The Role of Biosafety and Biosecurity in Agriculture

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Abstract

Biosafety and biosecurity of agricultural systems are responsible for sustainable social development, facilitating mankind's prolonged welfare. Proper implementation of biosecurity and biosafety measures develops resilient and resistant agriculture systems by safeguarding crops against biohazards such as invasive species, controlling and managing zoonotic diseases, preventing pathogen infiltration at the international level such as inspection at airports, seaports, and porous land borders by sufficient infrastructure and at the domestic level comprising proper farm management, proper handling of GMOs, adequate containment and eradication of pathogens, following laboratory guidelines and biosafety levels procedure, preventing interspecies contamination and wildlife conservation. Emerging threats and challenges to agriculture that require emphasis are emerging plant diseases and invasive species disturbing the food basket, continuous climate shifts influencing pest dynamics, the impact of emerging and reemerging zoonotic diseases on public health, the continuous emergence of super-resistant bacteria in livestock, misuse of biotechnology, use of pathogens as bioterrorism agents, financial losses due to biosecurity breaches and diseases outbreaks. Many international organizations participate to ensure the implementation of biosecurity and biosafety protocols in agriculture at the global level.

Keywords: Biosafety, Biosecurity, Agriculture, Zoonotic diseases, Bioterrorism, Pathogens.

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Introduction

Food safety and security, resilient agricultural systems, and a nourishing diet are the foundations of sustainable social development, facilitating mankind's prolonged welfare. Global challenges to conservative agriculture, nutritional sufficiency, and control and regulations include the appearance and recurrence of infectious agents, bio-warfare agents, urbanization, rising population, reduced crop productivity, climatic fluctuations, degradation of biodiversity, lowering investments, and water shortage. Biosecurity is an extensive term that constitutes laws and policies to safeguard people, food supplies, the agriculture sector, and the ecosystems against biological dangers that may threaten developments, standards, and techniques implemented to protect infectious agents, toxic chemicals, and sensitive innovations from illegal access, improper use, stealing, or unauthorized release (Khalil et al., 2018). The notion of biosafety in agriculture, comprising forestry, fisheries, and animal husbandry, entails evaluating and tracking potential gene flow, competitiveness, and the influence on other organisms alongside potential adverse impacts of the products on human and animal health. Biosafety policies impact food security and agricultural sustainability (Figure 1) (Djurle et al., 2022).

1. Significance of Biosecurity in Agriculture

1. Crop Biosecurity

Safeguarding Plants against Bio-Hazards

The policy and legislative structures that access and control plant survival and health constitute a comprehensive and systematic framework known as plant biosecurity. For instance, more and more types of invasive alien species are penetrating China through different channels as a consequence of economic cooperation and globalization. Furthermore, the rate at which these species are breeding, dispersing, and displacing native species is unimaginable and has resulted in a major threat to the security of the country's botanical assets by weakening the natural ecological equilibrium and the diversity of local species (Gao & Reitz, 2017). China has been attacked by more than 600 deadly alien species to date, more than 100 of which are widely distributed and potentially dangerous. Statistics demonstrate that 200,000 batches of pests, comprising over 3200 species, were captured at Chinese ports in 2009. This is 3.1 times the number found in 2002 and indicates an annual rise of more than 20% (Zhou et al., 2019). Biosecurity encompasses all actions intended to control non-native species' intentional and unintentional entry into a specific area and lessen their effects if they become invasive (Hulme, 2013). Improved phytosanitary inspection systems are needed to control and manage pests and pathogens transported through transport systems, trade and travel. Besides, plant biosecurity can be enhanced by diagnostic technology, including next-generation sequencing technology and field-based testing (Mumford et al., 2016).

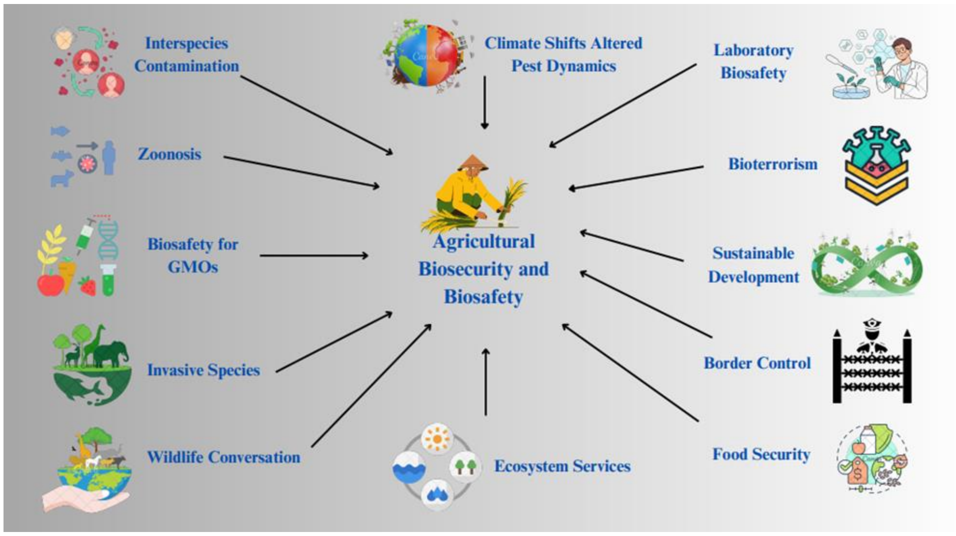

Fig. 1: Diagrammatic representation of concerns related to biosecurity and biosafety of agriculture.

2. Livestock Biosecurity

a. Control and Management of Zoonotic Diseases

Nearly half of the world's agricultural economy depends on the increased trade in livestock goods facilitated by globalization. Furthermore, the increased trade has contributed to increasing the risk of illnesses in humans and livestock. According to published research, 816 (58%) of the 1,407 human infections are zoonotic, and animals spread 73% of newly discovered human pathogens (Woolhouse & Gowtage-Sequeria, 2005). The main causes of the high prevalence of zoonotic and other transmissible diseases of animals are violations in livestock management biosecurity (Brown, 2004; Morse, 2004). Some instances of zoonotic infections that could endanger global health, economics, and food security (Figure 2) include the advent of viruses such as Ebola, SARS-Corona, Hendra, influenza virus H1N1, West Nile, Nipah, and Avian influenza (Mellor & Hamblin, 2004). Thus, a crucial biosecurity layer for controlling livestock diseases is provided by vaccination. Subunit vaccines, replication-defective particles, and recombinant vaccines are now available thanks to current advancements in molecular biology, offering substitute vaccinations for application (Plotkin, 2005). One of the best examples of a zoonotic infectious disease is influenza, successfully controlled by the proper application of vaccination (Peiris et al., 2007). A robust public health system and the establishment of a biosecurity system for the livestock, wildlife, and food safety sectors can reduce the effects of these diseases (Merianos, 2007).

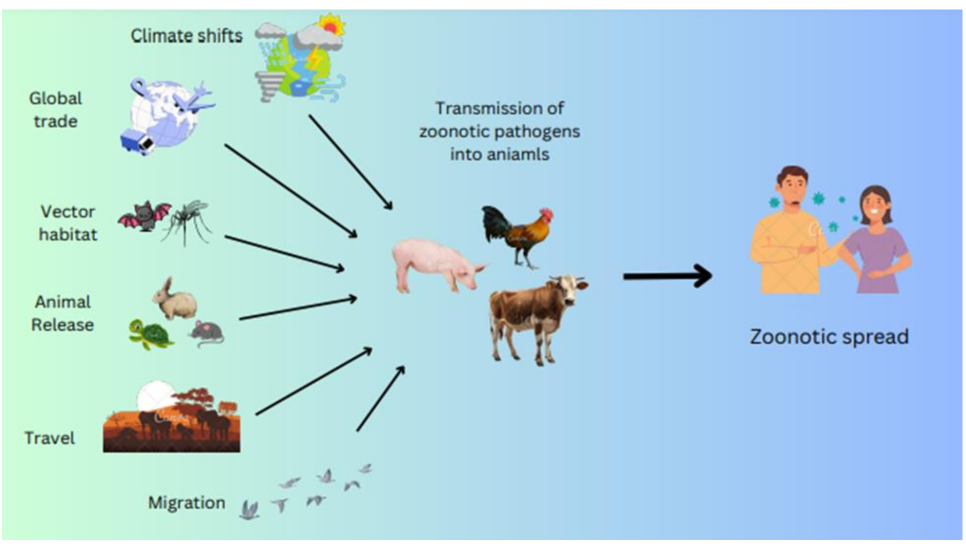

Fig. 2: Diagrammatic representation of zoonotic pathogen transmission pathways from different sources to animals and ultimately into humans.

b. Biosecurity Measures at the Domestic and International Level

The World Organization for Animal Health (OIE) is in charge of creating policies and standards to stop the spreading of diseases during the trade in animals and animal goods (Yogeshpriya & Rana, 2025). At the international level, to prevent pathogen infiltration, airports, seaports, and porous land borders must have sufficient infrastructure, including inspection and quarantine stations (Watson et al., 2011). Guaranteed pathogens-free imported livestock and livestock goods can be achieved by utilizing diagnostic facilities with tools, pen-side diagnostic tests and kits, and skilled human resources. At the domestic level, farm biosecurity (Dargatz et al., 2002), farm location and design (Abad et al., 2024), quarantine, testing, and vaccination of newly purchased and introduced animals (Maunsell & Donovan, 2008), risk analysis and biosecurity protocols (Sischo et al., 1997), farm management strategies, controlled on-site movement of workers (Abad et al., 2024), anti-contaminated animals bedding, feed and water (Nicholson et al., 2005), proper manure disposal management (Nachman et al., 2005), proper carcass disposal management (Nutsch & Kastner, 2008), proper management of wildlife, pests and feral animals (Tolhurst et al., 2011), sufficient sterilization and cleaning (Horsman et al., 2021), and diagnosis and medical care for infected animals.

3. Role of Biosafety in Agriculture

1. Plant Biosafety Measures

a. Proper Handling of Genetically Modified Organisms (GMOs)

Organisms whose genetic material has been artificially altered to modify their traits are known as genetically modified organisms or GMOs (James, 2004). Microorganisms have various environmental uses, including nitrogen fixation, bioremediation, biopesticides, plant growth promoters, biological control of plant diseases, and other similar agricultural techniques. The potential for using genetically modified microbes as soil or seed inoculants has been demonstrated by the prudent use of recombinant DNA technology (Bosworth et al., 1994; Corich et al.,1996; Schubert, 2002; Hennecke & Verma, 2013). They might, however, serve more unexpected ecological roles than the wild forms when released into the ecosystem (Tiedje et al., 1989; Heuer & Smalla, 2007; Tzotzos et al., 2010). Because they can proliferate and become persistent populations, GMOs may have long-lasting, profound effects on natural ecosystems and biological communities. However, the specific traits of the substituted gene may not be the only outcomes of DNA modification. Therefore, it's critical to make sure that these organisms don't negatively impact the ecosystem or public health when they are released into the wild (Andersson et al., 2006).

Consequently, national and international agencies and regulatory bodies are paying more attention to biosafety concerns related to the marketing of GMOs (Albergghina et al., 1994; Kuiper & Davies, 2010; Ishtiaq et al., 2023). The topic of risk assessment in the release of GMOs has been gaining more attention (Johnson et al., 2007). The goal of risk assessment is to use scientific data to estimate risks and determine the likelihood of certain outcomes. It is essential to raising quality, both in life and in products, and crucial for the innovations needed to optimize advantages. Finding situations that could have a negative impact is an important part of risk assessment (European Food Safety Authority, 2007). A risk needs to be handled after it has been evaluated. The decision of whether or not to acknowledge the prior assessed risk is the sole political action that results from risk management (Hill, 2005). Three important components of risk management are impact assessment, public participation/awareness, and the design of regulatory systems. These components are crucial for the governance of GMOs in the context of environmental concerns and regulations. Also, the significance of public understanding and the public's role in effective decision-making cannot be underestimated (Saravanan et al., 2022).

b. Containment and Eradication of Pathogens in Agricultural Research

In addition to endangering human and animal feed supplies, an invasive pathogen-caused plant disease outbreak can jeopardize a nation's agricultural industry, economy, and trade. Therefore, proper containment and eradication of the invasive pathogen is an appropriate response goal after identifying a new disease. A well-prepared infrastructure and an integrated process of prompt and rapid detection, pathogen recognition, and the adoption and meticulous application of a suitable plan are necessary to eradicate invasive pathogens. The most effective strategy in a given circumstance is determined by an accurate assessment of the efficiency of the assessable options as well as the possibility of their application and success—moreover, a quantitative evaluation of every factor affecting eradication (Gamliel & Fletcher, 2017).

2. Biosafety in Animal Husbandry

a. Laboratory Guidelines for Handling Pathogens

The infection spreads in laboratories through five major pathways:

i. parenteral administration using infected sharps or syringe needles,
ii. splashes and spills on mucous membranes and skin,
iii. exposure or ingestion via mouth pipetting or touching eyes or mouth with fingers or contaminated material,
iv. scrapes and bites from model animals
v. inhaling contagious aerosols (Richmond & McKinney, 2009).

The laboratory guidelines for handling pathogens include:

i. risk Assessment, which includes identifying hazards, identifying the sources of exposure, risk to personnel, and practices to control the risks,
ii. biosafety principles, including containment of pathogens, biosafety levels, material safety data sheet for chemicals and organisms and biosafety manual. There are four levels of biosafety: BSL-1 includes fundamental safety measures for harmless microbes; BSL-2 includes enhanced safety measures for intermediate-risk pathogens with a lower possibility of airborne transmission; BSL-3 includes high containment for diseases usually spread by aerosols and have dangerous impacts; BSL-4 optimum containment for extremely lethal and exotic pathogens for which no vaccine or treatment is currently available
iii. fundamental safety practices in diagnostic laboratories are necessary to protect personnel from infection. The personal protective equipment includes the appropriate use of gloves, closed-toe shoes, lab coats, goggles, masks, face shields, and respirators,
iv. safe handling practices include reducing aerosol generation, proper labeling of samples and containers, and antiseptic techniques
v. decontamination of the workplace and equipment with appropriate disinfectant and autoclave and adequate wastewater disposal
vi. proper laboratory design and engineering management includes airflow system, biosafety cabinets and access control
vii. proper specialized training of working personnel on handling techniques, emergency protocols for unintentional spill and exposure, and appropriate utilization and disposal of PPE
viii. develop an emergency response plan
ix. keep proper documentation and incident reporting

x. follow the national and international principles of biosafety, including the WHO biosafety manual, USDA/ APHIS guidelines, and Institutional Animal Care and Use Committee (IACUC) policies (Miller et al., 2012).

b. Prevention of Inter-species Contamination

Interspecific contamination is defined as the transmission of infectious pathogens among different species, leading to substantial risk to public health, agriculture and biodiversity. Therefore, practical implementations of effective biosafety measures are necessary to avoid such contamination. In laboratory research by implementing strict laboratory protocols including appropriate use of PPE, advanced containment systems, and disinfection of equipment (Edition, 2020), while in the field proper education about the diseases and their transmission pathways and training against pathogen incursion of epidemiological groups, veterinarians and animal health technicians serve as a barrier against pathogenic agent transmission from animal to animal as well as animal to human. Thus, lowering the risk of exposure in research as well as diagnostic settings. A key tactic is an assessment of the novel kinds of diseases and their causes, as well as the degree to which they pose a threat to agriculture. Also, preventing the transmission of pathogens between species can be achieved by quarantining animals before their introduction into fresh environments (Morris et al., 2023).

c. Case Study: Agricultural Biotechnology Biosafety Measures in Sub-Saharan Africa

This case study is documented by Komen et al. (2020); according to them, for new biotechnologies and risk-free adoption of GMOs in Sub-Saharan Africa, the regulation and execution of biosafety measures in agricultural systems are necessary. Biosafety systems were established in response to environmental and food safety concerns that emerged in the 1980s, mainly based on principles by the Cartagena Protocol on Biosafety, which focuses on controlling hazards associated with transboundary movement and the use of GMOs. To encourage agricultural innovation while tackling potential dangers, this case study demonstrates how biosafety measures were adopted and put into practice in selected African nations.

Nigeria, Kenya, Malawi, and other African nations offer real-world instances of biosafety control and management in agriculture. These countries incorporated biosafety procedures into their agricultural development strategies and reformed the regulations governing genetically modified crops. For example, Nigeria approved GM cowpea's commercial introduction in 2018 after extensive biosafety evaluations, Kenya incorporated GM cotton into its "Big 4 Agenda" to renew industrial agriculture and increase food stability, Malawi implemented biosafety measures into its development and growth planning, highlighting GM crops as a means of pest control and improving drought resistance.

Biosafety Measures were Included

i. risk analysis protocols in which assessments had been done before authorized GMO cultivation, concentrating on their impacts on the environment and human health

ii. community engagement in which governments encouraged community involvement in decision-making and raised awareness

iii. skill development included implementation of biosafety regulations was maintained by launching educational courses for researchers and controllers

iv. policy support by the Cartagena Protocol, nations implemented biosafety legislation, providing a regulatory framework based on science

v. control and monitoring systems led to constant surveillance of GMO production guaranteed adherence to safety regulations.

Numerous benefits resulted from the execution of biosafety measures, including a GM crops production rate enhanced by 22% (Qaim, 2019), sustainability enhanced as pesticide consumption reduced by 37% (Falck-Zepeda, 2016), and lower input prices and increased production, farmers enjoyed approximately 68% higher profits on average. Hence, Sub-Saharan African biosafety procedures are excellent examples of handling the interaction of regulatory structures and technical innovation. These tactics support food security, rural economies, and healthy agricultural growth by encouraging an equilibrium between innovation and safety (Da Costa et al., 2012; FMARD, 2016; Government of Malawi, 2017).

2. Challenges to Animal Biosecurity

a. Zoonotic disease: Emerging Challenge to the Public Health

Middle East respiratory syndrome coronavirus (MERS-CoV), Rift Valley fever, yellow fever, West Nile virus, SARS, Avian Influenza H5N1 and H7N9, and pandemic influenza H1N1 2009 are examples of emerging zoonotic diseases. Over the past 20 years, 18 of the 22 countries have reported new zoonotic illnesses, typically with major outbreaks and significant deaths that have never been reported in any other WHO zone (Malik et al., 2013). MERS-CoV's recent introduction is a prime instance of how unpredictable these animal-borne diseases can be, frequently caused by new viruses and only discovered during outbreaks. International travel for business, recreational or religious purposes, internationalization, and health systems' ability to catch outbreaks beforehand have been recognized as important risk factors for the emergence and immediate worldwide propagation of zoonotic disease, as the globe continuously faces outbreaks due to newly discovered infectious agents. The current approaches for managing and preventing zoonotic pathogens are still unclear with a lack of synergy between human and animal health divisions. There haven't been any significant initiatives for handling and regulating zoonotic outbreaks and potential risks to public health due to a shortage of finances and the right policy response (Negri & Eccleston-Turner, 2022).

b. Super Resistant Bacteria in Livestock

The emergence and propagation of antibiotic-resistant bacteria, as well as novel strains of resistant bacteria, have exhibited significant risks to human health lately. According to the WHO 2014 report on global antibiotic resistance, third-class cephalosporin-resistant Neisseria gonorrhoeae, carbapenem-resistant Klebsiella pneumoniae, and methicillin-resistant *Staphylococcus aureus* have become more prevalent, demonstrating that regular antibiotics are losing their effectiveness.

Moreover, global healthcare systems have been negatively impacted economically by antimicrobial resistance (AMR). American National Health Center and the Centers for Disease Control and Prevention documented that over 230,000 people die yearly from diseases brought on by resistant strains, and treating these strains burdens the US healthcare system with an estimated $200 trillion. An investigation published by the UK government in December 2014 stated that the resistant bacteria would cause a 2–3.5% decline in world GDP by 2050 (Zhou et al., 2019).

c. Use of Pathogens as Bioterrorism Agents

The deliberate applications of these pathogenic organisms as bioterrorism agents can also severely harm both human and animal health. Animals could trigger a bioterrorism outbreak by disseminating bio-warfare weapons worldwide through animal-to-animal transfer, which also proved challenging to control (Rabinowitz et al., 2006). Besides, many nations possess the scientific capacity to use the current biotechnology to generate new and innovative species. It is feasible to increase an organism's virulence or infectivity or to develop new pathogens by combining different species (Dudley & Woodford, 2002). Developing pathogen detection technology and a bioterrorism pathogen database, strengthening bioterrorist pathogen examination and identification, and reinforcing risk assessment and alert systems are all important actions against bioterrorism. To mitigate the consequences of bioterrorism, a national vaccination drug repository and an inventory for diagnostic assays must be developed, and research into multipurpose biotechnology must be broadened (Zhou et al., 2019).

3. Economic Impacts of Biosecurity Breaches and Disease Outbreaks

A current series of financial evaluations has significantly impacted public and political comprehension and understanding of biosecurity threats. According to studies conducted in the USA, the annual national costs of alien species are in the tens of billions (Pimentel et al., 2000; Pimentel, 2002) and had a significant role in the US Executive Order that established the National Invasive Species Council, an interdepartmental body, in 1996. Currently, governments have significant, obligatory contracts under the CBD, OIE, IPPC, and other agreements to prevent, remove, or control biosecurity threats. The cost of resolving national issues and sticking to international commitments could be high if biosecurity dangers kept increasing. These components have led to significant interest in the issue of who should bear the price for biosecurity, or more specifically, shifting the cost from the government and taxpayers to the people who pose a risk (Waage & Mumford, 2008).

Almost half of the global agricultural production value is derived from livestock goods (Raney et al., 2009). Externalities caused by livestock diseases harm productivity and distort values as a result of both domestic and foreign market shocks, thereby contributing to market inefficiencies (FAO, 2016). Livestock disease outbreaks and production-related mishaps pose a threat to smallholder farming systems, the future viability of marketed livestock goods, and the health of herds (Raney et al., 2009). Additionally, livestock diseases can promote harmful and undesirable behaviors. For instance, utilizing antibiotics to boost growth promotes animal size or treats persistent infections, but excessively employing them can have detrimental social consequences like antimicrobial resistance. Furthermore, unpredictable or recurrent disease outbreaks minimize animal productivity, but they may also have unexpected effects on the supply and demand for other market products. Consumer demand in the retail sector can be influenced by unfavorable information and publicity related to a disease outbreak, while shortages or excesses may arise through disruption in unaffiliated markets (Hennessy & Marsh, 2021).

4. Major Threats and Challenges

1. Challenges to Plant Biosecurity

a. Emerging Plant Diseases and Invasive Species Influencing the Food Basket

There are major worldwide ramifications for farmers, seed cooperations, lawmakers, and the general population when plant pathogens and insect pests emerge and spread among crops as well as other plant species, mainly in horticulture and forestry. Examples of such emerging diseases are black stem rust of wheat, late blight of potatoes, and Banana Xanthomonas Wilt (BXW). Therefore, improving the technical elements of quarantine, risk assessments, and other preventive strategies is essential. Several agricultural ministries around the globe have initiated projects to strengthen different defense measures against insect pests and plant diseases. Furthermore, it provides a platform to educate the general public about the importance of tackling serious problems associated with the danger of reemerging and emerging phytopathogens to forest trees, food crops, and other environmental ecosystem services (Mwangi et al., 2023).

b. Climate Shifts and Their Impacts on Altering Pest Dynamics

By the end of the century, the global mean temperature is expected to have increased by 1 to 2 degrees Celsius due to global warming (Raftery et al., 2017), upregulating the occurrences of storms and droughts (Sabine et al., 2013; Cook et al., 2016). As a result, different pathogens, including bacterial and fungal organisms, are encouraged to attack the plant at different places (Pandit et al., 2022). Thus, improving the virulence of pathogens. Noval genetically modified crop varieties may be produced in response to these climate modifications as well as their effects on crop plants and their associated pathogens. The procedure currently takes about 20 years on average (Lipper et al., 2014).

5. Legislative Frameworks and Regulatory Measures

Comprehension of the dangers of bioterrorism and bio crime has motivated various initiatives at domestic and global levels on laboratory biosafety and biosecurity beyond existing rules and regulations. The United Nations Security Council Resolution 1540 (UNSCR 1540) and the Biological and Toxins Weapons Convention16 (BWC) are two global agreements that pressurize nations to enhance their biosecurity management (BWC, 1972). UNSCR 1540, which was approved by the UN Security Council on April 28, 2004, designed, for the first time, enforced commitment on all UN member states under the seventh Chapter of the UN Charter to implement and uphold efficient preventives against the global dissemination of weapons of mass destruction, their distribution methods, and associated components (Gaudioso et al., 2009). The value of laboratory biosafety and biosecurity was officially acknowledged in 2005 with the introduction of World Health Assembly

Resolution 58.29. Particularly, this resolution encouraged WHO member states to establish a holistic approach to laboratory biosafety, comprising toxic agents and confinement of pathogenic agents. The Laboratory Biosafety Manual's third version, released in 2004, was nominated as one of the standard documents of the WHO (World Health Organization, 2024)). The OECD Best Practice Guidelines for Biological Resource Centers were issued by the Organization for Economic Cooperation and Development (OECD) in 2007 (Озерская, 2008). This extensive publication contains four series of optimal practical recommendations, including the Best Practice Guidelines on Biosecurity for biological resource centers, and discusses the rationale for developing an international network for BRCs.

6. Future Perspectives and Conclusion

Agricultural biosecurity and biosafety are important worldwide issues that require regular attention from scientists, farmers, consumers, and food security-related government organizations. The potential hazards and complications that the global population faces from emerging fatal infectious diseases to both cash crops and livestock, modifications in pest dynamics due to climate shifts and biological warfare are escalating along with the growth of globalization, the ongoing development and misuse of biotechnology, economic and infrastructural challenges to biosecurity and lack of education and untrained personnel in the field as well as laboratory. Also, contracts at the international level minimize the possibilities of modifications in biosecurity systems as they may result in hefty trade penalties. However, there will be growing pressure to become more diligent and preventative by collaborating to stop emerging pests and diseases at their origin and, eventually, attain freedom from invasive pests and diseases by developing resistant and resilient biosecurity systems, as the cost of the operating system on traditional principles enhances due to more prevalent violations and more losses in economic trades and eradication programs. These evolutions will expand biosecurity systems by incorporating new science that expands the identification, surveillance, and modeling of biosecurity risks as well as by developing new biotechnology techniques for plant and animal healthcare.

References

Abad, X., Cantero, G., & Solanes, D. (2024). Biosafety. In *Practical Management of Research Animal Care and Use Programs: Questions and Answers* (pp. 299-321). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-65414-5_15

Albergghina, L., Frontali, L., & Sensi, P. (1994). *ECB6: Proceedings of the 6th European Congress on Biotechnology,* Florence, Italy, June 13-17, 1993 (Vol. 9). Elsevier Publishing Company.

Andersson, C., Bartsch, D., Buhk, H. J., Davies, H., De Loose, M., Gasson, M., & Wal, J. M. (2006). Guidance document of the scientific panel on genetically modified organisms for the risk assessment of genetically modified microorganisms and their derived products intended for food and feed use:(Question No EFSA-Q-2003-005B). *European Food Safety Authority Journal,* 1-115.

Bosworth, A. H., Williams, M. K., Albrecht, K. A., Kwiatkowski, R., Beynon, J., Hankinson, T. R., & Triplett, E. W. (1994). Alfalfa yield response to inoculation with recombinant strains of *Rhizobium meliloti* with an extra copy of dctABD and/or modified nifA expression. *Applied and Environmental Microbiology*, *60*(10), 3815-3832. 10.1128/aem.60.10.3815-3832.1994

Brown, C. (2004). Emerging zoonoses and pathogens of public health significance--an overview. *Revue Scientifique et Technique-Office International Des Epizooties*, *23*(2), 435-442.

Cook, J., Oreskes, N., Doran, P. T., Anderegg, W. R., Verheggen, B., Maibach, E. W., & Rice, K. (2016). Consensus on consensus: a synthesis of consensus estimates on human-caused global warming. *Environmental Research Letters*, *11*(4), 048002. DOI 10.1088/1748-9326/11/4/048002

Corich, V., Bosco, F., Giacomini, A., Basaglia, M., Squartini, A., & Nuti, M. P. (1996). Fate of genetically modified *Rhizobium leguminosarum* biovar viciae during long-term storage of commercial inoculants. *Journal of Applied Microbiology*, *81*(3), 319-328. https://doi.org/10.1111/j.1365-2672.1996.tb04334.x

Da Costa, E., Agreement, A. A. I., Clearing-House, B. B., & Framework, R. R. A. (2012). Independent evaluation of the action plan for building capacities for the effective implementation of the Cartagena protocol on biosafety.

Dargatz, D. A., Garry, F. B., & Traub-Dargatz, J. L. (2002). An introduction to biosecurity of cattle operations. *The Veterinary Clinics of North America. Food Animal Practice*, *18*(1), 1-5.

Djurle, A., Young, B., Berlin, A., Vågsholm, I., Blomström, A. L., Nygren, J., & Kvarnheden, A. (2022). Addressing biohazards to food security in primary production. *Food Security*, *14*(6), 1475-1497. https://doi.org/10.1007/s12571-022-01296-7

Dudley, J. P., & Woodford, M. H. (2002). Bioweapons, bioterrorism and biodiversity: potential impacts of biological weapons attacks on agricultural and biological diversity. *Revue Scientifique et Technique-Office International Des Epizooties*, *21*(1), 125-138.

EDITION, F. (2020). *Laboratory biosafety manual fourth edition*. https://iris.who.int/bitstream/handle/10665/337961/9789240011410-eng.pdf

European Food Safety Authority (EFSA). (2007). Statement on the safe use of the nptII antibiotic resistance marker gene in genetically modified plants by the Scientific Panel on genetically modified organisms (GMO). *European Food Safety Authority Journal*, *5*(4), 742. http://www.efsa.europa.eu/etc/medialib.

FMARD (2016). Agriculture promotion policy 2016-2020: the green alternative (Abuja, Nigeria: Federal Ministry for Agriculture and Rural Development). https://nssp.ifpri.info/files/2017/12/2016-Nigeria-Agric-Sector-Policy-Roadmap_June-15-2016_Final.pdf

Food and Agriculture Organization of the United Nations (FAO). (2016). Economic analysis of animal diseases. *FAO animal production and health guidelines, (18).*

Falck-Zepeda, J. B. (2016). Experiences and prospects of genetically engineered crops. *Choices*, *31*(2), 1-7.

Gamliel, A., & Fletcher, J. (2017). Containment and eradication of invasive pathogens. *Practical Tools for Plant and Food Biosecurity: Results from a European Network of Excellence*, 243-256. https://doi.org/10.1007/978-3-319-46897-6_12

Gao, Y., & Reitz, S. R. (2017). Emerging themes in our understanding of species displacements. *Annual Review of Entomology*, *62*(1), 165-183.

Gaudioso, J., Gribble, L. A., & Salerno, R. M. (2009). Biosecurity: progress and challenges. *JALA: Journal of the Association for Laboratory Automation*, *14*(3), 141-147.

Government of Malawi. (2017). *The Malawi Growth and Development Strategy (MGDS) III (2017–2022)*. https://www.mw.undp.org/content/malawi/en/home/library/the-malawi-growth-and-development-strategy-iii-.html.

Hennecke, H., & Verma, D. P. S. (2013). *Advances in Molecular Genetics of Plant-Microbe Interactions, Vol. 1* (Vol. 10). Springer Science & Business Media.

Hennessy, D. A., & Marsh, T. L. (2021). Economics of animal health and livestock disease. In *Handbook of Agricultural Economics* (Vol. 5, pp. 4233-4330). Elsevier.

Heuer, H., & Smalla, K. (2007). Horizontal gene transfer between bacteria. *Environmental Biosafety Research*, *6*(1-2), 3-13. https://doi.org/10.1051/ebr:2007034.

Hill, R. A. (2005). Conceptualizing risk assessment methodology for genetically modified organisms. *Environmental Biosafety Research*, *4*(2), 67-70. https://doi.org/10.1051/ebr:2005012.

Horsman, S., Rynhoud, H., Zhou, X., Soares Magalhães, R. J., Gibson, J. S., & Meler, E. (2021). Environmental recovery of nosocomial bacteria in a companion animal shelter before and after infection control procedures. *Frontiers in Veterinary Science*, *7*, 608901. https://doi.org/10.3389/fvets.2020.608901

Hulme, P. E. (2013). An introduction to plant biosecurity: past, present and future. In *The Handbook of Plant Biosecurity: Principles and Practices for the Identification, Containment and Control of Organisms that Threaten Agriculture and the Environment Globally* (pp. 1-25). Dordrecht: Springer Netherlands.

Ishtiaq, M., Mazhar, M., Maqbool, M., & Mazhar, M. W. (2023). Genetically modified organisms: concerns and biosafety. In *Genetic Engineering* (pp. 245-257). Apple Academic Press.

James, C. (2004). Global status of commercialized biotech/GM crops: 2004. *ISAAA Briefs*, *32*, 1-12.

Johnson, K. L., Raybould, A. F., Hudson, M. D., & Poppy, G. M. (2007). How does scientific risk assessment of GM crops fit within the wider risk analysis?. *Trends in Plant Science*, *12*(1), 1-5. https://doi.org/10.1016/j.tplants.2006.11.004

Khalil, A. T., Iqrar, I., Bashir, S., Ali, M., Khalil, A. H., & Shinwari, Z. K. (2018). Preemptive and proactive strategies for food control and biosecurity. In *Food Safety and Preservation* (pp. 39-58). Academic Press.

Komen, J., Tripathi, L., Mkoko, B., Ofosu, D. O., Oloka, H., & Wangari, D. (2020). Biosafety regulatory reviews and leeway to operate: case studies from sub-Sahara Africa. *Frontiers in Plant Science*, *11*, 130. https://doi.org/10.3389/fpls.2020.00130

Kuiper, H. A., & Davies, H. V. (2010). The SAFE FOODS risk analysis framework suitable for GMOs? a case study. *Food Control*, *21*(12), 1662-1676. https://doi.org/10.1016/j.foodcont.2010.02.01

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., & Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature Climate Change*, *4*(12), 1068-1072.

Malik, M. R., El Bushra, H. E., Opoka, M., Formenty, P., Velayudhan, R., & Eremin, S. (2013). Strategic approach to control of viral haemorrhagic fever outbreaks in the Eastern Mediterranean Region: report from a regional consultation. *Eastern Mediterranean Health Journal*, *19*(10), 892-897.

Maunsell, F., & Donovan, G. A. (2008). Biosecurity and risk management for dairy replacements. *Veterinary Clinics of North America: Food Animal Practice*, *24*(1), 155-190.

Mellor, P. S., & Hamblin, C. (2004). African horse sickness. *Veterinary Research*, *35*(4), 445-466.

Merianos, A. (2007). Surveillance and response to disease emergence. *Wildlife and Emerging Zoonotic Diseases: The Biology, Circumstances and Consequences of Cross-Species Transmission*, 477-509.

Miller, J. M., Astles, R., Baszler, T., Chapin, K., Carey, R., Garcia, L., & Wiedbrauk, D. (2012). Guidelines for safe work practices in human and animal medical diagnostic laboratories. *MMWR Surveill Summ*, *6*(61), 1-102.

Morris, G., Ehlers, S., & Shutske, J. (2023). US small-scale livestock operation approach to biosecurity. *Agriculture*, *13*(11), 2086. https://doi.org/10.3390/agriculture13112086

Morse, S. (2004). Factors and determinants of disease emergence. *Revue Scientifique Et Technique-Office International Des Epizooties*, *23*(2), 443-452.

Mumford, R. A., Macarthur, R., & Boonham, N. (2016). The role and challenges of new diagnostic technology in plant biosecurity. *Food Security*, *8*, 103-109.

Mwangi, R. W., Mustafa, M., Charles, K., Wagara, I. W., & Kappel, N. (2023). Selected emerging and reemerging plant pathogens affecting the food basket: a threat to food security. *Journal of Agriculture and Food Research*, *14*, 100827. https://doi.org/10.1016/j.jafr.2023.100827

Nachman, K. E., Graham, J. P., Price, L. B., & Silbergeld, E. K. (2005). Arsenic: a roadblock to potential animal waste management solutions. *Environmental Health Perspectives*, *113*(9), 1123-1124.

Negri, S., & Eccleston-Turner, M. (2022). One Health and Pathogen Sharing: Filling the Gap in the International Health Regulations to Strengthen Global Pandemic Preparedness and Response. *International Organizations Law Review*, *19*(1), 188-214.

Nicholson, F. A., Groves, S. J., & Chambers, B. J. (2005). Pathogen survival during livestock manure storage and following land application. *Bioresource Technology*, *96*(2), 135-143.

Nutsch, A., & Kastner, J. (2008). Carcass disposal options. *Wiley Handbook of Science and Technology for Homeland Security*, 1-1.

Озерская, С. М. (2008). OECD best practice guidelines for biological resource centers. OECD, 2007, 115 р. *Прикладная биохимия и микробиология*, *44*(5), 615-616.

Pandit, M. A., Kumar, J., Gulati, S., Bhandari, N., Mehta, P., Katyal, R., & Kaur, J. (2022). Major biological control strategies for plant pathogens. *Pathogens*, *11*(2), 273.

Peiris, J. M., De Jong, M. D., & Guan, Y. (2007). Avian influenza virus (H5N1): a threat to human health. *Clinical Microbiology Reviews*, *20*(2), 243-267.
Pimentel, D. (2002). Biological invasions: economic and environmental costs of alien plant, animal, and microbe species. In *Biological Invasion* (pp. 369-pp). CRC Press.
Pimentel, D., Lach, L., Zuniga, R., & Morrison, D. (2000). Environmental and economic costs of nonindigenous species in the United States. *BioScience*, *50*(1), 53-65.
Plotkin, S. A. (2005). Vaccines: past, present and future. *Nature Medicine*, *11*(4), S5-S11. https://doi.org/10.1038/nm1209
Qaim, M. (2019). Genetically modified crops. *Annual Review of Resource Economics, 1*(1), 665-694.
Rabinowitz, P., Gordon, Z., Chudnov, D., Wilcox, M., Odofin, L., Liu, A., & Dein, J. (2006). Animals as sentinels of bioterrorism agents. *Emerging Infectious Diseases*, *12*(4), 647.
Raftery, A. E., Zimmer, A., Frierson, D. M., Startz, R., & Liu, P. (2017). Less than 2 C warming by 2100 unlikely. *Nature Climate Change*, *7*(9), 637-641.
Raney, T., Gerosa, S., Khwaja, Y., Skoet, J., Steinfeld, H., McLeod, A., & Cluff, M. (2009). *The state of food and agriculture 2009: Livestock in the balance.* Food and Agriculture Organization of the United Nations, Rome, Italy.
Richmond, J. Y., & McKinney, R. W. (2009). CDC/National Institutes of Health. In *Biosafety in Microbiological and Biomedical Laboratories*. US Government Printing Office. http://www.cdc.gov/biosafety/publications/bmbl5/BMBL.pdf
Saravanan, A., Kumar, P. S., Ramesh, B., & Srinivasan, S. (2022). Removal of toxic heavy metals using genetically engineered microbes: molecular tools, risk assessment and management strategies. *Chemosphere*, *298*, 134341.
Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., Chhabra, A., & Bala, G. (2013). Near-term climate change: projections and predictability. *Josep Canadell (Australia), Abha Chhabra*, 255-315.
Schubert, D. (2002). A different perspective on GM food. *Nature Biotechnology*, *20*(10), 969-969. https://doi.org/10.1038/nbt1002%2D969.
Sischo, W. M., Kiernan, N. E., Burns, C. M., & Byler, L. I. (1997). Implementing a quality assurance program using a risk assessment tool on dairy operations. *Journal of Dairy Science*, *80*(4), 777-787.
Tiedje, J. M., Colwell, R. K., Grossman, Y. L., Hodson, R. E., Lenski, R. E., Mack, R. N., & Regal, P. J. (1989). The planned introduction of genetically engineered organisms: ecological considerations and recommendations. *Ecology*, *70*(2), 298-315.
Tolhurst, B. A., Ward, A. I., & Delahay, R. J. (2011). A study of fox (*Vulpes vulpes*) visits to farm buildings in Southwest England and the implications for disease management. *European Journal of Wildlife Research*, *57*, 1227-1230.
Tzotzos, G. T., Head, G. P., & Hull, R. (2010). Principles of risk assessment. *Genetically Modified Plants*, *2009*, 33-63.
Waage, J. K., & Mumford, J. D. (2008). Agricultural biosecurity. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1492), 863-876.
Watson, J., Daniels, P., Kirkland, P., Carroll, A., & Jeggo, M. (2011). The 2007 outbreak of equine influenza in Australia: lessons learned for international trade in horses. *Revue Scientifique Et Technique (International Office of Epizootics)*, *30*(1), 87-93.
Woolhouse, M. E., & Gowtage-Sequeria, S. (2005). Host range and emerging and reemerging pathogens. *Emerging Infectious Diseases*, *11*(12), 1842.
World Health Organization. (2024). *Laboratory biosecurity guidance*. World Health Organization.
Yogeshpriya, S., & Rana, T. (2025). Role of OIE in global trade in animals and animal products. *Epidemiology and Environmental Hygiene in Veterinary Public Health*, 185.
Zhou, D., Song, H., Wang, J., Li, Z., Xu, S., Ji, X., & Xu, J. (2019). Biosafety and biosecurity. *Journal of Biosafety and Biosecurity*, *1*(1), 15-18. https://doi.org/10.1016/j.jobb.2019.01.001