Review

Advancing Livestock Technology: Intelligent Systemization for Enhanced Productivity, Welfare, and Sustainability

Petru Alexandru Vlaicu 1, Mihail Alexandru Gras 2,*, Arabela Elena Untea 1, Nicoleta Aurelia Lefter 3 and Mircea Catalin Rotar 2

1 Feed and Food Quality Department, National Research and Development Institute for Animal Biology and Nutrition, 077015 Balotesti, Romania; alexandru.vlaicu@outlook.com (P.A.V.); arabela.untea@ibna.ro (A.E.U.)
2 Animal Genetic Resources Management Department, National Research and Development Institute for Animal Biology and Nutrition, 077015 Balotesti, Romania; catalin.rotar@ibna.ro
3 Animal Nutrition and Biotechnology Department, National Research and Development Institute for Animal Biology and Nutrition, 077015 Balotesti, Romania; nicoleta.lefter@ibna.ro
* Correspondence: mihai.gras@ibna.ro

Abstract: The livestock industry is undergoing significant transformation with the integration of intelligent technologies aimed at enhancing productivity, welfare, and sustainability. This review explores the latest advancements in intelligent systemization (IS), including real-time monitoring, machine learning (ML), and the Internet of Things (IoT), and their impacts on livestock farming. The aim of this study is to provide a comprehensive overview of how these technologies can address industry challenges by improving animal health, optimizing resource use, and promoting sustainable practices. The methods involve an extensive review of the current literature and case studies on intelligent monitoring, data analytics, automation in feeding and climate control, and renewable energy integration. The results indicate that IS enhances livestock well-being through real-time health monitoring and early disease detection, optimizes feeding efficiency, and reduces operational costs through automation. Furthermore, these technologies contribute to environmental sustainability by minimizing waste and reducing the ecological footprint of livestock farming. This study highlights the transformative potential of intelligent technologies in creating a more efficient, humane, and sustainable livestock industry.

Keywords: smart farming; livestock technology; sustainability; smart systems; animals; farms; production systems

1. Introduction

In recent years, the agricultural sector has undergone profound transformation driven by technological advancements that have changed traditional farming practices, and one key area that has witnessed significant progress is livestock technology. The integration of cutting-edge technologies has not only improved the efficiency of livestock production, but also paved the way for sustainable and more humane practices [1].

Advanced livestock technology comprises a wide range of innovations, including precision farming, data analytics, genetic engineering, and intelligent systemization [2]. These advancements aim to address the challenges faced by the livestock industry, such as feeding a growing global population, minimizing environmental impact, and ensuring animal welfare. Precision farming within the realm of livestock technology involves the strategic use of information technology, satellite positioning data, and sensor technologies [3]. These tools aid farmers in optimizing the management of their resources, from feed distribution to monitoring animal health, with the purpose of maximizing productivity while minimizing waste and environmental impact. The advent of big data analytics has ushered in a new era for livestock farming. Data analytics tools process vast amounts of information collected from various sources, such as animal wearables, environmental sensors, and...
health records [4]. This wealth of data enables farmers to make informed decisions, identify patterns, and implement strategies that enhance their overall productivity and efficiency. These advanced technologies leverage genetic engineering to enhance desirable traits in animals [5]. As previously reported, through selective breeding and genetic modifications, farmers can develop livestock with improved disease resistance, higher reproduction rates, and optimized feed conversion rates [6]. This not only contributes to better animal welfare, but also enhances the economic viability of livestock farming. Moreover, at the core of advanced livestock technology is the concept of intelligent systemization, which involves the integration of artificial intelligence (AI), machine learning (ML), and automation into various aspects of livestock production, with the main purposes of IS being to analyze data in real-time, enable proactive decision making, the optimization of resource utilization, and streamlining overall farm management [7,8]. These will lead to more sustainable practices, which are the key in the advancement of livestock technology. From mitigating environmental impacts to promoting responsible resource management, technology plays a crucial role in fostering sustainable practices, such as the precision application of fertilizers, reduced water consumption, and the integration of renewable energy sources into power farm operations [9]. These tools also can help with the early detection of diseases, stress, or nutritional deficiencies, which allows farmers to intervene promptly, reducing the need for antibiotics and enhancing overall animal welfare. At the same time, robotics and automation have found their way into livestock farms, transforming labor-intensive tasks [10]. Automated feeding systems (AFS), robotic milking machines, and AI-powered sorting systems contribute to increased operational efficiency, which helps farmers to focus on strategic decision making and animal care while routine tasks are handled seamlessly by technological solutions. Furthermore, the integration of smart infrastructure, which includes connected devices and Internet of Things (IoT) applications, helps to facilitate the real-time monitoring of environmental conditions, such as temperature, humidity, and air quality [2,9,11]. Smart infrastructure enhances the overall living conditions for livestock, contributing to healthier and more comfortable environments. Also, livestock farmers are increasingly leveraging collaborative platforms that connect them with industry experts, researchers, and fellow farmers. These platforms facilitate the sharing of best practices, research findings, and innovative solutions [12–14]. The collaborative nature of these platforms accelerates the adoption of advanced technologies and fosters a community-driven approach to livestock farming.

The aim of this paper is to delve into the recent advancements and practical applications of intelligent technologies in livestock farming. The paper focuses on how these technologies can be systematized to improve productivity, animal welfare, and sustainability. By examining various intelligent tools and methodologies, the paper provides insights into the challenges and opportunities within the industry. The goal is to offer a comprehensive understanding of how IS can transform livestock farming into a more efficient and sustainable sector.

2. Importance of Intelligent Systemization in Livestock Production

Intelligent systemization (IS) plays an important role in shaping the future of livestock production. This involves the integration of AI, ML, and automation to optimize various aspects of farming operations. The importance of IS in livestock production can be understood through its impact on several key areas, as presented in Table 1. To facilitate effective predictions and decision making, techniques such as data analytics and ML are required. ML models have recently been utilized to forecast various key variables relevant to decision making, such as sales and feed performance [15]. Consequently, the acquisition and analysis of data play pivotal roles in gaining a competitive edge in the agricultural sector. As reported by Lee and Shin [16], the accessibility and availability of well-organized data are essential for the efficacy of ML models. Thus, exploring the complete process of data analytics is imperative for the practical application of enhanced data analytics techniques, as shown by others [17]. Data-driven decision processes in animal farms involve the use of...
real-time data in diverse aspects of livestock management. Utilizing data for performance recording and animal identification is vital for farmers, as the automated data acquisition of animal identity and trait measurements provides crucial insights into animal health, productivity, and efficiency, in line with ICAR guidelines for ruminants [18]. Adopting data-driven decision making revolutionizes livestock management by offering unprecedented insights into farm operations, thus enhancing efficiency and productivity. Through data analytics and technology, farmers and livestock managers can optimize resources and increase farm sustainability. The primary benefits of using data-driven decisions in livestock management include capital optimization, market demands prediction, environmental sustainability, preventive health care, and improved reproduction methods [19].

Since the 1970s, precision livestock farming (PLF) has evolved significantly, from electronic milk meters for cows to behavior-based estrus detection and rumination activity monitoring. PLF integrates information technology, data science, and animal husbandry [18,19]. Research in PLF is driven by perspectives from animal science, veterinary medicine, computer science, agricultural engineering, and environmental science. The demand for animal-derived products is rising due to population growth and increased affluence, necessitating the optimization of animal feed intake, disease mitigation, and welfare improvement [20,21]. Collaboration among farmers, feed manufacturers, and stakeholders is crucial for achieving optimized animal-based production, focusing on catering to individual animal needs, known as PLF. This transition involves collecting and analyzing comprehensive data on animal growth, production outcomes, disease prevalence, behavior, and environmental conditions. This data-driven approach aligns with the broader trend of precision farming observed in various agricultural disciplines [22].

Intelligent automation has revolutionized livestock feeding through automated feeding systems (AFSs), which dispense precise amounts of feed at optimal times, ensuring that each animal receives the necessary nutrients for growth and productivity. This reduces wastage, enhances cost efficiency, and optimizes resources. Although AFSs are popular in the United States, they are relatively new in European countries [23]. These systems alleviate the workload of livestock farmers, saving time and enhancing flexibility, allowing them to focus more on organizational duties [24]. Hansen et al. [25] found that automatic milking systems (AMSs) improve farmers’ well-being by reducing barn operation responsibilities. Lovarelli et al. [26] highlighted the potential of automatic systems in precision livestock farming (PLF) to enhance economic viability. Bragaglio et al. [27] compared traditional dairy farms to precision-agriculture-based farms, noting that AMSs and AFSs reduced energy consumption and environmental impact. Additionally, Rodrigues et al. [28] reported that administering a total mixed ration with an AFS can decrease ammonia (NH3-N) emissions from dairy cows’ waste compared to conventional feeding, though there was no significant difference in greenhouse gas (GHG) emissions.

Enhanced animal welfare is another significant benefit of IS, which monitors and responds to individual needs. Automated climate control systems, for instance, can adjust temperature and ventilation based on real-time data (such as the number of animals, NH3 levels, and dust particles), ensuring optimal conditions [29]. This not only improves livestock well-being, but also enhances the quality of final products. An overview of different ISs used in agriculture and livestock farming for decision making is presented in Table 2. By analyzing complex datasets, managers can gain a comprehensive overview, allowing them to optimize the functional flow of their operations, as mentioned by Wang et al. [30].

The integration of data analysis with new technologies has significantly boosted herd productivity in the past decade [31]. Platforms like HerdX democratize data analysis access, accelerating technology adoption in animal farming. Genetic editing, notably CRISPR-Cas, and omics technologies have transformed animal breeding [31]. Whole-genome sequencing and genomic information integration have become pivotal. Third-generation sequencing techniques have spurred technological breakthroughs in omics, aiding in gene function discovery, accurate genetic variation detection, and precise large-scale sequencing data...
Data integration into a Data Hub enables continuous monitoring and informed decision making [33].Farm applications utilize advanced analytics, integration, and real-time predictive tools like Dairy Brain for enhanced decision making. Data-driven decision making is crucial for addressing agriculture’s environmental impact [34].Online platforms such as CAP’2ER, CoolFarmTool, Farm Carbon Toolkit, and AGRECALC democratize carbon footprint calculations, aiding users in understanding and reducing emissions [34].These tools offer systematic methods for calculating carbon footprints, raising awareness, and facilitating emission reduction actions, allowing users to explore cost-efficient mitigation measures.

Table 1. The main methods and outcomes of using intelligent systems in livestock production.

<table>
<thead>
<tr>
<th>System</th>
<th>Methods</th>
<th>Outcomes</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data-driven decision making</td>
<td>Data analytics, machine learning (ML)</td>
<td>Improved predictions and decision making in agriculture; competitive edge gained through data acquisition and analysis</td>
<td>[15,17]</td>
</tr>
<tr>
<td>Performance recording and animal identification</td>
<td>Automated data acquisition, ICAR guidelines</td>
<td>Enhanced insights into animal health, productivity, and efficiency</td>
<td>[18]</td>
</tr>
<tr>
<td>Livestock management</td>
<td>Data analytics, real-time data utilization</td>
<td>Optimization of resources, increased sustainability, capital optimization, market demands prediction, environmental sustainability, preventive healthcare, and improved reproduction methods</td>
<td>[19]</td>
</tr>
<tr>
<td>Precision livestock farming (PLF)</td>
<td>Information technology, data science, and PLF technology</td>
<td>Optimized animal feed intake, disease risk mitigation, enhanced animal welfare and living conditions, and collaboration among stakeholders for optimized production of animal-derived products</td>
<td>[20,24]</td>
</tr>
<tr>
<td>Automated feeding systems</td>
<td>Automated feeding systems (AFS)</td>
<td>Precise feed dispensing, reduced wastage, cost efficiency, resource optimization, improved farmer well-being, reduced energy consumption, and environmental impact</td>
<td>[25,28]</td>
</tr>
<tr>
<td>Enhanced animal welfare</td>
<td>Automated climate control systems</td>
<td>Improved animal well-being and enhanced quality of final products</td>
<td>[29]</td>
</tr>
<tr>
<td>Optimized operations</td>
<td>Data analytics and data-driven decision making</td>
<td>General optimization of inputs/outputs and comprehensive operational view for managers</td>
<td>[30]</td>
</tr>
<tr>
<td>Technology integration</td>
<td>Novel technologies, online tools, genetic editing (CRISPR-Cas), omics technologies</td>
<td>Increased herd productivity, genetic improvement, major advances in omics technologies, precise gene expression analysis</td>
<td>[31,32]</td>
</tr>
<tr>
<td>Continuous monitoring</td>
<td>Data Hub, advanced data analytics, and real-time predictive tools</td>
<td>Facilitated continuous monitoring and informed decision making in short-, medium-, and long-term</td>
<td>[33]</td>
</tr>
<tr>
<td>Environmental impact</td>
<td>Online tools for carbon footprint calculation CAP’2ER, Cool-FarmTool, Farm Carbon Toolkit, AGRECALC</td>
<td>Informed decisions on carbon emissions, awareness and action on emission reduction, and sustainable and ethical farming practices</td>
<td>[34]</td>
</tr>
</tbody>
</table>
Table 2. Intelligent systematization technology used in livestock production for decision making.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Methods</th>
<th>Objective/Function</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big data analyses, ML, AI</td>
<td>ML, AI, sensors, wearable devices, and monitoring tools</td>
<td>This enables farmers to make informed decisions regarding feed management, breeding practices, and disease prevention. By analyzing historical data, these systems can predict trends and optimize strategies for enhanced productivity. Utilizing data to drive decisions in farming entails relying on predictions derived from information collected within the farm and throughout the supply chain.</td>
<td>[35]</td>
</tr>
<tr>
<td>Precision Livestock Farming (PLF)</td>
<td>Sensors, monitoring devices</td>
<td>Tracking individual animals' health, behavior, and performance, identify deviations from normal patterns, allowing for early detection of diseases or stress, minimizing the need for antibiotics and other interventions.</td>
<td>[23]</td>
</tr>
<tr>
<td>Genetic engineering for improved traits</td>
<td>Transgenic technology</td>
<td>Advances in genetic engineering have enabled the development of livestock with enhanced traits such as disease resistance, higher milk or meat yields, and improved feed efficiency, by analyzing genetic data, leading to the development of healthier and more productive animal populations.</td>
<td>[36,37]</td>
</tr>
<tr>
<td>Environmental monitoring and sustainability</td>
<td>Drones, sensors</td>
<td>IS allows farmers to monitor and manage factors such as water usage, greenhouse gas emissions, and waste disposal more effectively. By optimizing resource utilization and adopting sustainable practices, livestock producers can contribute to environmental conservation.</td>
<td>[38,39]</td>
</tr>
<tr>
<td>Supply chain optimization</td>
<td>AI, ML, blockchain technology</td>
<td>Integration with logistics, processing, and distribution systems ensures that the road from farm to table is efficient and transparent. This not only reduces waste, but also enhances the overall quality and safety of livestock products.</td>
<td>[40–42]</td>
</tr>
<tr>
<td>Remote monitoring and management</td>
<td>IoT, cloud computing, satellite imagery, drones, multispectral cameras</td>
<td>The ability to remotely monitor and manage livestock operations is a game-changer for farmers. IS enables real-time surveillance of farms, allowing farmers to address issues promptly and efficiently. This is particularly beneficial for large-scale operations where physical presence may be challenging.</td>
<td>[43,44]</td>
</tr>
<tr>
<td>Smart farming</td>
<td>Knowledge base, multi-agent technology</td>
<td>Smart farming involves different stages like collection of information on the farm, field, culture, data analysis, and decision making and implementation of decisions—agrotechnical operation.</td>
<td>[45,46]</td>
</tr>
</tbody>
</table>

The integration of AI, ML, and automation in livestock farming can drive significant improvements in productivity, animal welfare, and overall sustainability (Figure 1). Enhanced productivity is achieved through precision feeding, where AI systems analyze data to determine the optimal feeding regimes for each animal, improving growth rates and feed efficiency. Health monitoring benefits from ML algorithms that predict and detect diseases early by analyzing patterns in behavior, temperature, and movement, reducing illness and associated productivity losses [35]. Additionally, automated reproductive management systems monitor cycles and detect optimal breeding times, improving reproductive success rates. Improved animal welfare results from behavioral monitoring, where AI tracks and
analyzes animal behavior to identify signs of stress, discomfort, or illness, allowing for early interventions. Automated systems also maintain the optimal living conditions, such as temperature, humidity, and ventilation, reducing stress and promoting better health [23]. Furthermore, automation reduces the need for frequent human–animal interactions, minimizing stress and creating a more stable environment. Sustainability is enhanced through AI-driven systems that optimize resource use, such as water, feed, and energy, reducing waste and lowering the environmental footprint of farming operations [41,42]. Improved feed efficiency and health management also help to reduce methane emissions from livestock, contributing to lower greenhouse gas emissions. Comprehensive data collection and analysis enable more informed decision making, promoting practices that are both economically and environmentally sustainable [15,16].

3. Intelligent Systematization in Livestock Growth Analysis

IS in livestock growth analysis represents a pioneering approach at the intersection of agriculture, data science, and AI, as reported by Pivoto [47]. As the global demand for food continues to rise alongside the complexities of livestock management, there is an imperative need for innovative methodologies to optimize production efficiency, ensure animal welfare, and sustainably meet consumer demands. Livestock growth analysis traditionally relies on empirical observations and manual data collection, which can be time-consuming, error-prone, and limited in scope. However, with the appearance of IS, powered by advanced computational techniques such as ML, data mining, and predictive analytics, a paradigm shift is underway. IS, rooted in advanced computational techniques and a data-driven approach, is fundamental for monitoring and holds immense potential to positively impact both productivity and quality within various sectors, including agriculture and livestock farming [48,49]. Firstly, in terms of productivity, IS enables farmers to optimize their resource allocation and management practices [50]. Secondly, IS allows for the precise monitoring of environmental conditions, such as temperature, humidity, and air quality [51], enabling farmers to create optimal conditions for animal growth and productivity. Furthermore, IS facilitates automation and process optimization, reducing manual labor and operational inefficiencies [52]. Through the integration of sensors, actuators, and IoT devices, tasks such as feeding, watering, and monitoring can be automated, freeing up valuable time and resources for other critical activities. This increased efficiency not only boosts productivity, but also reduces costs and enhances overall farm profitability.

3.1. Utilizing Advanced Technologies for Animal Growth Monitoring

IS gathers the vast amounts of data generated within livestock farming operations, encompassing factors such as animal health records, genetic profiles, environmental conditions, and feed composition. By integrating these diverse datasets and employing sophisticated algorithms, it enables real-time monitoring, analysis, and decision making, fostering a holistic understanding of livestock growth dynamics. One of the primary goals of IS in livestock growth analysis is to optimize resource allocation and management practices. As reported by others, through predictive modeling and optimization algorithms, farmers can anticipate growth trajectories, identify potential health issues, and optimize feed...

![Figure 1](image-url) Graphic representation of the improvements of integrating artificial intelligence (AI), machine learning (ML), and automation to optimize various aspects of farming operations.
formulations tailored to individual animals or specific groups [15,53]. This personalized approach not only enhances production efficiency, but also minimizes waste and environmental impact. Moreover, IS empowers farmers with actionable insights to enhance animal welfare and mitigate risks [54]. By detecting early signs of disease or stress through data patterns and behavioral analysis, interventions can be implemented proactively, leading to improved growth, health outcomes, and reduced mortality rates. Furthermore, IS facilitates continuous learning and adaptation within livestock farming systems [55,56]. By leveraging historical data and feedback loops, algorithms can refine their predictive accuracy over time, adapting to changing environmental conditions, market dynamics, and regulatory requirements. The adoption of IS in livestock growth analysis is not without challenges. Data privacy, the interoperability of systems, and the need for domain expertise in both agriculture and data science require careful consideration. However, the potential benefits, including increased productivity, sustainability, and profitability, will probably far outweigh these challenges.

3.2. Data-Driven Approaches in Analyzing Livestock Development

In analyzing livestock development, data-driven approaches indicate a new era in agriculture, leveraging the vast amounts of data generated within livestock farming operations to optimize productivity, welfare, and sustainability [57,58]. These approaches collect diverse datasets, encompassing factors such as animal health records, genetic profiles, environmental conditions, and feed composition, fostering a comprehensive understanding of livestock development dynamics. One of the key advantages of data-driven approaches is their ability to provide actionable insights for optimizing livestock development strategies. By analyzing historical data and identifying patterns, trends, and correlations, farmers can make informed decisions regarding breeding programs, nutrition management, disease prevention, and growth optimizations [59]. This personalized approach not only maximizes productivity, but also enhances animal welfare and minimizes environmental impact. Furthermore, data-driven approaches facilitate the early detection and mitigation of risks to livestock development. By leveraging predictive analytics and anomaly detection algorithms, farmers can identify potential health issues, environmental stressors, or management inefficiencies before they escalate, enabling timely interventions to minimize losses and optimize outcomes [60]. Moreover, data-driven approaches foster continuous improvement and innovation within livestock development systems. By analyzing performance metrics, feedback loops, and experimental data, farmers can refine their practices, adapt to changing conditions, and optimize resource allocation over time [61]. This iterative process of learning and adaptation enables farmers to stay ahead of challenges and capitalize on emerging opportunities in the livestock industry [62]. However, the adoption of data-driven approaches in analyzing livestock development is not without challenges. Integrating AI in livestock farming faces several key challenges, including ensuring data quality, as the accuracy, consistency, and reliability of collected data are essential for effective AI applications [63]. Another issue is the interoperability of systems, as different technologies need to work seamlessly together despite varying standards and protocols [64]. Additionally, there is a need for skilled personnel with expertise in both agriculture and data science to effectively implement and manage AI technologies [65]. Additionally, concerns regarding data privacy, security, and regulatory compliance require careful consideration to ensure the ethical and responsible use of data [66]. Overall, as mentioned above, the power of data and advanced analytics hold the promise of maximizing productivity, enhancing animal welfare, and ensuring the long-term viability of livestock farming operations in an increasingly complex and interconnected world.

3.3. Intelligent Systematization Impacts on Productivity and Quality

In terms of quality, IS enables farmers to implement precise and targeted interventions to improve the health, genetics, and overall well-being of livestock. By analyzing vast amounts of data, including genetic profiles, health records, and environmental factors,
farmers can identify and address potential issues before they impact product quality. For example, recently, it was reported by Hassan et al. [67] that by monitoring animal behavior and health indicators in real time, farmers can detect signs of stress or disease early on, allowing for timely interventions and preventing the deterioration of product quality. A recent study conducted by Pak et al. [68] concluded that digital livestock systems have the potential to enhance the well-being and behavior of laying hens, while also positively impacting egg cholesterol and fatty acid compositions when compared to traditional livestock methods. The same author later demonstrated that the use of a digital livestock system can improve the growth performance of swine compared to both a conventional livestock system without a probiotic mixture and a conventional system with a probiotic mixture [69]. Other authors reported that the implementation of a smart poultry feeding system demonstrated significant improvements in egg production, egg quality parameters, blood parameters, immune cell growth, and cecal microflora balance compared to conventional feeding systems [70]. They also concluded that this technology, which integrates information and communications technology for the remote control management of livestock production environments, offers promising potential for enhancing the productivity and welfare of laying hens. Further, IS facilitates traceability and quality assurance throughout the production process. By recording and analyzing data at every stage, from breeding and feeding to processing and distribution, farmers can track the origins of products, monitor their quality attributes, and ensure compliance with regulatory standards and consumer expectations [71]. This transparency not only enhances consumer trust, but also enables farmers to command premium prices for high-quality products. The adoption of IS in agriculture and livestock farming has the potential to revolutionize productivity and quality across the entire value chain. Moreover, in the context of greenhouse gas emissions (GHG), Balafoutis et al. [72] stated that it is imperative to prioritize further research into quantifying the effects of IS and precision agriculture technologies on reducing GHG emissions, as well as their impact on productivity and income. They reported that the existing evidence suggests that these systems significantly contribute to mitigating climate change while enhancing production efficiency in terms of yield and economic outcomes. Recently, Di Vaio et al. [73] reported that digital technologies such as AI, ML, IoT, Cloud, and Blockchain are crucial in achieving supply chain traceability in the post-COVID era, as a pivotal method for safeguarding consumers and enhancing agricultural production quality. Therefore, it is essential to investigate these aspects thoroughly.

4. Automated Facilities in Livestock Management

In the context of modern agriculture, one notable advancement is the implementation of automated facilities in livestock management, which comprise a wide array of applications (monitoring animal health and behavior to optimizing feed distribution and waste management). These systems are typically deployed in various agricultural settings, including dairy farms, poultry farms, and swine production facilities, helping farmers to streamline operations, improve productivity, and enhance overall animal welfare.

One of the key functionalities of automated systems in livestock management is environmental sensing and control [74]. These systems employ a network of sensors to monitor crucial environmental parameters such as temperature, humidity, air quality, and lighting conditions within livestock facilities. For instance, in a poultry farm, sensors can detect fluctuations in temperature and adjust ventilation systems accordingly to maintain the optimal conditions for bird growth and health, as reported by others [68,69]. Moreover, automated systems can regulate feed and water delivery based on real-time environmental data, ensuring that animals always have access to sufficient nutrients and hydration. By optimizing environmental conditions, these systems help to mitigate stress levels among livestock, reduce the risk of disease outbreaks, and enhance overall production efficiency and management. Another significant advantage of automated facilities in livestock management is the reduction in manual labor and the consequent efficiency gains. Traditionally, tasks such as milking, egg collection, feeding, watering, and waste removal require con-
siderable time and labor investments from farm workers, as reported by Bhoj et al. [75]. However, with the integration of automated systems, many of these repetitive tasks can be mechanized and controlled remotely through centralized management platforms. For example, AFSs utilize programmable feeders equipped with sensors to dispense precise amounts of feed at scheduled intervals, eliminating the need for manual feeding by farm workers. Similarly, automated watering systems ensure a continuous supply of clean water to livestock, reducing the labor associated with monitoring and refilling water troughs. Furthermore, automated waste management systems, such as robotic manure scrapers and composting units, streamline the process of waste removal and recycling, minimizing the labor required for manual cleaning and disposal, as shown in a case study from Indonesia [76]. However, a significant concern arises with the adoption of automated facilities in livestock management such as the potential displacement of traditional manual labor jobs and the consequent need for a shift in the required skill sets for agricultural workers. Nevertheless, by automating these labor-intensive tasks, farmers can efficiently allocate resources, concentrate on higher-value activities, and attain enhanced operational scalability. The implementation of automated facilities in livestock management offers multiple benefits, ranging from environmental sensing and control to labor reduction and efficiency gains. By supporting and implementing advanced technologies, farmers can optimize animal welfare, improve production outcomes, and sustainably meet the growing demand for high-quality animal products in a rapidly evolving agricultural landscape.

5. Maintenance and Management

In the complex world of livestock operations, maintenance and management are indispensable pillars that ensure the smooth functioning, efficiency, and sustainability of agricultural enterprises, as reported by Stoliarchuk et al. [77]. From the upkeep of equipment and infrastructure to the management of resources and personnel, effective maintenance and management practices are essential for optimizing productivity, minimizing risks, and safeguarding the well-being of both animals and farmers.

Maintenance encompasses a wide range of activities aimed at preserving the functionality and longevity of the equipment, facilities, and infrastructure used in livestock operations. This includes routine inspections, repairs, and preventive maintenance tasks to identify and address potential issues before they escalate into costly problems. Additionally, maintenance involves activities such as remaking, redesigning, and rethinking processes to improve efficiency and sustainability [78]. For example, the regular servicing of tractors, feeding equipment, and ventilation systems helps to prevent breakdown and ensures uninterrupted operation, minimizing downtime and maximizing productivity. Furthermore, proactive maintenance strategies, such as predictive maintenance, leverage data analytics and sensor technologies to anticipate equipment failures and schedule maintenance activities accordingly. By monitoring equipment performance metrics and detecting early signs of wear or malfunction, farmers can take preemptive action to prevent costly breakdowns and extend the lifespan of their assets. This not only reduces maintenance costs, but also enhances operational reliability and efficiency.

Effective management practices are equally critical for the success of livestock operations, encompassing a wide range of responsibilities, including animal health and welfare, resource management, financial planning, and regulatory compliance [79]. Skilled managers must balance competing priorities and make informed decisions to optimize resource allocation, mitigate risks, and achieve operational objectives. For example, in the realm of animal health management, effective disease prevention and control strategies are paramount for safeguarding the health and welfare of livestock. This may involve implementing biosecurity measures, vaccination programs, and quarantine protocols to prevent the spread of infectious diseases and minimize the risk of outbreaks. Additionally, sound financial management practices, such as budgeting, cost analysis, and revenue forecasting, are essential for ensuring the long-term viability and sustainability of livestock operations. Moreover, effective management practices extend beyond the farm gate to
encompass broader issues such as environmental stewardship, community relations, and market access [80]. Sustainable management practices aim to minimize the environmental footprint of livestock operations, reduce resource consumption, and promote biodiversity conservation. By adopting sustainable practices such as rotational grazing, manure management, and energy-efficient technologies, farmers can minimize their impact on the environment while enhancing the resilience and profitability of their operations.

All in all, both maintenance and management are integral components of successful livestock operations, ensuring the efficient operation, productivity, and sustainability of agricultural enterprises. By implementing proactive maintenance strategies and adopting sound management practices, farmers can optimize resource utilization, minimize risks, and achieve their operational objectives in a rapidly evolving agricultural landscape.

5.1. Importance of Accurate Data in Livestock Management

In the context of livestock management, accurate data serve as the cornerstone upon which informed decisions are made and operational efficiency is achieved [81]. Livestock operations encompass a multitude of variables, including PLF, animal health, welfare, productivity metrics, and environmental conditions. Without precise data collection and analysis, farmers are left navigating these complexities blindfolded, risking inefficiencies, suboptimal outcomes, and even potential harm to their animals. Accurate data enable farmers to monitor and evaluate various aspects of their livestock operations with precision [82]. Technologies such as IoT sensors, RFID tagging, and automated data collection systems allow for the continuous monitoring of key parameters, including animal behavior, health indicators, feed intake, and environmental factors such as temperature and humidity, as reported recently [83,84]. Through data collection in real time, farmers gain invaluable insights into the well-being of their animals and the overall performance of their operations. Moreover, accurate data facilitate proactive decision making and preventive maintenance strategies. These aspects are very important, because by analyzing historical data trends and patterns, farmers can identify potential issues before they escalate into costly problems [85]. For example, by tracking changes in animal behavior or health indicators, farmers can detect early signs of disease or distress and intervene promptly, thus minimizing the risk of disease outbreaks and reducing the need for expensive treatments. Furthermore, precise data enable farmers to optimize resource utilization and operational efficiency. By monitoring production metrics such as milk yield, weight gain, or egg production in real time, farmers can adjust feeding regimens, breeding programs, and other management practices to maximize productivity while minimizing waste. Additionally, accurate data on environmental conditions allow farmers to optimize housing conditions, ventilation systems, and other infrastructure elements to ensure the comfort and well-being of their animals.

5.2. Real-Time Monitoring and Decision Support

Real-time monitoring technologies, enabled by IoT devices, wireless sensors, and cloud computing, provide farmers with instant access to critical information about their livestock and operations, regardless of their location. These technologies allow farmers to monitor key parameters such as animal health, behavior, and environmental conditions continuously [86]. For example, wearable devices equipped with sensors can track vital signs such as heart rate, body temperature, and activity levels, providing real-time insights into the health status of individual animals. Automated monitoring systems can also track feed consumption, water intake, and other production metrics, allowing farmers to detect deviations from normal patterns and take corrective action as needed [15]. Moreover, real-time monitoring systems enable farmers to respond swiftly to changing conditions and emerging issues. Alerts and notifications can be configured to notify farmers of potential problems, such as equipment failures, power outages, or adverse weather conditions, allowing them to intervene promptly and mitigate the impact on their operations. In some cases, advanced algorithms and AI can analyze the data collected by monitoring systems,
providing farmers with actionable insights and predictive analytics to inform their decision making [87]. By leveraging real-time monitoring technologies and decision support systems, farmers can optimize operational efficiency, improve animal welfare, and enhance overall productivity. These technologies enable farmers to make data-driven decisions, minimize risks, and seize opportunities in a rapidly evolving agricultural landscape, ultimately driving greater profitability and sustainability in the livestock industry.

6. Welfare Livestock Farming

Welfare livestock farming (WLF) represents a significant departure from conventional farming practices, placing a strong emphasis on the well-being and humane treatment of animals. At its core, this approach seeks to redefine the relationship between humans and livestock, recognizing animals as sentient beings deserving of compassion, dignity, and respect. Unlike traditional farming methods that prioritize maximum production at the expense of animal welfare, WLF adopts a holistic approach that considers the physical, mental, and emotional needs of animals. This paradigm shift is fueled by growing awareness among consumers, activists, and industry stakeholders regarding the ethical implications of intensive farming practices [88,89]. Central to WLF is the concept of providing animals with environments and conditions that allow them to express their natural behaviors and lead fulfilling lives. This entails moving away from confinement systems towards more spacious and enriched living environments. For example, instead of cramped cages, pigs may roam in open-air pastures, and chickens may have access to outdoor spaces for foraging and dust bathing. Moreover, WLF prioritizes the implementation of humane handling and management practices throughout the entire lifecycle of animals, from birth to slaughter [90,91]. This includes minimizing stress during transportation, ensuring prompt access to veterinary care, and employing humane slaughter methods that prioritize a quick and painless death. Furthermore, WLF integrates advancements in technology and innovation to enhance animal welfare outcomes. From precision feeding systems that tailor nutrition to individual animal needs to monitoring devices that track health parameters in real time, technology plays a vital role in optimizing animal care and management. Ultimately, WLF represents a shift towards a more ethical, sustainable, and compassionate approach to animal agriculture. By prioritizing the well-being of animals and acknowledging their inherent value, this farming model not only meets the demands of consumers who seek ethically produced food, but also fosters a more harmonious relationship between humans and animals. As society continues to evolve, WLF stands as a beacon of progress, demonstrating that agriculture can thrive while respecting the dignity and welfare of all living beings.

6.1. Integrating Technology for Animal Welfare

In the agriculture context, the integration of technology has sparked a revolution, transforming traditional farming practices into efficient and sustainable systems. One significant aspect of this transformation is evident in WLF, where technology is used not only for maximizing productivity, but also for enhancing the welfare of animals. This paradigm shift reveals a commitment to the compassionate and ethical treatment of livestock while meeting the demands of a growing global population. The application of technology in WLF encompasses various aspects, from advanced monitoring systems to precision feeding techniques [92,93]. For instance, sensors and monitoring devices are utilized to track vital parameters such as temperature, humidity, and even the behavioral patterns of animals. This data-driven approach allows farmers to detect signs of distress or illness early, enabling timely interventions and medical care. Moreover, AFSs ensure that animals receive the appropriate nutrition tailored and designed to their specific needs, promoting their overall health and well-being [90].
6.2. Ethical Considerations in Livestock Technology

As technology continues to permeate every aspect of livestock farming, ethical considerations take center stage in the discourse surrounding WLF. Central to this discussion is the acknowledgment of animals as sentient beings deserving of dignity and respect. Ethical frameworks guide the development and implementation of technological solutions, emphasizing the importance of minimizing stress and suffering among livestock [94]. One of the primary ethical concerns addressed by livestock technology is reductions in antibiotics, confinement, and overcrowding, as reported by Rollin [95]. Innovations such as robotic herding and automated handling systems mitigate the need for intensive confinement, allowing animals to exhibit their natural behaviors and access open spaces. Additionally, advancements in transportation technology ensure that animals are transported humanely, minimizing discomfort and distress during transit.

6.3. Achieving Sustainable and Humane Practices

WLF represents a harmonious convergence of sustainability and humane practices, where the welfare of animals is intricately linked to environmental stewardship and social responsibility. Sustainable agriculture principles guide the management of resources, ensuring the long-term viability of farming operations without compromising the well-being of current and future generations [96]. Technological innovations play an important role in promoting sustainability within WLF. For instance, precision farming techniques optimize resource utilization, minimizing the ecological footprint of livestock operations [97]. This shows that, by integrating adequate technology, addressing ethical considerations, and prioritizing sustainability, this innovative farming model not only enhances the welfare of livestock, but also fosters resilience in the face of global challenges. Obviously, as we continue to evolve towards a more enlightened relationship with the natural world, WLF stands as a beacon of progress, demonstrating that agriculture can thrive while respecting the intrinsic value of all living beings.

7. Addressing Livestock Challenges

Addressing livestock challenges involves a comprehensive approach that extends beyond disease control, environmental impact reduction, and energy efficiency. It encompasses a wide range of innovative strategies and practices aimed at addressing the various issues confronting the livestock industry, from animal welfare concerns to economic sustainability and social responsibility. Central to this approach is the recognition of the interconnectedness between livestock farming and broader societal and environmental systems. Innovations in animal welfare science are driving advancements in housing systems, handling techniques, and management practices that prioritize the physical and psychological well-being of animals [98]. From enriched environments that allow for natural behaviors to low-stress handling methods that minimize fear and anxiety, these innovations are reshaping the way animals are raised and cared for on farms. Moreover, addressing livestock challenges involves engaging with stakeholders across the agricultural value chain, including farmers, researchers, policymakers, and consumers. Collaborative initiatives are being launched to promote knowledge sharing, capacity building, and technology transfer, fostering a culture of innovation and continuous improvement within the livestock industry. Furthermore, efforts to address social and economic challenges in livestock farming are gaining traction, with a growing emphasis on equity, diversity, and inclusion [99]. Initiatives aimed at improving the livelihoods of smallholder farmers, empowering marginalized communities, and promoting fair labor practices are integral to creating a more just and sustainable food system. Additionally, addressing livestock challenges involves leveraging emerging technologies such as AI, blockchain, and big data analytics to enhance traceability, transparency, and efficiency within the livestock supply chain. These technologies enable the real-time monitoring of key performance indicators, facilitate data-driven decision making, and empower consumers to make informed
choices about the products they purchase, seeking to create a more resilient, equitable, and sustainable food system that meets the needs of present and future generations.

7.1. Disease Control Strategies

One of the foremost challenges in livestock farming is the management and prevention of diseases that can have devastating consequences on animal welfare, economic stability, food security, and public health [100]. Addressing this livestock challenge involves the implementation of proactive disease control strategies that minimize the risk of outbreaks and mitigate their impact when they occur. Innovative approaches to disease control include vaccination programs, biosecurity measures, and genetic selection for disease resistance. Advancements in biotechnology have led to the development of novel vaccines and diagnostic tools that target specific pathogens, providing farmers with more precise and effective disease management options [101]. Additionally, it was reported by Drewe et al. [102] that the adoption of data-driven approaches, such as predictive modeling by using ML and epidemiological surveillance, enables the early detection of disease threats and facilitates rapid response measures. Furthermore, biosecurity protocols are being enhanced to minimize the risk of disease introduction and transmission within and between farms [103,104]. From strict hygiene practices to controlled access measures, these biosecurity measures help to create barriers against pathogens, safeguarding the health and well-being of livestock populations.

7.2. Reduction of Environmental Impact

Livestock farming is often associated with environmental challenges, including air and water pollution, habitat destruction, and greenhouse gas emissions. Addressing these challenges requires innovative solutions that prioritize environmental conservation and sustainability. Technological innovations in waste management, such as anaerobic digestion systems and nutrient recovery technologies, offer sustainable alternatives for managing animal waste while reducing environmental impacts [105]. The same authors reported that these systems facilitate the conversion of organic waste into biogas for energy production and nutrient-rich fertilizers for soil enrichment, contributing to circular economy principles. Furthermore, precision farming techniques, such as GPS-guided equipment and remote sensing technologies, optimize land use and resource management, minimizing environmental footprint while maximizing productivity [106,107]. By enabling the targeted application of inputs, these technologies reduce the environmental impact of livestock production, conserving natural resources and preserving ecosystem integrity. Moreover, strategies to optimize feed efficiency and reduce methane emissions from enteric fermentation contribute to lowering the carbon footprint of livestock production.

7.3. Energy Efficiency in Livestock Production

The energy-intensive nature of livestock production also poses a challenge to sustainability and economic viability [108]. As reported by the authors, these livestock challenges involve embracing energy-efficient practices and technologies to minimize energy consumption and maximize resource utilization. Energy consumption is a significant contributor to the environmental footprint of livestock production, encompassing both direct energy use on farms and indirect energy inputs associated with feed production and transportation [109,110]. Addressing energy efficiency challenges requires a multifaceted approach that integrates renewable energy sources, improves operational efficiency, and promotes resource conservation. The adoption of renewable energy technologies, such as solar panels and wind turbines, enables farms to generate clean, sustainable energy onsite, reducing reliance on fossil fuels and lowering greenhouse gas emissions. Additionally, energy-efficient practices, such as improved insulation, LED lighting, and automated ventilation systems, optimize energy use and reduce operational costs [111]. Moreover, efforts to enhance energy efficiency extend beyond on-farm operations to include supply chain management and transportation logistics. Strategies such as the local sourcing of feed
ingredients, optimizing transportation routes, and implementing energy-efficient transport vehicles help to minimize energy consumption and the carbon emissions associated with livestock production.

8. Future Directions and Challenges

The future of livestock technology is filled with opportunities to boost productivity, animal welfare, and sustainability in agriculture. Intelligent monitoring, like sensors and IoT devices paired with advanced analytics, provides real-time insights into animal health and environmental conditions. Precision livestock farming, powered by automation and AI, shows potential in optimizing feeding, health monitoring, and breeding. Nutrition and feed efficiency research, especially on alternative sources and precision feeding, is crucial for reducing environmental impacts while maintaining animal health. Advancements in health management, including early detection tools and improved vaccines, contribute to healthier livestock. Sustainability remains a key focus, with initiatives to cut emissions and develop innovative waste solutions. AI-driven behavioral analysis and precise housing designs support animal welfare, aligning farming with ethical standards. Supply chain optimization through blockchain and smart logistics boosts transparency and efficiency. Industry collaboration and farmer education are crucial for technology adoption and maximizing benefits. Challenges like data privacy, technology accessibility, regulations, and costs must be addressed. Ethical dilemmas, such as balancing productivity with animal welfare, interdisciplinary collaboration, and climate resilience, require thoughtful solutions. In conclusion, advancing livestock technology demands a holistic approach. By tackling challenges and embracing emerging opportunities, we can pave the way for a sustainable, efficient, and ethically responsible future in livestock farming.

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