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The Forensic Frontier: Countering Agro-Terrorism in The Agricultural Sector

Sahil Sharma[1], Loveleen[2], Vikas Bhargav[3], Arindam Adhikary[4]
[1]Assistant Professor, Department of Forensic Science, Geeta University, Panipat
[2]Assistant Professor, Forensic Science, USAHS, Rayat Bahra University, Mohali
[3]Assistant Professor, Forensic Science, USAHS, Rayat Bahra University, Mohali
[4]Assistant Professor, Medical Microbiology, USAHS, Rayat Bahra University, Mohali
Corresponding Author mail id: sahil.fs@geetauniversity.edu.in

ABSTRACT
The intentional use of biological agents to target agriculture, known as agro-terrorism, poses a significant risk to both global food security and economic stability. This paper examines how forensic science intersects with agro-terrorism, delving into the methodologies and technologies used to detect, attribute, and mitigate agricultural threats. By studying past incidents, current prevention tactics, and emerging forensic tools, the paper explores the ethical and legal frameworks governing forensic investigations in agro-terrorism contexts. It emphasizes the importance of forensic science in safeguarding the agricultural sector from deliberate harm and underscores the necessity of employing forensic methodologies to prevent future attacks. Additionally, the paper discusses forthcoming challenges and opportunities, highlighting the ongoing relevance of forensic science in protecting global food systems. It offers valuable insights for policymakers, researchers, and practitioners involved in securing agriculture against terrorist acts, aiming to provide a comprehensive understanding of how forensic science plays a crucial role in this endeavour and guiding future research efforts.
Keywords: *agro-terrorism, forensic science, agriculture*

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INTRODUCTION

Agro terrorism is the use of biological, chemical or radiological nuclear agents to cause harm to plants, animals, and human populations. This can include the use of pathogens, toxins, or other harmful substances to disrupt agricultural production, food supply chains, or cause panic and fear among the public [1]. Broadly the agents which can be used to cause is classified as

Chemical Threat: Chemical threats in agroterrorism involve the deliberate use of toxic chemicals to target agriculture, livestock, or food supplies. While there haven't been many documented cases of chemical attacks specifically categorized as agroterrorism, the potential risks are significant. Pesticides and Herbicides: Chemicals commonly used in agriculture for pest control and weed management could be misused in a harmful manner. Large-scale contamination of crops or soil with pesticides or herbicides could devastate agricultural production and food supplies. Toxic Industrial Chemicals (TICs): Industrial chemicals, such as ammonia, chlorine, or sulfur dioxide, could be released near agricultural areas to contaminate crops, water sources, or livestock. This could result in widespread damage to agricultural resources and pose health risks to humans and animals. Chemical Warfare Agents: Highly toxic chemicals, such as nerve agents (e.g., sarin, VX) or blister agents (e.g., sulfur mustard), could be deployed to target agricultural areas. These chemicals can cause rapid illness or death in humans and animals and contaminate soil and water resources, rendering land unusable for cultivation. Toxic Industrial Waste: Deliberate release of hazardous waste materials from industrial facilities or waste disposal sites into agricultural areas could result in soil contamination, crop damage, and environmental pollution.

Biological Threat:

Bioterrorism involves the deliberate release of biological agents, including pathogens, to cause harm to humans, animals, or plants. Several types of pathogens have been considered as potential agents for

bioterrorism due to their ability to cause widespread illness, fear, and disruption. Some of the key pathogens that have been of concern in bioterrorism scenarios include:

Anthrax (Bacillus anthracis): Anthrax spores can be dispersed in the air, water, or food supply. When inhaled, ingested, or entering through skin abrasions, anthrax can cause severe illness and, if untreated, can be fatal.

Botulism (*Clostridium botulinum* toxin): Botulinum toxin, produced by the bacterium Clostridium botulinum, is one of the most potent toxins known. It can cause paralysis and respiratory failure if ingested or inhaled.

Plague (*Yersinia pestis*): The bacterium *Yersinia pestis*, which causes plague, can be weaponized for aerosol dissemination. Plague can manifest as bubonic, septicemic, or pneumonic forms, with pneumonic plague being particularly concerning due to its potential for person-to-person transmission.

Tularemia (*Francisella tularensis*): *Francisella tularensis* is a highly infectious bacterium that can cause tularemia. It can be transmitted through aerosolization, ingestion, or contact with infected animals. Tularemia can cause severe illness with symptoms ranging from fever and respiratory distress to sepsis.

Smallpox (*Variola virus*): Smallpox is a highly contagious viral disease that was eradicated through vaccination efforts. However, concerns remain about the potential use of smallpox virus as a bioweapon due to its high mortality rate and lack of widespread immunity in the population.

Viral Hemorrhagic Fevers (e.g., Ebola virus, Marburg virus): Viral hemorrhagic fevers, caused by several different viruses, can lead to severe hemorrhagic fever with high fatality rates. These viruses could be aerosolized or introduced into the water supply to cause outbreaks.

Ricin: Ricin is a toxin derived from the castor bean plant. It can be used as a bioterrorism agent when purified and dispersed in aerosol form. Ricin can cause severe poisoning and organ failure if ingested, inhaled, or injected.

Radiological-Nuclear Threat: Radiological-nuclear agents could be used to target agricultural resources, food supplies, or the environment. While radiological-nuclear agents are not typically associated with agriculture, their use in agroterrorism could result in significant disruption and harm. Here are some potential scenarios involving radiological-nuclear agents in agroterrorism:

Radiological Contamination of Agricultural Land: Radioactive materials could be dispersed over agricultural fields, contaminating soil and crops. This contamination could render the land unsuitable for agriculture and pose risks to human health through ingestion of contaminated food.

Contamination of Water Sources: Radiological materials could be introduced into water sources used for irrigation or livestock watering, leading to contamination of agricultural products and posing risks to both human and animal health.

Targeting of Agricultural Infrastructure: Radiological-nuclear devices could be detonated near agricultural infrastructure such as storage facilities, processing plants, or distribution centers. This could result in widespread contamination of agricultural products and disruption of food supplies.

Terrorizing Agricultural Communities: Threats or hoaxes involving radiological-nuclear materials could instill fear and panic among farmers, agricultural workers, and rural communities. This psychological impact could lead to economic disruption and social instability.

Contamination of Livestock: Radiological materials could be introduced into livestock feed or water sources, leading to contamination of meat and dairy products. This could pose risks to human health through consumption of contaminated animal products.

The relatively indirect and indiscriminate nature of an agro-terror attack meshes perfectly with the perceived shift in terrorism goals, which have ostensibly veered away from attempting to kill large numbers of people [2]. Agro terrorism is a subset of agro- crime. It can be understood as terrorist attacks directed against crops and livestock, in an effort to disrupt a population's economy and food supply [3]. Agroterrorism can be segregated possess threat not only to plant but also to livestock as well. Livestock agroterrorism involves deliberately introducing animal diseases to induce fear, cause economic damage, and threaten social stability. It's attractive to terrorists due to the ease of acquiring livestock-targeting agents and the significant economic impact. The goal isn't necessarily to kill animals but to disrupt society and economies, potentially jeopardizing human health. Highly contagious diseases like foot-and-mouth disease can cause devastating consequences. Livestock are vulnerable targets, and bioterrorist attacks on them are considered viable due to the ease of acquiring disease agents and their potential for widespread impact. These biological agents target livestock or poultry through airborne transmission, direct Transmission and vector transmission. These attacks don't require advanced technology but careful planning and access to disease agents. Livestock agroterrorism poses a serious threat globally, capable of causing catastrophic epidemics and economic disruption.

Preventing and responding to agro-terrorism requires international cooperation, strong regulatory frameworks, and public awareness. This includes measures such as biosecurity, surveillance, and response plans for potential incidents. Agro- security involves the issues that the agricultural industry, communities, and the government need to address to protect against agro terrorism. These include the broad areas of agriculture that could provide targets in an agro terrorism event, such as farm animals and livestock, plant crops, and the food processing industry [4]. The consequences of an agro terrorism attack can affect the domestic supply of food, rural livelihoods, potential export revenues, and the safety of food in importing countries. Forensic science plays a crucial role in the context of agricultural threats. It involves the application of scientific methods in investigating possible violations of the law related to agricultural threats. This includes the identification and analysis of biological and chemical agents used in such attacks. Forensic science plays a pivotal role in safeguarding agricultural systems from the threat of agro terrorism, which seeks to disrupt food production and distribution through deliberate acts of contamination or sabotage. Through advanced analytical techniques, forensic scientists can swiftly detect and identify biological, chemical, or radiological agents used in such attacks, enabling authorities to respond effectively and mitigate the impact on public health and economic stability. Furthermore, forensic analysis facilitates the tracing of the origin and pathway of agro terrorism incidents, aiding in the apprehension of perpetrators and the implementation of preventive measures. By serving as the backbone of investigation, response, and recovery efforts, forensic science serves as a critical line of defense against the insidious threat of agro terrorism, ensuring the resilience and security of agricultural systems worldwide. Forensic science helps in the identification and analysis of microorganisms, generally pathogens, involved in criminal actions. The ultimate goal of microbial forensics is to understand the nature and origin of these pathogens and how they can be used in agricultural threats [5].

THE CONSEQUENCES OF SUCH EVENTS INCLUDE

Economic Impact: Agro terrorism can inflict severe economic damage by disrupting agricultural production, trade, and markets. Attacks targeting crops or livestock can result in substantial financial losses for farmers, agribusinesses, and the broader economy. A study by the Congressional Research Service (CRS) highlights the economic vulnerability of the agriculture sector to intentional attacks, emphasizing the potential for significant disruptions to food production and supply chains. For example, the deliberate introduction of animal diseases, such as foot-and-mouth disease (FMD), can lead to widespread culling of livestock, trade embargoes, and market closures, causing billions of dollars in economic losses.

Food Safety concerns: Agroterrorism poses serious threats to food security by jeopardizing the availability, accessibility, and affordability of food supplies. The intentional contamination of agricultural products or the introduction of plant and animal diseases can disrupt food production, distribution, and consumption patterns, leading to food shortages and price volatility. A report by the Food and Agriculture Organization of the United Nations (FAO) underscores the vulnerability of global food systems to deliberate attacks, highlighting the potential for agroterrorism to undermine food security and exacerbate hunger and malnutrition, particularly in vulnerable populations.

Public health risks: The use of biological agents in agroterrorism attacks can pose significant public health risks, endangering both animal and human populations. Pathogens targeting livestock or crops can lead to widespread disease outbreaks, resulting in animal deaths, crop failures, and foodborne illnesses. A study published in the journal Food Security emphasizes the potential for agroterrorism to compromise food safety and public health, highlighting the need for enhanced surveillance, detection, and response measures to mitigate biological threats to agricultural systems.

Psychological Impact: Agroterrorism incidents can instill fear, uncertainty, and anxiety in society, affecting individuals' mental health and well-being. The deliberate targeting of agricultural assets can evoke feelings of vulnerability and insecurity, undermining public confidence in the safety and reliability of food supplies. A report by the Department of Homeland Security (DHS) underscores the psychological impact of agro terrorism, noting the potential for heightened anxiety, stress, and social disruption in affected communities. Fear of consuming contaminated food or contracting diseases can prompt behavioral changes, such as dietary restrictions and avoidance of certain foods, further exacerbating psychological distress.

Political and Social Consequences: Agro terrorism incidents can have significant political and social ramifications, influencing government policies, public discourse, and societal cohesion. The deliberate targeting of agricultural assets may be perceived as acts of terrorism or aggression, prompting government responses aimed at enhancing national security and protecting critical infrastructure. A study by the RAND Corporation highlights the potential for agro terrorism to fuel political instability,

exacerbate social tensions, and undermine trust in government institutions. Socially, agro terrorism incidents can deepen divisions within society, fuelling distrust, prejudice, and discrimination against specific groups or communities

HISTORICAL PERSPECTIVE ON AGRO TERRORISM

Before the 1975 United Nations Biological Weapons Convention (BWC), several countries pursued bioweapons programs, researching animal pathogens like anthrax and foot-and-mouth disease. Most nations now abide by the BWC, prohibiting biological weapons development. However, concerns escalated after the 2001 anthrax attacks, leading to UN Security Council Resolution 1540 in 2004 to prevent non-state actors from obtaining such weapons. Agro-terrorism, targeting agriculture, poses economic and security threats, exploiting vulnerabilities in livestock and global trade. Animal pathogens are appealing bioweapon options due to their accessibility and economic impact. Despite being primarily zoonotic, they endanger animal health and food security. Animals are more vulnerable to bioterrorism due to farming practices, limited veterinary resources, and global trade. Efforts to combat agro-terrorism include international collaborations like the consortium formed by the World Organisation for Animal Health, FAO, and INTERPOL, supported by initiatives like Global Affairs Canada's Weapons Threat Reduction Programme, focusing on enhancing prevention and response measures. [6] Throughout history, various countries, including Canada, France, Japan, Germany, the United Kingdom, the Soviet Union, Iraq, South Africa, Hungary, and the United States, have pursued offensive biological weapons programs. Examples range from attempts to attack draft horses during World War I to the development of anti-animal and anti-crop agents during World War II. Several agro terrorism agents and diseases have been studied or weaponized globally, including in Russia, the United States, and Iraq. Despite prohibitions on biological weapons development, some countries continue research on offensive biological weapons, raising concerns about their intentions and capabilities. The lack of information on the status of research and development in these countries, such as Syria, Iran, and North Korea, adds to the uncertainty surrounding their biological warfare potential. The biological agents and agricultural pathogen like *Bacillus anthracis* (Anthrax) & *Burkholderia mallei* (glanders), rinderpest virus, *Phytopthora infestans* [7].

FORENSIC TECHNIQUES FOR DETECTION AND SURVEILLANCE IN AGRO TERRORISM

Forensic science, applied to legal and policy matters, serves as an investigative tool, providing evidence for attribution in criminal or civil cases, intelligence, and policy decisions. Forensic methods play a vital role in identifying and monitoring agro-terrorism risks, which entail intentional assaults on agricultural systems to disrupt food production and inflict economic harm. These methods involve diverse approaches for scrutinizing evidence associated with potential attacks on crops, livestock, or agricultural facilities.

An optimal bio forensic inquiry aims to identify and profile a particular microorganism, ascertain its production method, and reconstruct how it was introduced. This process furnishes scientific evidence crucial for linking the microbe to the perpetrator(s). The bio forensic investigation comprises a set of established and verified techniques that reduce the time from on-site sample collection to arrival at the forensics laboratory and expedite controlled laboratory analysis. The detection of microbes in plant samples, whether through observing disease symptoms, pathogen signs, or molecular assays, confirms the presence of an organism but does not necessarily establish its causative role in the disease. Challenges arise when multiple pathogens induce similar symptoms or coexist in the same plant, potentially masking each other's effects or exacerbating disease severity. Plant disease diagnosis involves a comprehensive approach, considering various factors such as plant and pathogen characteristics, environmental conditions, and epidemiological data, often supplemented by serological, DNA-, or RNA-based assays and adherence to Koch's postulates for new diseases. While serological and nucleic acid-based assays offer precise but inconclusive presumptive diagnoses, they are insufficient for applications in agricultural biosecurity and forensic plant pathology, which demand rigorous sample handling and legal accountability. Diagnostic procedures for these purposes should encompass a range of methods, including microscopy, biological assays, and serological and molecular tests, tailored to the specific pathogen, available methodologies, and genomic stability considerations. Symptoms alone are too variable for reliable diagnosis of plant diseases. Biological assays and indexing can provide accurate data but are often costly, time-consuming, and not suitable for high throughput. ELISA, PCR, and microarrays offer rapid and sensitive detection, enabling timely decision-making. ELISA is cost-effective and allows processing of numerous predetermined tests, while PCR, real-time PCR, and their variations offer high sensitivity, albeit limited multiplex capabilities. Microarrays provide comparable sensitivity to ELISA and offer high throughput and specificity. However, despite technological advancements, accurate and timely plant

disease diagnosis ultimately relies on human interpretation of evidence, combining hands-on experience, information from databases and journals, and consultation/validation with external laboratories. [8]
Microbial forensics, a specialized field within forensic science, focuses on rapidly producing reliable conclusion to protect public health and aid law enforcement and policy-making. This interdisciplinary field involves collaboration between microbiology, genetics, public health, and other disciplines to identify and characterize pathogens or toxins involved in biological events. Microbial forensics emerged in the 1990s with the formation of the FBI's Hazardous Materials Response Unit, aiming to support bioterrorism investigations with scientific evidence. The contemporary landscape of microbial forensics heavily relies on the examination of biodiversity, phylogenetics, phylogeography, genomics, and the advancement of techniques for enhanced detection sensitivity and detailed analysis. This includes refining extraction methodologies and collection strategies. Understanding the potential consequences of various bioterrorism scenarios serves two main purposes: assessing the seriousness of biological weapons proliferation and gauging the effectiveness of defensive strategies. Prior modelling efforts have mainly focused on extreme scenarios, like large-scale attacks resulting in millions of casualties. However, such scenarios might be less probable than localized threats. To comprehensively address the spectrum of potential outcomes, a broader range of simulations is necessary. This highlights a crucial need for training and support in epidemiological modelling to ensure sufficient expertise in this field [9, 10].

CYBER-AGRO TERRORISM

Cyber assaults targeting smart farming infrastructure allow assailants to remotely manipulate and misuse on-field sensors and autonomous vehicles like tractors, drones, and other automated machinery. These agricultural attacks have the potential to render farming environments unsafe and unproductive. For instance, vulnerabilities could be exploited to devastate entire fields of crops, inundate farmlands, or indiscriminately dispense pesticides using smart drones, leading to hazardous consumption and economic decline. When orchestrated on a large scale, such coordinated attacks are commonly termed Cyber-Agroterrorism. In recent years, the IoT domain has experienced numerous security threats, indicating vulnerabilities that can extend to smart farming ecosystems. The example for latest types of attacks can be password cracking, evil twin access point, key reinstallation attacks, Kr00k - CVE-2019-15126, ARP spoofing attack, DNS spoofing attack etc.[11] The integration of agriculture and food production into cyber-enabled life sciences technologies, facilitated by developments like the worldwide web, has highlighted the importance of cyber biosecurity. Government agencies, producers, and security experts recognize it as vital for safeguarding the food and agriculture sector against cyber threats that could disrupt the nation's food supply chain. Smart farming technologies, projected to reach a market value of nearly 26 billion USD by 2028, particularly in North America, offer numerous benefits but also present vulnerabilities to cyberattacks. Risks associated with precision agriculture and smart technologies include false sensor data, unauthorized access to data and machinery, and ransomware attacks. Recognizing these risks, the Department of Defense funded research initiatives to address cyber biosecurity, aiming to develop preventative measures for the industry. However, implementing these measures poses challenges, as not all producers have the resources to invest in cybersecurity. Collaboration between agriculture and security experts is essential to adapt and adopt cybersecurity procedures from other fields and develop tailored practices for the agricultural sector. [12]

MITIGATION AND RESPONSE STRATEGY

Agroterrorism poses unique challenges due to its potential to devastate agricultural systems, food supplies, and economies. Mitigation and response strategies for agroterrorism require a multi-faceted approach involving prevention, preparedness, detection, and response. Deliberate spreading of biological agents such as bacteria, parasites, toxins, and viruses presents significant dangers, necessitating thorough risk evaluation and response plans. Collaboration among emergency entities is vital for grasping and countering these risks effectively. The concept of actionable knowledge underscores the value of practical insights in tackling such threats. Cooperation among intelligence, law enforcement, public health, and animal health sectors, termed the "one health" approach, is crucial. Strengthened cooperation, facilitated by initiatives like the European Union CBRN Action Plan, is essential for combating bio- and agroterrorism. Sharing information is paramount, particularly in dealing with intricate threats like bioterrorism in the food supply. Establishing efficient biological warning systems and grasping dynamic baselines are critical for prompt detection and decision-making. Achieving coordinated decision-making relies on shared situational awareness and actionable knowledge. Strategic planning and analytical methods are central in early warning decision-making processes. Overall, a multidisciplinary and collaborative strategy is imperative for effectively addressing bio- and agroterrorism threats. Surveillance

approaches like Persistent surveillance analytic approaches can effectively monitor biothreat-related warning events such as bioterror attacks or safety breaches in animal slaughterhouses. By identifying critical parameters and indicators associated with event timelines, behaviours, and facilities, a systematic change detection framework can be established. This method, known as Persistent Surveillance of Known Threats (PSKT), allows for early detection, tracking, and precision in understanding threat developments. PSKT systems rely on prior identification of potential threats, detailed knowledge of event dynamics, development of change detection indicators, continual information collection, systematic monitoring, and interaction between analysts and decision-makers to provide timely and actionable warnings. [13].

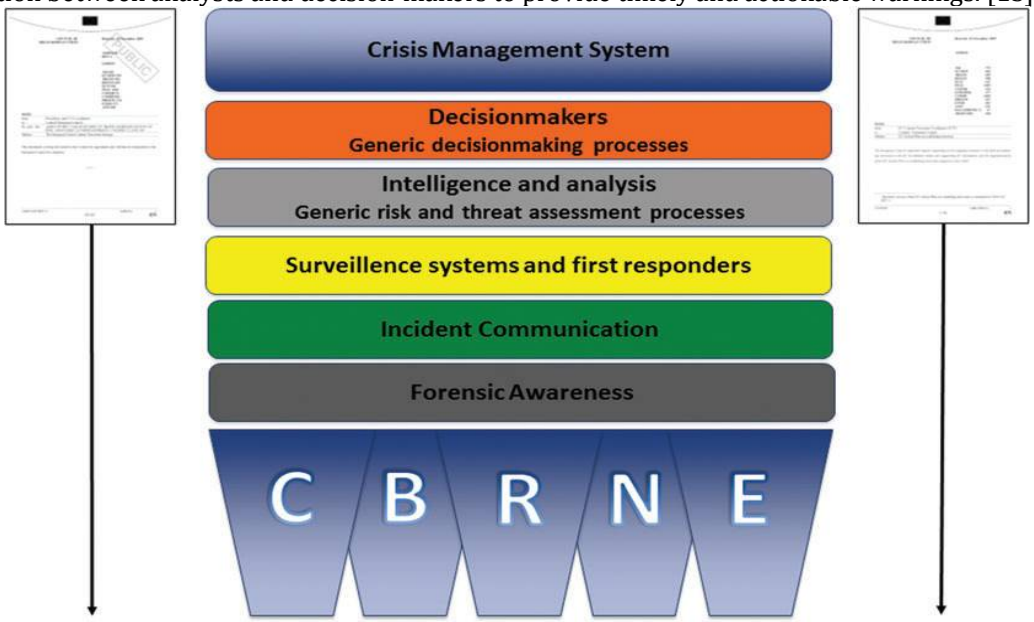

Figure 1: EU CBRN action plan [13]

The primary focus is on prevention, but preparedness is also crucial. Authorities aim to identify, minimize impacts, rescue, investigate, and normalize situations in such incidents. International cooperation is essential due to the seriousness and potential scale of CBRNE events. Prevention efforts involve political means, supervision, control, and global health security measures. Threat assessment and situation awareness rely on national and international collaboration, including intelligence sharing. Regulations govern CBRNE activities, including safety measures, detection capabilities, and response planning through joint efforts, training, and exercises. In incident management, prompt identification, dynamic assessment, and coordinated actions are vital to minimize damage, protect lives, and mitigate environmental impact. Leadership coordination, common situational awareness, and effective communication are emphasized for efficient response. [14]

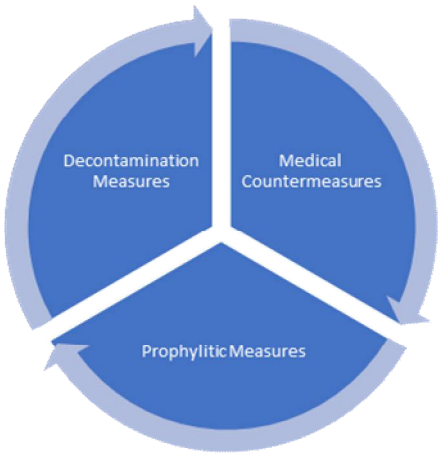

Figure 2: Response Strategy

CONCLUSION

The forensic science approaches discussed in this paper, including diagnostic testing, genomic analysis, isotope analysis, trace element analysis, forensic epidemiology, bioinformatics, data analytics, and

forensic entomology, offer valuable tools for identifying and responding to agro-terrorism incidents. By leveraging these techniques, authorities can enhance their capabilities to rapidly detect and characterize pathogens, toxins, or pests introduced into agricultural systems. Furthermore, the integration of forensic science with traditional investigative methods enables more robust attribution efforts, facilitating the identification of perpetrators and their motives. This attribution is crucial for holding individuals or groups accountable and deterring future acts of agro-terrorism. Moreover, the mitigation strategies outlined in this paper underscore the importance of enhancing agricultural resilience and security. By strengthening biosecurity measures, implementing surveillance systems, and fostering collaboration between government agencies, industry stakeholders, and research institutions, societies can reduce the vulnerability of agricultural systems to deliberate threats. Overall, this review emphasizes the interdisciplinary nature of addressing agro-terrorism and underscores the need for continuous research, innovation, and collaboration to safeguard agricultural resources, protect public health, and ensure food security in an increasingly complex and interconnected world.

CONFLICT OF INTEREST

No conflicts of interest are disclosed by the authors

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