welfare considerations aim to prevent unnecessary suffering. Despite medical interventions, animals with severe or chronic health issues may be culled to spare them from prolonged discomfort. Additionally, culling is employed as a preventive measure to control disease outbreaks and minimize the risk of spreading contagious illnesses, thereby safeguarding the health and welfare of the entire herd (Boettcher *et al.*, 2015).

Productivity and Efficiency Metrics

Productivity and efficiency metrics determine when to cull dairy cattle and buffalo. Producers employ various performance indicators to assess an animal's contribution to the overall productivity of the herd. Metrics such as milk yield, reproductive efficiency, and feed conversion ratios offer insights into an animal's efficiency in converting resources into valuable dairy products. Animals that consistently underperform in these metrics may be culled to optimize herd productivity.

These perspectives on culling criteria and practices underscore the multifaceted nature of decision-making in the dairy industry. Balancing economic considerations, health and

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welfare concerns and productivity metrics is an intricate task that requires a nuanced understanding of each dairy operation's unique challenges and goals. Producers aim to optimize herd health, productivity, and sustainability by aligning culling practices with these diverse criteria while upholding ethical and economic standards (Liu *et al.*, 2010).

Technological Advances

Biotechnology and Genomics

Biotechnology and genomics have heralded a revolution in dairy farming, offering powerful tools to enhance longevity and productivity in dairy cattle and buffalo. Genomic selection, a technique that utilizes genetic markers to predict an animal's future performance, has become a cornerstone of breeding programs. It enables the identification of animals with superior genetic predispositions for longevity, milk production, and disease resistance. Biotechnology also includes reproductive technologies such as artificial insemination (AI) and embryo transfer (ET), which allow for the selective breeding of high-quality sires and the multiplication of superior genetics. These advancements accelerate genetic progress and contribute to preserving and disseminating valuable genetic material, ultimately extending the productive lives of these animals (Mottet and Tempio, 2017).

Precision Livestock Farming

Precision livestock farming leverages technology and data analytics to optimize the management of dairy cattle and buffalo. Sensors and monitoring systems are deployed to collect real-time data on vital parameters, including feed intake, activity, and health status. This data-driven approach facilitates early detection of health issues, timely interventions, and more efficient resource allocation, all instrumental in extending animal lifespan. Precision livestock farming also offers environmental benefits by minimizing resource wastage and reducing the carbon footprint of dairy operations. Moreover, it aligns with the principles of sustainability and animal welfare, ensuring that the well-being of the animals remains at the forefront of modern dairy farming practices (Tedeschi *et al.*, 2015).

Data Analytics and Decision Support Systems

Data analytics and decision support systems have emerged as essential components of modern dairy management. The volume of data generated by dairy operations is immense, encompassing everything from milk production records to health monitoring data. Advanced analytics tools enable the extraction of valuable insights from this data, facilitating informed decision-making. These systems can predict disease outbreaks, optimize breeding schedules, and fine-tune feeding regimens, contributing to herd health and longevity (Lotfi *et al.*, 2017). Furthermore, decision support systems offer real-time recommendations, allowing dairy producers to make timely interventions to prevent issues that may lead to culling. Integrating data analytics and decision support systems represents a significant leap forward in managing and optimizing dairy cattle and buffalo herds.

These technological advances, encompassing biotechnology and genomics, precision livestock farming, and data analytics with decision support systems, underscore the transformative potential of modern dairy farming. They empower dairy producers with the tools and insights to enhance longevity, productivity, and sustainability while addressing

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these valuable animals' welfare and well-being (Bleckwehl and Rada-Iglesias, 2019).

Economic Impact and Industry Trends

The economic impact extends to rural communities, where dairy farming often forms the backbone of local economies. Culling decisions in dairy farming directly influence economic outcomes. Premature culling can result in substantial financial losses due to replacement costs, reduced milk production, and wasted resources. Conversely, extending the productive lives of dairy cattle and buffalo has a positive economic impact by increasing overall herd efficiency and profitability (Morozov *et al.*, 2016).

Industry Trends:

The dairy industry is marked by several notable trends:

Sustainability

Sustainability has become a central theme, driven by environmental concerns. Dairy operations are adopting sustainable practices, such as reduced water usage, renewable energy adoption, and improved waste management, to minimize their ecological footprint (Tonus *et al.*, 2017).

Ethical Farming

Ethical considerations, including animal welfare and responsible practices, are gaining prominence. The industry is moving towards more humane treatment of animals, aligning with societal expectations and regulatory standards (Khetan, 2022).

Consumer Preferences

Evolving consumer preferences for organic, sustainable, and ethically produced dairy products are shaping market dynamics. Producers are adapting to meet these demands, leading to shifts in product offerings and marketing strategies (Park *et al.*, 2020).

Globalization

The dairy industry is increasingly globalized, with international trade playing a significant role. Market access, tariffs, and trade agreements directly impact the industry's economic viability (Liu *et al.*, 2012).

Health and Wellness

Growing awareness of health and wellness drives demand for dairy products with specific health benefits, such as probiotics and functional dairy foods. Producers are innovating to meet these demands (Whyte *et al.*, 2015).

Conclusion

In summary, the longevity and productivity of dairy cattle and buffalo are significantly influenced by genetic, nutritional, environmental, and technological factors. Our investigation into genetics has revealed the viability of precision breeding programs, leveraging genomic markers to enhance genetic predispositions favoring extended lifespans. Nutrition, as an evolving science, highlights the critical need for precise dietary management to ensure enduring health and vitality. Additionally, environmental factors, including housing, welfare, and sustainable practices, align with modern ethical considerations and environmental consciousness (Petitte *et al.*, 2004).

The thickness of the ribbons corresponds to the strength or importance of these relationships. In this specific Chord Diagram, concepts such as "Genetics," "Nutrition," "Environment," "Technology," "Economics," "Sustainability," "Culling," and "Industry Trends" are represented as sectors, and the ribbons between them show how these

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concepts are interconnected. The direction of the ribbons indicates the flow or influence between concepts (WJ Rogers, 2011).

This diagram provides a unique and visually striking representation of the complex interplay of ideas and concepts in your conclusion, making it easier for viewers to grasp the intricate relationships within your research or analysis.

Moreover, integrating cutting-edge biotechnology, genomics, and precision farming technologies is reshaping dairy management paradigms, offering unprecedented insights into animal health and resource optimization. This, in turn, aligns with burgeoning consumer preferences for sustainable, ethically sourced, and health-conscious dairy products (Cardoso *et al.*, 2016).

Simultaneously, economic factors emphasize the necessity of judicious culling practices that strike a balance between financial viability and sustainability. Concurrently, industry dynamics mirror a landscape influenced by sustainability, ethics, technological innovation, globalization, and shifting consumer preferences. The economic ramifications of culling are significant, with prudent decisions serving as a crucial determinant of profitability and effective resource utilization (Gross, 2023).

In the grand tapestry of the dairy industry, sustainability and ethics have emerged as guiding stars, directing practices toward preserving both environmental equilibrium and ethical stewardship. The collective endeavors of the industry and its stakeholders are forging a path that harmonizes economic prosperity, ecological sustainability, and ethical commitment.

As we navigate the complexities of dairy cattle and buffalo management, our pursuit transcends mere industry practice; it is a collaborative endeavor to preserve invaluable genetic resources, enhancing animal well-being, and conserving our environmental heritage. Ultimately, the future of dairy farming hinges on the synergy of science, ethics, and economics, forging a prosperous and principled trajectory (Riekerink *et al.*, 2008).

Recommendations

Selective Breeding Programs: Harness the power of genomics and genetic markers to establish selective breeding programs to enhance genetic predispositions for longevity. Continuously assess the genetic potential of breeding stock and incorporate animals with superior genetic traits into the herd to promote longer lifespans and improved productivity (van Pelt, 2017).

Nutritional Optimization: Implement precise nutritional management practices that account for the nutritional needs of dairy cattle and buffalo at various life stages. Consider using advanced feed additives and dietary regimens to optimize metabolic health and enhance overall well-being (Essl, 1998).

Environmental Well-Being: Prioritize the creation of comfortable, low-stress housing environments that align with ethical standards and enhance animal welfare. Consider investments in well-ventilated, spacious housing, access to outdoor spaces, and animal social interaction opportunities (Dallago *et al.*, 2021).

Healthcare Protocols: Establish comprehensive healthcare protocols that include regular veterinary care, vaccinations, and disease prevention strategies. Embrace emerging technologies like telemedicine and remote monitoring to enable early disease detection and targeted interventions.

Reproductive Efficiency: Implement efficient reproductive management practices that optimize breeding schedules and reduce non-productive periods. Explore using advanced reproductive technologies like sexed semen and in vitro fertilization to propagate superior genetics (Katothya, 2017).

Precision Livestock Farming: Embrace precision livestock farming technologies to efficiently monitor and manage dairy cattle and buffalo. Leverage real-time data analytics and decision support systems to enhance animal health, productivity, and resource allocation.

Sustainability Integration: Integrate sustainable practices into dairy farming operations, focusing on resource efficiency, reduced environmental impact, and circular economy principles. Explore renewable energy sources, waste management solutions, and sustainable land use practices (Bousquet and Blondin, 2004).

Incorporating these recommendations into dairy cattle and buffalo management practices can help optimize longevity, enhance productivity, ensure sustainability, uphold ethical standards, and navigate the dynamic landscape of the dairy industry. By continually refining and adapting practices in alignment with these principles, dairy producers can contribute to a more prosperous and conscientious future for the industry and its valuable animals (Schaeffer, 2006).

Future Research Directions

Precision Breeding and Genomics: Future research should delve deeper into the genomics of dairy cattle and buffalo to identify additional genetic markers associated with longevity, disease resistance, and environmental adaptability. Investigate the potential of gene editing techniques to enhance desirable traits while ensuring animal welfare and ethical considerations.

Nutritional Science: Advance nutritional research to optimize dietary regimens, considering individual variations and environmental factors. Explore using precision feeding techniques to tailor diets for each animal, maximizing health and productivity while minimizing resource wastage.

Environmental Sustainability: Research should focus on innovative sustainable practices for dairy farming, including novel manure management strategies, carbon sequestration, and resource-efficient land use. Investigate the potential of regenerative agriculture practices to enhance environmental sustainability.

Animal Welfare: Enhance our understanding of animal behavior and psychology to create housing environments promoting well-being. Explore the impact of different housing designs, social interactions, and enrichment activities on dairy cattle and buffalo's mental and emotional health.

Disease Prevention and Management: Future research should concentrate on developing advanced disease prediction models based on big data analytics and machine learning. Investigate the potential of precision medicine approaches for dairy cattle and buffalo, tailoring healthcare interventions to individual animal needs.

Conflict of Interest

The authors have not declared any conflict of interest.

Authors Contributions

HMB Akhtar: Conceptualization & Paper writeup, AA Wadood: Paper review and writeup, S Mehmood: Paper Review, A Umer: Proof reading, SMH Andrabi: Supervision, MN Riaz: Supervision & Funding.

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