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THE IMPACT OF AGRICULTURE 4.0 ON WORKPLACE SAFETY IN ANIMAL HANDLING

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Abstract: The article examines the impact of Agriculture 4.0 technologies on workplace safety in animal handling. Agriculture 4.0, inspired by the concept of Industry 4.0, incorporates innovative technologies such as artificial intelligence, the Internet of Things, big data analytics, and automation, which streamline production processes and promote sustainable development. Despite the benefits of automation, such as reducing physical injury risks and enabling animal health monitoring, new challenges arise concerning potential health and psychological hazards for workers. These challenges stem from the need to adapt to advanced technologies and decreased vigilance in monitoring animal behaviors. The article highlights the necessity for comprehensive worker training and the implementation of safety standards that minimize risks associated with modern agricultural technologies.
Keywords: livestock farming, animal husbandry, Agriculture 4.0, safety at work, occupational safety

1. INTRODUCTION

In 2020, there were 10.3 million farms operating in the EU. Small farms predominated, with 7.0 million of them generating an annual turnover of less than 8,000 euros. Although there were significantly more of them, they accounted for a small fraction of the total agricultural production. In contrast, the 278,000 largest farms generated over half of all agricultural production in the EU (Kraft et al., 2022).

Agriculture has evolved through multiple phases, with the current phase known as Agriculture 4.0, a concept derived from Industry 4.0. This phase is characterized by the intensive integration of advanced technologies aimed at enhancing productivity and fostering sustainable development (da Silveira et al., 2021). Technologies such as artificial intelligence (AI), Big Data, the Internet of Things (IoT), nanotechnology, biotechnology, and drones are increasingly employed, facilitating the collection and analysis of precise information crucial for strategic decision-making in agriculture (Kraft et al., 2022; Ślusarczyk and Wiśniewska, 2024). However, while the digital transformation holds significant promise, its implementation poses various challenges, particularly for small and medium enterprises (Ingaldi and Ulewicz, 2020; Fobel and Kuzior 2019; Pacana and Ulewicz, 2017). An important consideration is the need to optimize maintenance, repair,

and operation processes, as highlighted by Krynke et al. (2022).The most important element of Agriculture 4.0 is the use of precise information that supports farmers in making strategic decisions. The Food and Agriculture Organization of the United Nations (FAO) refers to this stage as the "digital revolution in agriculture" (Trendov et al., 2019).

Livestock farming faces many challenges related to increased production and sustainability (Klerkx and Begemann, 2020). These challenges include reducing the impact of livestock production on greenhouse gas emissions, meeting rising consumer and societal expectations regarding animal welfare and environmental standards, and addressing interactions between animal and human health (e.g., One Health) (Baum et al., 2017; Herrero and Thornton, 2013; Romera et al., 2020; Szczyrba and Dziuba, 2023). Livestock farming is currently at a crossroads. On one hand, there is a growing demand for animal products, and on the other hand, there is pressure to reduce its environmental impact and improve animal welfare. At the same time, this sector must contend with challenges such as greenhouse gas emissions, high consumer expectations regarding food quality and provenance, public health issues (One Health), and competition from alternative protein sources (Klerkx and Begemann, 2020; Romera et al., 2020).

Changes in agricultural conditions, such as a shortage of skilled labor, rising production costs, and changing climatic conditions, make technological development a solution for agriculture (Griepentrog, 2017). Technologies such as artificial neural networks (ANN) are used to optimize the application of fertilizers, pesticides, and herbicides, allowing for more precise resource management (Boursianis et al., 2020). Drones that assist in weed detection and robots that help with milking cows are becoming standard in modern agriculture. Unmanned aerial vehicles (UAVs) are increasingly used for fertilization and chemical spraying.

The transformation of agriculture through modern technologies inspired by Industry 4.0 has brought profound changes, giving rise to the concept of Agriculture 4.0. An important aspect of this transformation is also the improvement of occupational safety and health, which is particularly significant in agriculture, one of the most dangerous sectors in terms of accidents and occupational hazards.

Working with livestock presents numerous hazards for employees. Daily animal care involves routine tasks associated with the rearing and breeding of animals. This includes activities such as feeding animals, cleaning bedding, watering animals, milking, and grooming. Periodically, animals undergo hoof trimming, hoof care, herding to pasture, dehorning, and transportation. Employees are at risk of injuries such as strikes, kicks, crush injuries, or bites, especially in stressful situations for the animals or during sudden changes in the environment. Additionally, working with live animals creates the risk of exposure to zoonotic diseases. As Woolhouse and Gowtage-Sequeria (2005) indicate, about 75% of emerging and re-emerging pathogens are capable of causing infectious diseases in animals (termed zoonotic pathogens), meaning they can be transmitted from animals to humans.

In livestock housing, employees are exposed to harmful substances, such as gas contaminants and dust, which can lead to respiratory diseases. These hazards, while initially unnoticed, can accumulate and result in serious health problems over time (Jędrych and Kuś, 2016; Rautiainen, 2004).

Working with livestock, especially in the context of modern Agriculture 4.0 technologies, involves continuous exposure of employees to various hazards. These risks arise both

from the unpredictability of animal behavior and from modern technological solutions in the work environment.
Modern technologies in Agriculture 4.0 offer tremendous potential for increasing production efficiency. However, to fully realize their capabilities, it is essential to be aware of the associated risks. Therefore, it is crucial not only to continually improve employee skills but also to implement safety systems that minimize risk and promote sustainable agricultural development.
The digital transformation observed in Agriculture 4.0 mirrors trends seen in other sectors, where automation and digitalization redefine not only operational processes but also human roles within organizations. As Kuzior et al. (2022) argue, creating a sustainable and ethical organization demands careful management of digitalization processes, particularly concerning their effects on human resources and work ethics. This perspective underscores the need for balancing technological innovation with social responsibility.
The aim of this study is to investigate the impact of Agriculture 4.0 technologies on workplace safety for those handling farm animals.

2. UTILIZATION OF AGRICULTURE 4.0 TECHNOLOGIES IN ANIMAL HUSBANDRY

The implementation of Agriculture 4.0 technologies, particularly Artificial Intelligence (AI), is transforming animal husbandry by enabling automatic health monitoring, optimizing nutrition, and predicting diseases. AI supports real-time data analysis, facilitating rapid responses and boosting production efficiency. However, this shift brings notable challenges, including device compatibility issues, insufficient user support, and a lack of standardized procedures (Bahlo et al., 2019; Eastwood and Renwick, 2020; Neethirajan, 2020). As Dziuba and Szczyrba (2023) note, agile management approaches can play a crucial role in addressing these technological challenges by fostering adaptability and efficiency within agricultural enterprises. The Internet of Things (IoT) plays a key role in modern livestock management. A network of sensors collects data about animals and environmental conditions, enabling remote monitoring and analysis. This facilitates the optimization of breeding processes and increases production efficiency (da Rosa Righi et al., 2020; Guntoro et al., 2019; Wolfert et al., 2017).
In practice, IoT is used to monitor animal health. Wearable sensors, such as collars, record their activity, heart rate, and body temperature, allowing for early disease detection (Zhou and Yamamoto, 1997). These systems also gather data on the entire herd, supporting effective management. IoT enables control over conditions in livestock housing, such as temperature, humidity, and ventilation, which enhances animal welfare. Despite many advantages, IoT systems have limitations, such as unidirectional data transfer and the handling of simple information packets (da Rosa Righi et al., 2020; Wolfert et al., 2017).
Sensors optimize nutrition by monitoring feed intake and adjusting rations to the individual needs of animals. Applications include monitoring ruminating, activity, body temperature, and hoof condition in cattle, as well as detecting respiratory diseases in pigs through sound analysis. In poultry farming, cameras are used to monitor the behavior of chicks, allowing for assessments of their health and welfare (Buller et al., 2020; Caja et al., 2016; Green et al., 2017; Halachmi and Guarino, 2016; Knight, 2020; Norton et al., 2019). Sensors are also utilized for monitoring machinery and precise weighing of feed (Shalloo et al., 2018). AI supports the detection of estrus in cows by analyzing data from sensors mounted on collars that monitor their activity 24/7 (Dineva et al., 2021). Analysis of ear,

eye, and other facial movements helps determine the emotional and physical state of animals, enabling early detection of pain and stress (Paris et al., 2022; Sih et al., 2004).
Automation and robotics are replacing humans in many tasks in animal husbandry, such as milking cows, feeding, cleaning barns, and collecting eggs. However, the diversity of animals and variability in weather conditions make full automation a challenge (Bahlo et al., 2019). In intensive animal farming, virtual fencing, which combines sensors, IoT, and automated systems, allows for precise control of animal movement without direct human involvement (Britt et al., 2018). Cloud computing and big data analytics offer numerous benefits in animal husbandry. Storing data on remote servers reduces the risk of data loss, and increased computing power allows for the use of advanced analytical tools. Farmers can process data related to animal health, performance, and environmental conditions, transforming it into practical information. Advanced algorithms assist in early disease detection, nutrition optimization, and herd management, leading to improved animal performance and health while minimizing losses (Eastwood et al., 2021; Olejnik et al., 2022; Pan et al., 2016). By monitoring environmental conditions such as temperature and humidity in barns, pigsties, and chicken coops, farmers can ensure optimal conditions for animals. Furthermore, cloud computing enables remote data management, facilitating work and increasing flexibility on the farm (Nikander et al., 2020; Smith, 2020). Big Data refers to the analysis of vast datasets to gain valuable insights. In the context of animal husbandry, it is used to analyze production outcomes, allowing for the evaluation of breeding efficiency and making decisions regarding future actions. Data analysis enables better tailoring of breeding methods to the individual needs of animals, contributing to improved animal welfare. Additionally, analyzing data from various sources allows for predicting threats and taking appropriate actions, which is significant for workplace safety (Johar et al., 2024; Kraft et al., 2022; Lashari et al., 2023; Van Limbergen et al., 2020).

3. IDENTIFICATION OF HAZARDS WHEN WORKING WITH ANIMALS IN AGRICULTURE 4.0

The introduction of Agriculture 4.0 technologies into animal husbandry brings innovations that significantly impact management efficiency and workplace safety. Automated systems, such as milking and feeding robots, health monitoring of animals through sensors, and behavior analysis using artificial intelligence, minimize the need for direct human contact with animals, thereby reducing the risk of accidents and injuries (Dawkins, 2017). The automation of tasks such as feeding and milking reduces the physical burden on workers and eliminates many risks associated with working in close proximity to animals (Berckmans, 2014). Animal health monitoring systems enable early detection of diseases, including zoonoses, which limits the risk of infections being transmitted to humans. Artificial intelligence, by analyzing animal behaviors, allows for the prediction of dangerous situations, such as aggression or stress, enabling quicker responses and preventing hazardous incidents. Precise estrus detection increases the safety of breeders and improves animal welfare by reducing stress associated with uncontrolled reproductive cycles (Dineva et al., 2021).
Analyzing the movements of animals' ears, eyes, and other facial features using facial recognition technology (Paris et al., 2022; Sih et al., 2004) contributes to improving the safety of livestock handlers. Animals experiencing pain, stress, or fear often exhibit characteristic changes in facial expressions and body movements. Through this analysis,

workers can proactively identify potentially aggressive animal behaviors and take appropriate precautions, thus reducing the risk of accidents.
However, modern technologies in animal husbandry are not without challenges. Errors in data collection or analysis by sensors can lead to incorrect diagnoses, delaying the detection of diseases or behavioral problems, jeopardizing the health of both animals and workers (Dawkins, 2017). The introduction of autonomous systems, such as milking and feeding robots, may cause stress in animals, especially during the initial adaptation phase. Animals unaccustomed to machines may react negatively to new stimuli, such as noise, vibrations, or irregular movements of equipment (Aiello et al., 2022). As a result, behavioral disorders, such as increased aggression or disruptions in circadian rhythms, may occur.
Noise-induced stress is particularly dangerous for large animals, such as cattle and horses. Their reactions to strong stimuli are often violent and unpredictable, which can lead to panic responses, attempts to escape, or attacks. In the case of cattle or horses, such reactions can pose serious threats to worker safety, as these animals, often weighing several hundred kilograms, can inadvertently trample people, damage equipment, or even injure themselves. Attempts to manage them in such situations are difficult and dangerous. Automated systems (Patel et al., 2022), which reduce human contact with animals, can also lead to behavioral problems due to a lack of interaction with caregivers. Autonomous machines, such as milking or feeding robots, may inadvertently interact with workers, creating additional hazards. Furthermore, work automation may decrease workers' vigilance. When machines take over tasks, people may monitor the health and behavior of animals less attentively, which can result in overlooking significant threats such as diseases or aggressive behaviors. Over-reliance on technology is also associated with the risk of diminishing manual skills among workers, which can pose a danger in emergencies (Dawkins, 2017). IoT technologies, such as sensors monitoring animal health and environmental conditions, can optimize breeding processes and reduce injury risks associated with traditional control methods. On the other hand, there is a risk of long-term effects of electromagnetic radiation on human health, although current research does not provide conclusive evidence of negative impacts.
The rapid pace of technological development, especially in artificial intelligence and IoT, presents new challenges for workers. Difficulties in mastering new machines and concerns about automation can lead to increased stress and decreased performance capacity (Fielding, 1999). Agriculture 4.0 technologies offer many benefits, but their full implementation requires process optimization and better training for workers to enable them to work effectively and safely in an automated environment.

4. RESEARCH LIMITATIONS AND FUTURE DIRECTIONS

Research on the impact of Agriculture 4.0 on workplace safety when handling animals encounters several limitations that may affect the results and their interpretation. First, many existing studies focus on technologies rather than their effects on specific aspects of workplace safety, which limits the understanding of potential hazards. Additionally, many technological applications in animal husbandry are still in the experimental phase, making it difficult to assess the long-term effects of their implementation on the health and safety of workers.

The lack of standardized protocols for technology implementation in agriculture complicates the comparison of research findings. The diversity of farms and the ongoing technological development make it challenging to generalize results.
To fully harness the potential of technology in agriculture, future research should concentrate on a comprehensive analysis of its impact. Investigating the interactions between different technologies and their influence on worker health and adaptability to new working conditions is essential. Long-term studies will be crucial in evaluating the lasting effects of technological implementations. It is also important to consider legal aspects to ensure workplace safety.
An essential component of the research should be the engagement of workers, whose opinions and experiences are vital for designing effective safety systems and training programs. Implementing risk assessment and workplace ergonomics methods is necessary to improve working conditions when adopting Agriculture 4.0 technologies.

5. CONCLUSION

The integration of Industry 4.0 technologies in agriculture, especially in areas involving animal handling, introduces substantial advancements for workplace safety. Technologies such as IoT, robotics, AI, and real-time data analytics contribute to safer and more efficient farming practices. IoT devices allow continuous monitoring of environmental conditions, which helps ensure optimal animal welfare while minimizing the need for direct human-animal interactions. By automating tasks such as feeding and health monitoring, these technologies significantly reduce physical risks to workers, addressing historical hazards in livestock handling environments
Collaborative robots and autonomous vehicles are key components in this technological shift, taking over physically demanding tasks. These systems reduce the risk of musculoskeletal injuries among workers, who can now focus on less physically intense tasks. Robots equipped with safety sensors can detect worker proximity, adjusting their operations to prevent accidents, which is a major safety enhancement in agricultural environments. However, Industry 4.0 also brings new safety and psychological challenges. As employees become increasingly dependent on automated systems, there's a risk of "automation complacency," where workers may become less vigilant in monitoring animal behavior. This reduced awareness could lead to delayed responses to animal distress or changes in health. Furthermore, the rapid influx of data from IoT and AI systems can lead to data overload, potentially increasing workplace stress as employees attempt to process and respond to vast amounts of information in real-time
To mitigate these challenges, comprehensive training programs are essential. Training should cover not only the technical operation of new systems but also emphasize situational awareness and best practices for monitoring animal welfare. This approach can help employees maintain critical observational skills despite automated processes. Implementing ergonomic assessments and establishing mental health support are also necessary to promote physical and psychological safety within this digitalized environment. Such efforts will be crucial for leveraging Industry 4.0's benefits in agriculture while ensuring a safe and productive workplace.

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