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EDITORIAL
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Rethinking Wearable Technology in Dairy Cows: Challenges and Prospects for Smart Collars

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Abstract:
The increasing global demand for animal-derived products, alongside concerns about sustainability and animal welfare, has accelerated the adoption of Precision Livestock Farming sensories. Among these, smart collars for dairy cows represent a key innovation, offering continuous, objective monitoring of animal behaviour. Despite their advantages, such as early disease detection and support for preventive management aligned with One Health principles, significant limitations persist. Current devices suffer from poor multisensory integration, limited interoperability, energy inefficiency, and high operational costs, especially for small to medium farms. This editorial critically examines the technological and functional gaps of existing solutions, advocating for a paradigm shift towards modular, interconnected, user-centered smart collars. Achieving this transformation requires a transdisciplinary effort to ensure that future wearable technologies fully meet the biological, operational, and ethical demands of modern dairy farming.

Keywords: PLF, Wearable technology, Smart collars, Dairy cattle monitoring, Animal welfare, Sustainable farming.

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1. INTRODUCTION

The global population is projected to increase from the current 8.2 billion people to 9.4 billion in 2050. This demographic growth will inevitably lead to a heightened global demand for animal-derived food products as

to meet evolving nutritional needs [1,2]. Within this context, several key issues are gaining increasing prominence: the need to enhance production efficiency, rising societal expectations around animal welfare, the imperative to reduce greenhouse gas emissions from the livestock sector, and the growing consumer demand for transparency throughout the food supply chain. These elements are directly shaping market dynamics, shifting the focus toward products that are not only high in quality but also produced in accordance with environmental, social, and economic sustainability criteria [3,4].

To effectively address these challenges, there is a growing interest in the adoption of digital solutions aimed at improving herd management [5]. In this regard, Precision Livestock Farming (PLF) has emerged as an innovative and transformative approach. PLF represents a multidisciplinary and interdisciplinary paradigm that integrates principles from computer science [6], biostatistics, physics and engineering [7], and economics into livestock production, reproduction, behaviour, and nutrition [8]. The overarching goal is to maximize operational efficiency, improve animal health and welfare, and ensure the overall sustainability of livestock production systems. This is achieved through the automated, continuous, real-time collection of data with minimal or no impact on the animals themselves.

Among the wearable technologies employed in PLF, classified as "on-animal" technologies, are ear tags [9], pedometers, ruminal boluses, and collars [10]. The latter represents one of the most widely adopted solutions in dairy cattle farming. These devices enable continuous behavioural monitoring by detecting parameters such as feeding, rumination, locomotion, resting, and oestrous activity. The availability of such data is highly valuable not only to researchers and veterinarians but also to farmers seeking to optimize herd management [9,10]. By combining motion sensors (i.e., accelerometers) with analytical algorithms, collars can identify behavioural patterns, detect early warning signs of anomalies, and contribute to the prevention of disease onset [10,11].

Despite significant advancements in recent years and increasing market availability, current devices still exhibit important technological, functional, and operational limitations. These shortcomings hinder their practical effectiveness and limit their broader implementation at the farm system level [10]. This editorial aims to highlight both the major strengths of smart collars and the barriers that must be overcome to unlock their full practical potential in dairy farming.

2. DISCUSSION

The primary advantage of smart collars lies in their ability to collect data objectively, continuously, and non-invasively. Unlike direct observations, which are time-consuming and subject to observer bias, these devices provide a steady and reliable flow of information. This enables the early detection of clinical or subclinical disturbances, even before overt symptoms appear [12-15]. For instance, a reduction in rumination time may indicate digestive disorders or stress, while changes in resting behaviour can signal pain conditions, such as lameness. Integration with artificial intelligence algorithms is further enhancing the predictive capabilities of these systems. It is now possible to anticipate risks related to lameness, mastitis, metritis, or reproductive disorders and intervene proactively. These features align closely with the One Health approach, which recognizes animal health as a critical component of global food security and the fight against antimicrobial resistance. In this sense, collars serve as effective tools for preventive management, with positive outcomes in terms of reduced veterinary costs and more rational use of pharmaceuticals.

However, field experience reveals several critical issues. Nearly all commercially available collars rely on single-sensor technologies or a limited number of integrated sensors. While such devices can detect general behavioural patterns, they often lack the accuracy to distinguish between similar behaviours, such as feeding versus rumination or standing versus alertness. The core limitation lies in the poor multisensor integration; a truly comprehensive understanding of an animal's condition would require combining data from multiple systems, including accelerometers, gyroscopes, magnetometers, microphones, thermometers, GPS units, and RFID technologies. This integration would not only improve behavioural analysis but also enhance adaptability to complex and dynamic farm environments. Yet, current devices often operate as closed, non-interoperable systems, limiting connectivity with other farm tools such as milking robots, environmental monitoring stations, or management software. The result is fragmented information flows that hinder the development of truly integrated decision-support systems [16]. Furthermore, even when different devices are integrated, this occurs only between tools developed by the same manufacturing company, conditioning the choice of farmers and directing the market towards a *de facto* oligopoly.

Another critical aspect concerns energy autonomy. Many devices require manual replacement or recharging after short periods, interrupting data collection and increasing the operational burden on the farmer. This issue becomes more severe in extensive farming systems or in any case those that require long periods of grazing. Without the adoption of advanced solutions such as wireless, solar, or kinetic charging, the large-scale implementation of these tools will continue to be hampered by issues of practicality and sustainability [10].

From an economic perspective, the cost-benefit ratio is not always favourable, particularly for small and medium-sized operations. The actual utility of the device depends on how easily the farmer can interpret the collected data and on the system's ability to generate timely and actionable reports [10].

Overcoming current technological and operational barriers requires a radical rethinking of the role of smart collars. These devices, too often conceived as standalone, isolated units, should evolve into fully interconnected nodes within an integrated digital ecosystem. The future vision demands a paradigm shift: from rigid, standardized tools to modular and flexible platforms, adaptable to various management and research contexts. Personalization must go hand in hand with robust and lasting energy autonomy, as well as cloud-native infrastructures that ensure full interoperability with pre-existing systems on the farm.

Another fundamental issue concerns economic accessibility and ethical sustainability. Future solutions should be designed not only with scientific rigor but also in adherence to data privacy principles and transparency in information management. In this context, the user interface, which is often overlooked, must be intuitive and functional, enabling use even by non-specialized personnel [10].

Facilitating this transition requires a transdisciplinary approach, involving engineers, veterinarians, ethologists, data scientists, and, critically, farmers themselves. Without the direct involvement of end users, any innovation has the risk of being disconnected from real-world operations, limiting both its effectiveness and adoption [17].

As the advantages of smart collars are being recognized, their uptake and use differs widely from country to country because of differences in livestock rearing systems, economic conditions, and technological willingness. For example, the USA is well ahead in terms of both research outputs and commercial uptake, due to its large-scale farming operations where precision tools improve profitability and productivity. Other European countries, such as Italy, have a strong interest in innovation, in particular for high-value production chains which comprises DOP (Protected Designation of Origin) dairy products. Here, smart collars support enhanced traceability and quality control. Australia, with its extensive grazing systems, emphasizes remote monitoring capabilities to manage cattle over a vast landscapes, prioritizing GPS-based and low-maintenance solutions. Meanwhile, countries like China and others in Europe demonstrate a growing but more cautious approach, often limited by cost or infrastructure constraints. These disparities highlights the need for modular, cost-sensitive, and context-adaptable smart collar designs, to ensure global applicability and equitable technological diffusion across the dairy sector [18].

CONCLUSION

Smart collars must not be viewed as an end in themselves, but rather as strategic tools to support more informed, efficient, and responsible livestock farming. The opportunities offered by artificial intelligence, the Internet of Things, and wearable technologies places the dairy sector at a pivotal crossroads. The challenge lies in building digital systems that can truly respond to the biological complexity of animals, the need for sustainable productivity, and the environmental responsibilities demanded by contemporary society. Unless the current limitations are addressed through rigorous scientific inquiry and user-centred design, the potential of smart collars will remain unfulfilled. Only then can these devices become structural components of a modern, resilient, and ethically driven livestock production model.

AUTHORS' CONTRIBUTIONS

The authors confirm contribution to the paper as follows: M.L., D.C.: Study conception and design; M.L.: Draft manuscript; M.B., G.B., A.R.: Critical revision and editing; D.C.: Project administration and supervision. All authors reviewed the results and approved the final version of the manuscript.

LIST OF ABBREVIATIONS

PLF	=	Precision Livestock Farming
DOP	=	Protected Designation of Origin

AVAILABILITY OF DATA AND MATERIALS

The data supporting the findings of this article are available from the corresponding author upon reasonable request.

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CONFLICT OF INTEREST

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