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THE IMPACT OF ENVIRONMENTAL AND TECHNOLOGICAL VARIABLES ON WORKPLACE SAFETY IN AGRICULTURE: AN INTERDISCIPLINARY RISK ANALYSIS

Abstract

Agriculture is one of the most hazardous sectors, exposing workers to mechanical, chemical, biological, and weather-related risks. This article aims to analyze the impact of environmental variables and modern technologies on occupational safety in agriculture. Key risk factors, such as extreme weather events, improper machinery operation, and exposure to chemicals, were identified. Innovative technologies, such as *IoT*, were discussed as potential tools for risk management. The findings emphasize the need for an interdisciplinary approach that integrates education, protective technology development, and effective risk management. The article highlights the importance of collaboration between researchers, farmers, and policymakers to create safer working conditions.

Keywords

agriculture, workplace, safety, impact

Introduction

Agriculture, one of the oldest and most fundamental human activities, has played a crucial role since the dawn of civilization in meeting the basic needs of societies—providing food, natural resources, and creating jobs. According to data from the International Labour Organization (ILO), the agricultural sector is one of the most hazardous employment areas, with accident rates exceeding the average for most other industries. In 2021, as much as 27% of all reported occupational accidents worldwide occurred in agriculture, reflecting the exceptionally high level of risk associated with work in this sector[1].

The nature of agricultural work exposes employees to multidimensional hazards on a daily basis. Among these is direct contact with agricultural machinery, which, while significantly increasing production efficiency, constitutes a major source of accidents. Studies indicate that up to 60% of accidents on farms in the European Union are related to the use of machinery, often stemming from insufficient training or neglect in maintenance[2]. An additional challenge is exposure to chemicals such as pesticides and fertilizers. While indispensable for boosting crop yields, these substances can cause serious health consequences, including poisoning, allergies, and chronic diseases. Moreover, variable weather conditions, including increasingly frequent and intense atmospheric phenomena linked to global warming, substantially heighten the risks of working in open spaces. Heatwaves, violent storms, and prolonged droughts not only endanger workers' health but also complicate preventive efforts.

The agricultural sector is characterized by a significant diversity depending on farm size. Small family farms often struggle with limited access to modern protective technologies, which exacerbates their exposure to occupational risks. On the other hand, large agricultural businesses, despite being more technologically advanced, face challenges such as managing risks associated with the use of complex machinery or ensuring the cybersecurity of systems reliant on the Internet of Things (IoT) technologies.

Technological development and global environmental changes have significantly impacted the nature and scale of risks in agriculture. The automation and digitization of agricultural processes have brought numerous benefits, such as improved efficiency, reduced physical strain, and the ability to manage resources with precision. For instance, the use of GPS systems in agricultural machinery enables route optimization, reduced fuel consumption, and minimized risk of field collisions[3]. However, these technologies also introduce new types of risks, such as inadequate operator

1 M. Ekmekci, S. Yaman, *Occupational health and safety among farmers: a comprehensive study in Central Anatolia,* Ankara 2024, p. 27-32.

2 S. Cheluvaraj, P. N. Bidare Sastry, N. K. Somanna, *Occupational Hazards Among Agricultural Workers in South India,* Bengaluru 2024, p. 45-50.

3 W. Choi, K. Kim, W. Jung, *A Mini Review (PRISMA) on Causes of Incidents and Injuries in Agricultural Workplaces,* Seoul 2024, p. 12-16.

training, vulnerability to cyberattacks, and high implementation costs, which may exclude less affluent farms.

Climate change is also driving the agricultural sector to adapt to increasingly unpredictable environmental conditions. Rising temperatures and more frequent extreme weather events, such as droughts and floods, present new challenges to workplace safety. For example, research conducted in Spain revealed that the number of heat stroke-related hospitalizations among agricultural workers has increased by 25% over the past two decades[4]. Such data underscore the urgent need for systemic solutions, such as work schedule management during heatwaves and the development of protective clothing with a high UV reflectance rate.

The goal of this article is to provide an in-depth analysis of the impact of environmental and technological variables on workplace safety in the agricultural sector. The article adopts an interdisciplinary approach, integrating research on technology, ergonomics, risk management, and climate change adaptation. Key risk factors will be identified, including both traditional hazards and new challenges stemming from technological advancements. Special attention will be given to modern technologies such as IoT and advanced monitoring systems, which can support farmers in reducing occupational risks. Challenges related to limited access to technology at smaller farms and technological inequalities within the sector will also be discussed.

This study emphasizes the need for a comprehensive perspective on agricultural safety. It considers both technical and social aspects, highlighting the importance of collaboration between researchers, agricultural practitioners, and policymakers. Additionally, the article acknowledges research limitations, such as the lack of detailed economic analyses of technology implementation at small farms and regional disparities in climate change adaptation levels. Practical recommendations are also proposed to enhance workplace safety in agriculture and align the sector with the challenges of the 21st century.

Environmental Variability and Work Safety in Agriculture

Climate change represents one of the most significant challenges facing modern agriculture, impacting not only production efficiency and the availability of natural resources but also the health and safety of those working in the sector. Working in open environments, typical of agriculture, exposes workers to the direct effects of variable weather conditions. Extreme weather events such as droughts, heavy rainfall, storms, heatwaves, and unexpected frosts are becoming more frequent and intense. According to the Intergovernmental Panel on Climate Change (IPCC), the frequency of extreme weather events has increased by 40% over the last 30 years, which necessitates the agricultural sector adapting and implementing effective protective measures[5].

4 See G. Balakrishnan, K. Prabhakar, D. K. Chandran, R. Murugesan, M. Gheisari, *Revolutionizing Agriculture: A Comprehensive Review of IoT Farming Technologies,* Chennai 2024, p. 45-50.

5 S. Niu, *Climate Change and Its Impacts on the Safety and Health of the Global Workforce: An ILO Perspective,* Geneva 2024, p. 12-16.

One of the most tangible effects of climate change is the occurrence of heatwaves. Studies conducted in Spain show that the number of heat stroke-related hospitalizations among agricultural workers has risen by 25% over two decades. High temperatures lead to overheating, dehydration, reduced concentration, and diminished responsiveness. This significantly increases the risk of accidents when operating agricultural machinery such as tractors, harvesters, and other mechanical devices requiring constant attention and coordination. A report by the European Agency for Safety and Health at Work (EU-OSHA) indicates that the number of farm accidents increases by 15–20% on days with high temperatures[6].

Intense rainfall and storms also pose significant threats to workplace safety in agriculture. Heavy rains can destabilize the terrain, causing slips, falls, and difficulties operating machinery in waterlogged areas. In Germany, after record rainfall in 2021, many farms suffered substantial losses, and the number of reported accidents related to working in challenging conditions increased by 30% compared to previous years[7]. Storms often damage infrastructure such as power lines, storage facilities, and irrigation systems, which requires interventions under hazardous conditions. Farmers, attempting to save their crops during such events, often take risky actions that further elevate the likelihood of accidents.

Exposure to UV radiation is another critical hazard associated with outdoor work. Prolonged exposure to sunlight without adequate protection increases the risk of skin cancer and leads to skin damage such as burns and accelerated aging. Data from the World Health Organization (WHO) highlights that farmers are among the occupational groups that are most exposed to the effects of UV radiation, particularly in regions with intense sunlight, such as Southern Europe and Africa.

Droughts, which are increasingly common in various regions worldwide, have a multifaceted impact on agricultural workplace safety. Water shortages not only limit farm productivity but also contribute to increased psychological stress among farmers, who must make difficult decisions about resource management. In Australia, studies have shown that droughts are one of the leading factors contributing to occupational burnout among farmers. Psychological stress, combined with physical exhaustion from intensive labour, increases the risk of errors and accidents.

Changing environmental conditions compel the agricultural sector to adapt on multiple levels. Systemic solutions, such as the development of technologies for monitoring weather conditions, can help farmers address climate challenges. Examples include weather apps that provide real-time updates on sudden weather changes and warning systems for dangerous phenomena like storms or heavy rainfall. In the United States, the implementation of such systems has reduced the number of accidents related to extreme weather conditions by 15% over five years.

6 T. Semeraro, A. Scarano, A. Leggieri, A. Calisi, M. De Caroli, *Impact of Climate Change on Agroecosystems and Potential Adaptation Strategies,* Bari 2023, p. 11-17.

7 R. M. Adams, C. C. Chen, B. A. McCarl, D. E. Schimmelpfennig, *Climate Variability and Climate Change: Implications for Agriculture,* Leeds 2001, p. 95-113.

However, implementing these technologies faces barriers, especially at smaller family farms. The costs of purchasing and maintaining advanced monitoring systems are often beyond the reach of less affluent farmers. Therefore, developing financial and educational support programs is essential to facilitate the adoption of these technologies on a broader scale. Examples of effective measures include government subsidies for protective systems in European Union countries, enabling the implementation of innovative solutions at small farms.

Educating agricultural workers on environmental hazard protection should be a priority. Information campaigns and training sessions on using personal protective equipment, such as UV-resistant clothing, sun hats, and waterproof footwear, can significantly reduce the risks associated with working in extreme conditions. In Scandinavian countries, the introduction of mandatory training on managing work schedules during heatwaves has led to a 10% reduction in accidents over a decade[8].

The environmental variability intensified by climate change significantly impacts workplace safety in the agricultural sector. Adapting to these changes requires an interdisciplinary approach that combines education, the development of protective technologies, and the implementation of safety management systems. Only through coordinated efforts can safe and efficient working conditions in agriculture be ensured in the era of a changing climate.

Modern Technologies in Agriculture: Benefits and Threats

The development of technology in agriculture, also known as AgTech, has revolutionized the way agricultural production is managed globally. The introduction of advanced machinery, monitoring systems, and process automation has significantly increased efficiency and improved working conditions. Automating key stages of production, such as sowing, irrigation, harvesting, and storage, has reduced the physical burden on workers while simultaneously decreasing the risk of injuries associated with heavy physical labour. As a result, agriculture has become more efficient and accessible, particularly at large-scale farms with an intensive production profile.

One of the most significant technological achievements in agriculture is the implementation of machines equipped with advanced control systems, such as harvesters, tractors with autonomous navigation, and plant care robots. These machines enhance operational precision and optimize labour even in challenging weather conditions. GPS systems, now standard in modern machinery, enable route optimization, reduced fuel consumption, and minimized crop losses. Research conducted by Wageningen University in the Netherlands demonstrated that using GPS systems can increase farm productivity by 15% annually[9].

8 N. Artık, Y. Güçer, E. S. Poyrazoğlu, *Impact of Climate Change on Agricultural Production and Food Security,* Istanbul 2024, s. 45-50.

9 P. B. Angon, P. Aich, *Progress and Potential Drawbacks of Modern Agricultural Technologies: A Literature Review,* Istanbul 2024, p. 1858-1864.

Technologies such as the Internet of Things (IoT) allow real-time monitoring of soil conditions, moisture levels, temperature, and nutrient content. An example is the CropX system, which enables farmers to precisely adjust irrigation and fertilization, reducing water usage by 25% compared to traditional methods[10]. Additionally, drones used for crop monitoring, field mapping, and pesticide application significantly improve precision while reducing the usage of chemicals by up to 20%[11].

What is more, these technologies contribute to environmental protection. Thanks to precise management of resources, greenhouse gas emissions related to transportation and energy consumption are reduced. For instance, IoT-managed drip irrigation systems minimize water wastage and lower CO_2 emissions.

Despite numerous benefits, implementing modern technologies in agriculture brings various challenges and risks. Operating advanced equipment requires technical skills that are not always readily available among agricultural workers. A lack of proper training is one of the main risk factors for accidents involving machinery. According to the European Agency for Safety and Health at Work (EU-OSHA), in 2021, 40% of agricultural accidents were related to improper equipment operation or maintenance neglect[12]. Incorrect configuration of automated control systems can lead to machine collisions, crop damage, and even risks to people working nearby.

Another issue is cybersecurity threats. IoT systems that monitor and manage farm processes are vulnerable to hacking. In one case described in research by the University of California, Davis, a cyberattack on an irrigation system caused losses amounting to $1.5 million[13]. To counter such threats, implementing safeguards like data encryption and regular software updates is essential.

An important aspect is the diversity of technology users. Women, who often make up a significant portion of the agricultural workforce, may have limited access to technical training or equipment, which leads to inequalities in the use of modern tools. Organizations such as the FAO emphasize the need for user-friendly technologies and training programs tailored to different demographic groups.

The use of modern agricultural technologies requires appropriate regulations which will ensure workplace safety and mitigate risks. The European Union has introduced certification requirements for autonomous machines, reducing the risks associated with their operation. However, drone usage regulations vary between countries, potentially hindering widespread adoption. For instance, in the U.S., the Federal Aviation Administration (FAA) requires a license for the use of commercial drones, which limits their application at small farms.

10 G. Balakrishnan, K. Prabhakar, D. K. Chandran, R. Murugesan, M. Gheisari, *Revolutionizing Agriculture: A Comprehensive Review of IoT Farming Technologies*, Chennai 2024, p. 45-50.

11 A. Jadhav, K. Manohar, C. M. Rajesh, R. P. R. Prasad, P. Bhat, V. Jagadeesh, *Revolutionizing Farm Management with Modern Agricultural Extension Techniques: A Review*, Mumbai 2024, p. 27-32.

12 V. Sharma, S. Rajawat, A. Kumar, V. Kumar, Y. Parihar, S. Jaat, *A Review on Advancing Sustainable and Smart Farming Practices: A Comprehensive Exploration of IoT and Sensor Technologies in Agriculture,* Jaipur 2024, s. 15-20.

13 A. Kumar, S. Satapathy, K. Muduli, *IoT, AI, and Robotics Applications in the Agriculture Sector*, Delhi 2024, s. 243-272.

Education plays a key role in minimizing risks associated with technologies. Training programs, such as the SmartFarm initiative in Germany, offer farmers courses on operating agricultural machinery, programming drones, and managing IoT systems. In developing countries, NGOs like the Gates Foundation support training programs for women in agriculture, enabling them better access to modern tools[14].

Modern technologies in agriculture offer immense benefits, but their full utilization requires a responsible approach and elimination of existing barriers. Improved access to training, financial support, development of low-cost technologies, and harmonized regulations can contribute to the more effective and safer implementation of new solutions. Taking into consideration the diversity of users and the environmental benefits of these technologies is crucial for achieving sustainable development in the agricultural sector.

Exposure to Chemical Factors in Agriculture

The use of pesticides, fertilizers, and other chemical agents is an integral part of modern agriculture, aimed at increasing efficiency and protecting crops from pests, diseases, and weeds. Despite their numerous benefits, these chemicals pose serious risks to workers' health and the environment, particularly when they are misused, improperly stored, or when personal protective equipment is lacking. As agricultural production becomes more intensive, the issue of exposure to toxic substances has emerged as one of the key challenges for workplace safety in the agricultural sector.

The most common hazard associated with pesticides is inhaling their vapours during application. These substances, in aerosol or dust form, can easily penetrate the respiratory system, leading to poisoning, lung damage, and allergic reactions. According to the World Health Organization (WHO), approximately 385,000 deaths were attributed to acute pesticide poisoning in 2019, illustrating the magnitude of the issue. Direct skin contact with pesticides, especially in the absence of proper protective clothing, can cause irritation, chemical burns, and even chronic dermatological conditions[15].

Prolonged exposure to chemical agents is also linked to more severe health consequences, such as nervous system damage, hormonal disorders, and an increased risk of cancers, including non-Hodgkin's lymphoma and skin cancer. Research conducted as part of the Agricultural Health Study in the United States found that agricultural workers exposed to pesticides have a 30% higher risk of developing lymphatic system cancers compared to the general population[16].

14 K. Somashekar, H. M. A. Rehaman, G. V. S. Kumar, K. Bai, N. Belagalla, G. J. Abhishek, J. M. S. Kapoor, *Technology for a Food-Secure Future: A Review of Technology Advances in Sustainable Agriculture*, Bengaluru 2024, p. 234-256.

15 A. Moreira, M. Vieira da Silva, *Analysis of Health Effects Reported by Agricultural Workers and the Adverse Human Effects Indicated on Pesticide Labels: A Systematic Review*, Lisbon 2024, p. 16-69.

16 H. Yadav, N. Kumar, *Contamination Levels and Distribution of Pesticides in Crops and Its Hazardous Effects on Living Beings*, Kolkata 2024, p. 24-125.

In spite of being less toxic than pesticides, synthetic fertilizers also pose significant risks. Nitrates present in fertilizers can leach into groundwater, leading to contamination. This results in eutrophication, which degrades aquatic ecosystems. People exposed to nitrate-contaminated water may suffer from methemoglobinemia, also known as "blue baby syndrome," which reduces the ability of blood to transport oxygen.

The long-term use of chemicals in agriculture also contributes to soil degradation, including the loss of biodiversity and reduced organic matter content. This phenomenon diminishes the capacity of soil to retain water and nutrients, which, in the long run, affects crop yields negatively.

Grading of Threats[17]:

- respiratory health – inhaling pesticides is the most immediate and common threat;
- skin contact – causes long-term dermatological issues and allergic reactions;
- Groundwater contamination – a threat to both the environment and human health.

Studies indicate that using personal protective equipment, such as filtering masks, chemical-resistant gloves, or specialized protective clothing, significantly reduces the risk of exposure to chemical substances. However, despite the availability of such equipment, its practical application in agriculture often falls short. In developing countries, according to a 2022 FAO report, as many as 60% of farmers do not use adequate protective measures, mainly due to a lack of awareness, training, or funding access.

Women and older individuals, who often constitute a significant portion of the agricultural workforce, face additional challenges in accessing protective equipment and training. The Self Employed Women's Association (SEWA) in India has implemented educational programs targeted at women, teaching them proper use of chemicals and health protection. Similar initiatives should be introduced in other regions.

Improper storage and disposal of chemicals remain one of the greatest threats to both health and the environment. Pesticides and fertilizers are often kept in unsecured facilities, increasing the risk of accidental exposure for children and animals. Many countries have implemented chemical waste collection programs, such as "CleanFarms" in Germany, which have reduced cases of improper disposal by 40%[18].

Global regulations, such as the Stockholm Convention on Persistent Organic Pollutants, play a crucial role in limiting the use of the most hazardous pesticides. The introduction of such standards enables the gradual phasing out of the most harmful substances and their replacement with more environmentally friendly alternatives.

Modern technologies can significantly reduce the risks associated with exposure to chemical agents. Smart pesticide application systems, such as sprayers equipped

17 See R. Tahir, F. Afzal, H. Jamil, M. Razzaq, M. S. Khan, *Physiological Impacts of Pesticidal Contamination: Challenge to Sustainable Agriculture and Biodegradation Methods*, Karachi 2024, p. 24-37.

18 See F. Ahmad, A. Alsayegh, M. Abdullah, *Pesticides Impacts on Human Health and the Environment with Their Mechanisms of Action and Possible Countermeasures*, Riyadh 2024, p. 112-120.

with shields and sensors, adjust the amount of product applied based on field conditions, reducing wastes as well as workers' exposure. Biological alternatives, such as microorganism-based biopreparations (e.g., *Bacillus thuringiensis*), offer less toxic crop protection options and are widely used in organic farming.

Exposure to chemical agents in agriculture poses a serious challenge to workers' health and safety as well as the environment. Minimizing these risks requires a multifaceted approach that combines education, technological advancement, and effective regulations. The adoption of innovations such as smart pesticide application systems and biological alternatives can significantly improve workplace safety and reduce the environmental impact of agriculture.

Risk Management System in Agriculture: Challenges and Solutions

Risk management on agricultural farms is a key pillar for ensuring workplace safety, protecting workers' health, and optimizing production processes. In a sector characterized by high levels of risk, the complexity of operations, and dynamically changing environmental conditions, effective risk management requires a holistic approach integrating technology, education, and management procedures.

Agriculture is a sector where risks are multidimensional and encompass various hazards. Mechanical risks from machinery use, chemical hazards from pesticides and fertilizers, and biological risks from exposure to microorganisms are just a few examples. Additionally, environmental factors like fluctuating weather conditions and risks stemming from production intensification add to the challenges. To address these issues, it is essential to implement systems that enable the identification, assessment, and effective mitigation of risks.

An important step in effective risk management is prioritizing actions based on the grading of threats[19]:

- mechanical risks – the most common causes of accidents on farms, such as improper machine handling or lack of equipment maintenance. According to data from the European Agency for Safety and Health at Work (EU-OSHA), machine-related accidents account for approximately 35% of all agricultural incidents;
- chemical risks – hazards associated with pesticides and fertilizers, including exposure to toxic substances and their impact on health and the environment. In the USA, farmers exposed to pesticides face a 30% higher risk of respiratory diseases;
- environmental risks – the effects of variable weather conditions, such as storms, droughts, or extreme temperatures, which are exacerbated by ongoing climate change;

19 See Y. Boneva, B. Vatchova, K. Stoilova, *Risk Management in Farming: An Overview of Sources, Decision-Making and Reduction Strategies*, Sofia 2024, p. 1-4.

– biological risks – exposure to microorganisms, viruses, or parasites that can lead to infections or occupational diseases, particularly in the livestock sector.

The development of agricultural technology has opened new possibilities for risk management. Technologies based on the Internet of Things (IoT) enable real-time monitoring of environmental parameters and machinery performance. Sensors mounted on agricultural equipment measure key parameters such as noise levels, vibrations, temperature, and humidity, and these data are analysed in real time by means of advanced management systems. A 2021 study by Wageningen University showed that farms using IoT reduced machinery-related accidents by 25% over two years[20].

Artificial intelligence (AI) and *Big Data* are entering the realm of risk management in agriculture, offering predictive capabilities. For instance, systems like *Climate FieldView* analyse weather and soil condition data to minimize losses caused by extreme weather events. Other applications, such as *FarmLogs*, assist in optimizing machinery operations and forecasting risks.

Risk management in agriculture varies by region. In developed countries, such as EU member states, the priority is implementing modern technologies like *IoT* and *AI* systems. In developing countries, such as India or sub-Saharan Africa, basic training and access to personal protective equipment are critical. For example, an *FAO* initiative in Ethiopia provided 50,000 farmers with affordable protective masks and gloves, reducing reported accidents by 18% within a year.

The HACCP (Hazard Analysis and Critical Control Points) system is widely used on food-producing farms in Europe and North America. In Poland, 70% of large farms have implemented the *HACCP* system, contributing to a 30% reduction in cases of food contamination over the past five years.

Modern risk management requires educating workers at all levels. Programs like SmartFarm in Germany offer courses on advanced technology operation and risk management[21]. In developing countries, initiatives focusing on the diverse demographics of the workforce, including support for women and older workers, are especially important.

Sustainable practices, such as agroforestry and water management, play a vital role in risk reduction. Projects like *Climate-Smart Agriculture* promote techniques that reduce soil erosion and minimize pesticide exposure.

Small farms often face financial barriers while implementing modern technologies. Programs like the *European Agricultural Fund for Rural Development (EAFRD)* support investments in workplace safety by providing grants for basic protective equipment and *IoT* technology[22].

20 See J. J. García, J. Greblikaitė, C. E. Iranzo, *Risk Management Tools in the Agriculture Sector: An Updated Bibliometric Mapping Analysis*, Valencia 2024, p. 45-50.

21 See X. Zou, *Research on the Agricultural Risk Management in the Era of Big Data*, Beijing 2023, p. 15-20.

22 See R. Zhuravel, *Methodological Approaches to the Formation of a Risk Minimization System in the Agricultural Sector of the Economy*, Uzhhorod 2024, p. 32-38.

Risk management at agricultural farms requires the integration of technology, education, and innovative strategies. The implementation of solutions such as *IoT, AI, HACCP* systems, and sustainable practices enables more effective risk management, improved workplace safety, and environmental protection. At the same time, regional differences and support for smaller farms must be considered. Thanks to an interdisciplinary approach, it is possible to create a sustainable agricultural system that meets the challenges of the modern world.

Summary

Workplace safety in agriculture presents a multidimensional challenge that requires a comprehensive and integrated approach encompassing both technological and social aspects. The agricultural sector, due to its unique nature, combines risks stemming from natural environmental conditions, the intensive nature of physical labour, and a growing reliance on advanced technologies. According to data from *the European Agency for Safety and Health at Work (EU-OSHA)*, agriculture accounts for approximately 10% of all reported workplace accidents in Europe, underscoring the significance of the issue. Environmental variability, including the impacts of climate change, and the dynamic development of technology can both increase and reduce accident risks. A key factor determining workplace safety is the level of awareness, knowledge, and preparation among workers.

Crucial Data and Challenges:

- 10% of reported accidents in Europe occur in the agricultural sector (*EU-OSHA*);
- farms using IoT reduced accidents by 25% over two years (*Wageningen University*);
- 18% reduction in risk in California following the introduction of autonomous machinery (*University of California*).

Effective workplace safety management in agriculture requires implementing systemic solutions that combine the development of protective technologies, such as *IoT* systems and autonomous machines, with educational programs and training tailored to agricultural workers. For instance, studies by Wageningen University revealed that farms using *IoT* systems reduced accident rates by 25% within two years. Raising awareness about personal protective equipment, safe machinery operation, and managing chemical and biological risks is particularly significant.

For smaller farms, access to advanced technology is often limited due to high initial costs and a lack of adequate financial support. In such cases, EU programs like the *European Agricultural Fund for Rural Development (EAFRD)*, which offers grants for basic protective equipment and *IoT* technologies, play a crucial role. Additionally, simplified versions of advanced devices, such as autonomous tractors with basic navigation systems, can be effective solutions for farms with limited budgets.

Modern challenges also necessitate the development of new methods for real-time hazard monitoring, enabling swift responses and risk minimization. Simultaneously, educational programs should be tailored to the demographic diversity in agriculture, addressing the needs of women, older individuals, and young farmers. For example, the *Women in Agriculture Initiative* implemented by *FAO* supports the education of women in rural areas on the use of personal protective equipment and modern technology operation.

Predictive systems based on *Big Data* analysis enable forecasting environmental hazards, such as droughts or storms, by means of historical and current weather data. Tools like *Climate FieldView* integrate data on weather conditions, soil quality, and crop performance, allowing farmers to make better risk management decisions. Implementing such solutions can be particularly beneficial in regions with variable climatic conditions, such as Southern Europe or South Asia.

Workplace safety management in agriculture varies by region. In developed countries like EU member states, the priority is adopting modern technologies such as *IoT* and *AI* systems. In developing nations like India or sub-Saharan Africa, basic training and access to personal protective equipment are critical. For instance, an *FAO* initiative in Ethiopia provided 50,000 farmers with affordable protective masks and gloves, reducing reported accidents by 18% within a year.

The adoption of sustainable practices, such as agroforestry, biotechnological pest control, or regenerative techniques, can play a vital role in reducing risks. Projects like *Climate-Smart Agriculture*, which promote techniques that reduce soil erosion and minimize exposure to toxic substances, exemplify the integration of production efficiency with environmental protection.

Future research should focus on assessing the effectiveness of implemented solutions and developing innovative tools to support safety management. A crucial direction involves designing technologies tailored to the needs of smaller farms, which often face financial barriers to accessing modern equipment. Global collaboration among universities, research institutes, and non-governmental organizations can contribute to the faster development of effective risk management tools.

Building a safer work environment in agriculture requires collaboration among scientists, farmers, policymakers, NGOs, and technology companies. For example, a partnership between the University of California and local farms resulted in the introduction of autonomous machinery, reducing accident risks by 18% over three years. The synergy between scientific knowledge, practical experience, and appropriate legal regulations is the foundation of an effective risk management system.

Improving working conditions in agriculture is not only a matter of health and safety but also a cornerstone of the sustainable development of this essential sector. An integrated approach that includes technology development, educational programs, and sustainable practices enables the agricultural sector to meet modern challenges while promoting workplace safety and environmental protection.

Bibliography

Adams R. M., Chen C. C., McCarl B. A., Schimmelpfennig D. E., *Climate Variability and Climate Change: Implications for Agriculture*, Leeds 2001.

Ahmad F., Alsayegh A., Abdullah M., *Pesticides Impacts on Human Health and the Environment with Their Mechanisms of Action and Possible Countermeasures*, Riyadh 2024.

Angon P. B., Aich P., *Progress and Potential Drawbacks of Modern Agricultural Technologies: A Literature Review*, Istanbul 2024.

Artık N., Güçer Y., Poyrazoğlu E. S., *Impact of Climate Change on Agricultural Production and Food Security*, Istanbul 2024.

Balakrishnan G., Prabhakar K., Chandran D. K., Murugesan R., Gheisari M., *Revolutionizing Agriculture: A Comprehensive Review of IoT Farming Technologies*, Chennai 2024.

Boneva Y., Vatchova B., Stoilova K., *Risk Management in Farming: An Overview of Sources, Decision-Making and Reduction Strategies*, Sofia 2024.

Cheluvaraj S., Bidare Sastry P. N., Somanna N. K., *Occupational Hazards Among Agricultural Workers in South India*, Bengaluru 2024.

Choi W., Kim K., Jung W., *A Mini Review (PRISMA) on Causes of Incidents and Injuries in Agricultural Workplaces*, Seoul 2024.

Ekmekci M., Yaman S., *Occupational health and safety among farmers: a comprehensive study in Central Anatolia*, Ankara 2024.

García J. J., Greblikaitė J., Iranzo C. E., *Risk Management Tools in the Agriculture Sector: An Updated Bibliometric Mapping Analysis*, Valencia 2024.

Jadhav A., Manohar K., Rajesh C. M., Prasad R. P. R., Bhat P., Jagadeesh V., *Revolutionizing Farm Management with Modern Agricultural Extension Techniques: A Review*, Mumbai 2024.

Kumar A., Satapathy S., Muduli K., *IoT, AI, and Robotics Applications in the Agriculture Sector*, Delhi 2024.

Moreira A., Vieira da Silva M., *Analysis of Health Effects Reported by Agricultural Workers and the Adverse Human Effects Indicated on Pesticide Labels: A Systematic Review*, Lisbon 2024.

Niu S., *Climate Change and Its Impacts on the Safety and Health of the Global Workforce: An ILO Perspective*, Geneva 2024.

Semeraro T., Scarano A., Leggieri A., Calisi A., De Caroli M., *Impact of Climate Change on Agroecosystems and Potential Adaptation Strategies*, Bari 2023.

Sharma V., Rajawat S., Kumar A., Kumar V., Parihar Y., Jaat S., *A Review on Advancing Sustainable and Smart Farming Practices: A Comprehensive Exploration of IoT and Sensor Technologies in Agriculture*, Jaipur 2024.

Somashekar K., Rehaman H. M. A., Kumar G. V. S., Bai K., Belagalla N., Abhishek G. J., Kapoor J. M. S., *Technology for a Food-Secure Future: A Review of Technology Advances in Sustainable Agriculture*, Bengaluru 2024.

Yadav H., Kumar N., *Contamination Levels and Distribution of Pesticides in Crops and Its Hazardous Effects on Living Beings*, Kolkata 2024.

Tahir R., Afzal F., Jamil H., Razzaq M., Khan M. S., *Physiological Impacts of Pesticidal Contamination: Challenge to Sustainable Agriculture and Biodegradation Methods*, Karachi 2024.

Zhuravel R., *Methodological Approaches to the Formation of a Risk Minimization System in the Agricultural Sector of the Economy*, Uzhhorod 2024.

Zou X., *Research on the Agricultural Risk Management in the Era of Big Data*, Beijing 2023.

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