Defence Life Science Journal, Vol. 5, No. 2, April 2020, pp. 125-132, DOI : 10.14429/dlsj.5.15568

Agroterrorism in Indian Context

Sibnarayan Datta*, Vanlalhmuaka, and Sanjai Kumar Dwivedi

DRDO-Defence Research Laboratory, Tezpur - 784 001, India

**E-mail: sndatta@drl.drdo.in*

ABSTRACT

In the context of change in global scenario of terrorism and economic competition, the risk of deliberate attack on agriculture is increasing. In a country, like India, whose economy is largely dependent on agriculture produce and exports, any such malicious attack can grossly destabilise the socio-economic structure. Additionally, an attack on major food crops can lead to potential threat to food security, subsequently, leading to destabilised law and order situation of a state. It is therefore very important to understand the risks and threats of agroterrorism for a given country in order to be prepared for any such circumstance. In this review we discuss different aspects of agroterrorism, its history, possibilities of such incidences in Indian scenario and mitigation strategies, which can be achieved through regular surveillance of pathogens in vulnerable crop ecosystems. We also describe a recent episode of outbreak of cotton leaf curl disease in the Northwest Indian cotton growing region and discuss it from the perspective of a possible threat on one of the most important economic crops of our country.

Keywords: Agroterrorism; Food security; Economic crops; Mitigation

1. INTRODUCTION

Since ancient times, military power has been used to protect or redefine boundaries, raise or supress revolutions, attain religious feats. With technological development, military tactics and targets have changed a lot. With the collapse of erstwhile USSR and bipolar world, opening of markets, focus of international security scenario has shifted from politico-military to politico-economic conflicts. Following two devastating world wars (WW I and WW II), numerous international peace treaties have now made the possibility of full-fledged military conflicts inconsequential. Though conventional military remains central to offensive and defensive strategies, many nations have focused on weapons of mass destruction (WMD), which may be based on either nuclear, chemical or biological materials. As compared to nuclear and chemical weapons, bio-weapons or biological warfare (BW) agents are far cheaper, can be prepared using simple processes in legitimate and moderately equipped biological laboratories and are therefore easy to conceal[1]. BW agents are self-propagating in nature, due to which very small starting amounts are required to affect target population in a large geographic area, within a very short-time frame.

Since, no state publicises or report such BW facilities or capabilities, authentic reports on this topic are rare and available information is mostly based on declassified intelligence reports and unconfirmed or suspected incidences. These reports suggest that different state and non-state (terrorist) organisations and even religious cults have purposefully used biological agents for various nefarious purposes. Additionally, increasing economic competition among nations has raised the possibility of damaging economic assets of the competitor to destabilise its socio-political and economic affairs. Agriculture is one such sector, which can easily be targeted with maligned intentions. Deliberate use of biological agents to destroy agriculture is broadly termed as '*agroterrorism*', and can be used to seriously destabilise socio-economic matters of an agriculture-based state by targeting its food crops, cash crops, agriculture-based industries etc.[2]. Such a warfare is elusive yet devastating for nations whose economies are directly dependent on agricultural sectors or indirectly to its allies that import food from these nations. Agroterrorism aptly fits into the prediction by Shintaro Ishihara, a Japanese politician who said that "the twenty-first century will be a century of economic warfare"[3].

Agriculture or agriculture-based sectors are relatively easy targets, attacks are difficult to detect, and have far reaching effects, as compared to BW against humans. It has been estimated that about a dozen countries are conducting clandestine research programs in developing anti-agricultural agents for tactical applications[2]. The fact that, economies of several countries are dependent on a small number of principal crops, which makes them even more vulnerable to agroterrorism. Nations, such as ours, whose economy is heavily agriculture-based (producer, exporter), and is neighboured by nations having competitive economies and anecdotal BW capabilities, are more susceptible to such threats. At present, agroterrorism is primarily aimed at disrupting food security or crippling economy[1,2,4,5]. Based on the objectives, agroterrorism has been broadly classified into three different scenarios- Biowarfare, Bioterrorism and Biocrime[5].

Received : 27 September 2019, Revised : 10 February 2020
Accepted : 12 February 2020, Online published : 08 April 2020

2. A BRIEF HISTORY OF AGROTERRORISM

Since ancient times, infectious microorganisms or biological toxins are used in asymmetric warfare. Even though primarily used against humans, there are several incidences signifying use of biological agents against animals, agriculture, food and water. It is claimed that during 660 BC, Assyrians used mycotoxin containing rye ergot (*Claviceps purpurea*) to contaminate enemy water sources[6,7]. In the 20th century, during World War I (WW I), Germans allegedly used glanders (*Burkholderia mallei*) and anthrax (*Bacillus anthracis*) to infect horses while used fungi to contaminate food grain stores, intended for supplies to allied forces in Europe[8,9]. Reportedly, during WW II, US initiated large scale BW research and development program to counter similar programs by Japan and Germany and biological agents causing rust in rice, wheat or rye and animal diseases like anthrax, glanders and rinderpest, were allegedly stockpiled[1,8,9]. It is claimed that initially US planned to destroy rice crop in Japan, but later decided to use atomic bomb to force Japan to surrender[1]. Nevertheless, during WW II, Japan supposedly used biological agents against crops and livestock in Mongolia and Russia[10,11]. US reportedly stockpiled wheat stem rust and rice blast pathogens, while UK (under "*Operation Vegetarian*") stockpiled anthrax cakes to spread over Germany. Following WW II, few countries including USA, UK and former Soviet Union apparently continued offensive research programs on anti-agriculture fungal and bacterial pathogens against potato, rice, wheat, rubber[11,12]. Officially, US and UK have now abandoned offensive BW research programs[11].

During 1970s, sensing impending dangers of rapidly proliferating chemical and biological weapons, the international community constituted the Biological and Toxin Weapons Convention (BTWC) in 1972 to "prohibit the development, production, acquisition, transfer, retention, stockpiling and use of biological and toxin weapons"[13]. Till 2018, more than 180 countries have signed this treaty, but absence of monitoring mechanism has limited its efficacy and several member nations are claimed to continue developing BW facilities. It has been reported that former Soviet Union continued its BW program until 1992 and are suspected to have weaponised biological agents against wheat and rice[14,15]. Following Gulf War in 1991, the UN Special Commission reported an Iraqi BW program, primarily focussed on fungal pathogens causing devastation of cereal crops[16].

According to the Center for Non-proliferation Studies, several alleged, failed or confirmed incidences of agroterrorism have took place around the globe in recent past, with the primary aim to destruct economically important crops. Lately, biocontrol programs, by UK and US-led UNDCP (United Nations International Drug Control Program) were undertaken to use fungal pathogens (*Mycoherbicides*) against drug crops (coca and poppy) in drug growing countries[17,18]. Although the UN General Assembly explicitly rejected the proposal, USA continued funding the research and maintained its categorisation as 'biological control' instead of 'biological weapons' and justified their use with the approval by government of the state where they are intended to be used[17]. The anti-coca mycoherbicide species, *Fusarium oxysporum f. sp. erythroxyli* (isolate EN-4) was isolated by USDA (US Department of Agriculture), whereas the anti-opium poppy mycoherbicide species *Pleospora papaveracea* was isolated by the Tashkent Institute of Genetics, Plants and Experimental Biology, Uzbekistan, under combined program of US, UK, and UNDCP[17]. Nevertheless, there remains a risk of their aggressive / non-peaceful use and their effect on non-target plants/crops, which may lead to unknown consequences on environment and human health[17,18].

3. ADVANTAGES OF TARGETING AN AGRICULTURAL SYSTEM

As compared to use of anti-human BW agents, agroterrorism has numerous advantages. Agricultural lands are large and highly dispersed in terms of geographical areas, have poor surveillance and are thus most vulnerable to deliberate attacks. In general, practise of mono-culture of crops (less or no genetic variability) makes an agro-ecosystem more susceptible to agroterrorism. Furthermore, pathogens/pests once established in an agro-ecosystem are difficult to eradicate, resulting in severe effect on consecutive crops. Additionally, attack with an unknown pests/pathogen are difficult to diagnose, causing failure of mitigation strategies. Such introduction often resembles natural outbreak, and multiple introductions can be initiated remotely through contaminated seeds and planting materials, fertilizers, keeping the attack clandestine[19]. As compared to chemical/nuclear or biological-agents against humans, technical know-how required to weaponise an anti-agriculture agent is considerably less. Being harmless to humans, manipulation, stockpiling and transportation of anti-agriculture agents require minimum containment facilities. Moreover, emotional repulsion of the perpetrator following an agro-terrorist attack would be significantly less than that associated with an attack on humans.

4. DIFFERENCE BETWEEN NATURAL DISEASE OUTBREAK AND A POSSIBLE AGROTERRORISM ATTACK

Although it is extremely difficult, there are certain cues that may sometimes help to differentiate an act of agroterrorism from a natural outbreak. Generally, an attack may be distinguished by rapid and vigorous effects on target crops, as compared to natural outbreak having defined dynamics, spatio-temporal distribution and mode of transmission. Moreover, an intentional attack is mostly targeted towards a highly productive crop, while a natural outbreak can occur irrespective of the productivity. Additionally, if disease symptoms indicate a vector-borne disease, natural vectors may or may not be present in an intentional attack or their population dynamics may show unpredicted patterns, while in natural outbreak, vectors are expected to show expected patterns of population dynamics.

In recent years genetic profiling through molecular biology tools has become an essential component of surveillance and monitoring. Deliberate spread of exotic pathogens/pests or their strains, may be distinguished by comparing the genetic fingerprint of the endemic pathogens/pests. Therefore, a genetic database of pathogens/pests endemic in a vulnerable crop-ecosystems needs to be created and regularly updated.

Taken together, precise disease pattern and genetic make-up of the causative agent are important factors in differentiating between natural and deliberate attack. Thus, baseline disease surveillance data (epidemiological/genetic), continued monitoring, investigation and ground intelligence on unusual outbreaks are essential to identify an act of agroterrorism.

5. POTENTIAL AGENTS/ GENETICALLY MODIFIED PATHOGENS FOR AGROTERRORIST ATTACK

It is estimated that there are thousands of plant diseases[20] and hundreds of different diseases for a given crop, worldwide. Of these, several pathogens can be used by terrorists as weapon, according to the feasibility under certain environmental conditions to cause maximum damage. However, there are very scanty reports on organisms that could potentially be used as weapons. This is more important because a certain plant pathogen in a given geographic environment may be endemic, but effect of its introduction into a new agro-ecosystem may be disastrous. Thus, it is important for a country to have a list of pathogens that are common or endemic within its boundaries, and at the same time another list of pathogens that are not present/ reported but have potential to destroy agriculture, which should be updated continuously.

In the last few decades, rapid advances in biotechnology and genetic engineering technologies, have raised the possibility of using these technologies by adversaries to modify natural pathogens to make them virulent, resistance breaking and tolerant to diverse weather conditions to suit military requirements. Although, many of these technologies are believed to have largely remained within the access of state facilities or with agricultural corporations, there remains a potent risk of illegally acquiring virulent organisms by terrorist organisations from these facilities. Remarkably, in 2002, during raids on terrorist organisation *Al-Qaida* hide-outs in Afghanistan, US Marines confiscated handwritten documents which clearly indicated that this terror group was actively pursuing research on anti-personal, anti-veterinary and anti-plant warfare agents[21].

Apart from using anti-crop pathogens, agriculture-based economy of a country can be systematically controlled or destroyed by using genetically modified agricultural products or genetically modified (GM) crops. The 'terminator technology' or the 'suicide seeds technology' is an example of biotechnology that can be used for malign intentions. This technology render seeds infertile after certain generations and can be used for controlling agro-economy of a state or for waging silent agro-economic warfare. Moreover, through introduction of genetically modified (GM) crops with unknown genetic manipulations, reproductive potential or long-term effects on an agro-ecosystem can be used to systematically destroy the existing agro-economy of a country. Interestingly, field trials of newly developed GM crops are largely carried out in developing countries/ low income countries to protect the agro-ecosystem of the countries where these modified crops are actually developed. One of the best examples of the unforeseen effects of GM crops comes from the introduction of Bt-cotton hybrid varieties (expressing *Cry* toxin, highly toxic to Lepidopteran insects) in the Indian subcontinent. Bt-cotton was originally aimed at eradicating extremely damaging bollworm complex (Order Lepidoptera) from North-west Indian cotton producing regions[22]. Even though this intervention effectively removed bollworm menace, their ecological niche was gradually occupied by various sap feeding hemipteran insects (including whitefly, aphids, thrips), to which, the *Cry* toxin is not only non-toxic but can even augment their population[23,24]. This dramatic shift has now made this cotton ecosystem highly vulnerable to trans-border transmission and outbreaks of cotton leaf curl virus (transmitted by whitefly, *Bemisia tabaci*) that cause serious economic damage.

6. LOSSES DUE TO AGROTERRORISM ATTACKS

Disturbance in agricultural sector of an agriculture-based country can cause destruction of livelihood of numerous people, can cause mass unemployment, food shortage, rises in food prices, ultimately resulting in destabilised socio-political fibre. Losses due to a well- executed anti-agriculture attack include both direct and indirect losses. Direct loss includes economic losses comprising price of lost crops, expenses for destroying and containing infected crop to prevent further spread of pathogen, destruction of potentially exposed healthy crops, and compensation paid to farmers. In addition, it may lead to severe consequences in international trade and export, further crippling the economy.

On the other hand, indirect losses may be economic or may cause loss in other terms. In severe and wide-spread bacterial, fungal or viral attacks, choices are limited, and complete destruction of exposed as well as healthy crop within a certain radius is the only option. However, in some cases, pest/vector infested and/or pathogen infected crops are often treated with various approved chemicals for controlling the pests/vectors or the pathogens. This strategy may reduce direct losses to some extent, but this method itself is expensive, labour intensive, and in general, have serious long-term effects on the said agro-ecosystem. In addition, such attacks may also disturb trade of other non-affected crops, resulting in additional losses.

7. ROLE OF AGRICULTURE IN INDIAN ECONOMY

Agricultural practise in Indian subcontinent dates back to 10,000 years[25,26]. Presence of great Himalayas to the North, Deccan Plateau in South, Gangetic delta to its centre and East and Thar desert to West, India has blessed India with vastly diverse agro-ecological zones, varying from temperate alpine climate in north, humid and dry tropical climates in south and central regions[27]. India harbours 4 of 34 global biodiversity hotspots, hosting about 8 % of global species diversity[27].

India is seventh largest and second most populous country in world, accommodating a population of more than 1.3 billion[27]. The developing market economy of India is among world's fastest growing economies, and with USD 2.936 trillion worth (nominal; 2019 est.), it ranks fifth in terms of nominal GDP, while third in purchasing power parity (PPP)[27-29]. In Indian economy, agriculture is the most important sector, which contributed 23 % of GDP and provided employment to 59 % workforce in 2016[30]. Even though, contribution of agriculture in GDP has steadily declined in recent years, it still significantly contributed to Indian economy (15-18 % of GDP; employing 50 % workforce) during 2017-2018[30,31]. Since its independence in 1947, government of India has prioritised agricultural production to ensure food to rapidly growing population, livelihood to rural population and also for earning foreign trade. Owing to adoption of diverse revolutionary programmes, India is today top producer of milk, jute and pulses, while second in wheat, rice, potato, cotton, sugarcane, groundnut, fruits and vegetables[27]. It is also a major producer of plantation crops, spices, livestock, fish etc. India is seventh largest agricultural exporter, mostly serving developing and less developed nations[32]. India exports agricultural/horticultural and processed foods to more than 120 countries, including Middle East, SAARC countries, European Union and United States[33]. Among the major staple foods, India ranks as the third largest net-exporter of rice[34].

Despite India's rapid economic development in industry and service sectors, over 70 % of the population is still primarily dependent on agriculture for livelihood, of which a large proportion (~82 %) are small and marginal farmers[30]. Globally, India ranks first in terms of highest net cropped area, followed by US and China[35]. In terms of cultivation of biotech crops, India ranks fifth, ahead of China. Bt Cotton is the principal GM crop[36] that accounts for nearly 25 % of the global cotton produce, making India the second largest exporter of cotton[37]. Despite acquiring self-sufficiency in production, Indian agricultural sector is seriously challenged with sustainability issues, especially with reference to receding water resources, desertification and degradation of farming lands. Additionally, agriculture sector being critical to the growth of Indian economy also present as a vulnerable target for competitor states. Therefore, it is extremely important to analyse and assess the risks associated with agroterrorism, especially in context of food and cash crops.

8. VULNERABILITY OF AGROTERRORISM ATTACKS IN INDIA

Indian agricultural economy is considerably susceptible to threat from exotic pathogens/pests that could be deliberately introduced to cause huge economic losses. India shares long borders with hostile neighbours, which make the threat of such introduction even more real. Moreover, climatic conditions are favourable for faster propagation and rapid spread of pests, pathogens and their vectors in diverse agro-climatic regions of India. Another aspect of our agriculture is the trend of monoculture, which make such crops exceedingly vulnerable to genotype-specific engineered pathogens. It is very much possible that several plant diseases and pests have already been introduced into our agro-ecosystems through vectors, imported contaminated seeds, fertilizers, which might have gone unnoticed. Therefore, in present international politico-economic scenario, the threat to Indian agricultural sector has to be taken seriously.

A large number of destructive agricultural pathogens/pests could be used as potential bio-weapons in India. Especially vulnerable crops are rice, wheat and potato, where India ranks second in production and are also the principal staples. Accordingly, *Puccinia triticina* (cereal rusts), Rice blast (*Pyricularia oryzae*), *Pyricularia graminis-tritici* (Pygt) (Wheat blast), *Phytophthora infestans* (causing late blight in potato, tomato), *Ralstonia solanacearum* (Ralstonia wilt of solanaceous crops) and *Xanthomonas campestris* pv. *malvacearum* (virulent African pathovar XcmN, still unreported from India), rice tungro virus, geminiviruses (causing leaf curl disease), citrus tristeza virus, banana bunchy top virus. are important from the perspective of Indian agriculture sector. Recently, a study on *Phytophthora infestans* from 2013–14 late blight epidemics in eastern and northeastern India has revealed an aggressive and fungicide resistant European genotype of *P. infestans* to replace the existing populations, especially in regions bordering Bangladesh and Nepal[38,39]. Likewise, in 2016, *Magnaporthe oryzae* pathotype *Triticum* (MoT), the devastating wheat-blast causing fungus was reported from Bangladesh, its first incidence in Asia, since its outbreak in South America in 1985[40,41]. An *ex ante* impact assessment suggested enormous potentials of this fungus to cause economic losses amounting to several million USDs, in addition to devastating effect on food security[40,41]. Although newspaper reports indicated spread of this fungus in two districts of West Bengal (Nadia and Murshidabad) that border Bangladesh, immediate quarantine and preventive measures by the government contained its further spread[42,43]. As a preventive measure, government implemented a 'wheat holiday' (banned wheat cultivation) in these two districts for three years, and prohibited cultivation within 5 kilometres of the international border in other districts adjoining Bangladesh[44].

On the other hand, different insect vectors and pests have been reported from India, which can transmit virulent disease pathogens or can cause significant damage to crops. These include highly polyphagous *Bemisia tabaci* (reported to attack more than 600 plant species); brown plant hopper (*Nilaparvata lugens*); rice gall midge (*Orseolia oryzae*). Very recently, fall armyworm (*Spodoptera frugiperda*) was detected in Karnataka, which subsequently has spread extremely rapidly in at least 10 different states of India. This pest is known to feed upon at least 300 major food crops[45]. Recently, Mizoram has reported a loss of Rupees 20 crores worth of maize crops due to this pest, which indicates the magnitude of damage it can cause in a short time[46]. It remains to be investigated, if the pest was deliberately introduced in Indian agro-ecosystem or is a natural invader.

A list of potential anti-crop agents presents in India, potential threat agents not reported from India are provided in Tables 1 and 2, respectively.

9. THE 2015 OUTBREAK OF COTTON LEAF CURL DISEASE IN PUNJAB (INDIA)

Cotton is economically the most important non-food crop, significantly contributing to several economies in Indian and African subcontinents. Cotton leaf curl virus associated cotton leaf curl disease (CLCuD, transmitted by whiteflies) is the most devastating disease of cotton and repeated outbreaks of CLCuD have severely damaged cotton crops in Pakistan, and in northwestern India. Interestingly, outbreak causing virulent strains, namely *Cotton leaf curl Multan virus* (CLCuMuV), '*resistance breaking*' *Cotton leaf curl Kokhran virus-Burewala* (CLCuKoV-Bu), their interspecies recombinants originally evolved and caused outbreaks in Pakistan[47,48], followed by their trans-border spread and large scale damage to cotton in contiguous regions in India[47-50].

During 2015, severe infestation of whitefly was reported from southern Punjab (India), followed by severe outbreak of CLCuD, causing complete destruction of 2/3rd cotton crop estimating to loss of 630–670 million US dollars[51]. Apart from badly shattering the national economy; unable to withstand losses, at least 15 cotton farmers committed suicide, triggering violent protests and socio-political chaos in Punjab[51-52]. A thorough investigation of outbreak associated virus complex (virus and associated alpha and beta satellite molecules) sequences revealed clear evidence of phylogenetic and epidemiological relatedness with recently evolved virus complexes reported from Pakistan[53-55]. These sequences (from India and Pakistan) denoted a novel clade of CLCuMuV, distinct from previously circulating strains, and had unique recombination patterns[53,54].

Remarkably, pattern of 2015 CLCuD outbreak was fairly distinct from previous outbreaks. Previous CLCuD outbreaks in India (associated with CLCuMuV or CLCuKoV-Bu complexes) were preceded by outbreak with same virus complexes in farmer's fields in Pakistan[48-50]. Therefore, natural transborder transmission of viruses (by whiteflies) from farmer' fields in Pakistan side to adjacent fields in Indian side is apprehensible. Unusually however, virus sequences associated with 2015 CLCuD outbreak have not been reported from any of the farmer's fields in Pakistan till date. Rather, these virus complex sequences were actually detected and reported only from experimental cotton plants (cultivated and non-cultivated varieties), maintained at two different cotton research institutes (Cotton Research Station, Vehari and Central Cotton Research Institute, Multan) situated in the Punjab province of Pakistan[53-55]. In fact, these research stations have maintained infective virus complexes from the first CLCuD epidemic (occurred during 1990s), from which the recent virus complex is suggested to have evolved through recombination[49,53-55]. Taken together, finding of newly evolved CLCuMuV sequences exclusively from experimental plants in research stations in Pakistan, followed by trans-border outbreak of the virus complexes in India without the involvement of farmer's fields in Pakistan side, do not appear to signify a natural pattern of transmission.

Table 1. Some potentially devastating pests and pathogens present in India

Insect pests	Brown plant hopper (*Nilaparvata lugens*) Rice gall midge (*Orseolia oryzae*) Mustard aphid (*Lipaphis erysimi*)
Insect Pest (Virus vector)	*Bemisia tabaci, Aphids*
Viruses	Rice tungro bacilliform virus Rice tungro spherical virus Cotton leaf curl virus/ other Begomoviruses Groundnut bud necrosis virus Banana bunchy top virus Tobacco streak virus Citrus tristeza virus
Bacterial pathogens	*Bulkholderia solanacearum* *Xanthomonas campestris* pv. *malvacearum*
Fungal pathogens	Cereal Rusts (*Puccinia triticina*) Rice blast (*Pyricularia oryzae*)
Oomycete pathogens	*P. infestans, P. nicotianae, P. melonis* and forest Phytophthoras

Table 2. Some potentially devastating pathogens and pests not reported in India

Against agriculture & horticultural Crops	*Magnaporthe oryzae* pathotype *Triticum* (MoT) *Clavibacter michiganensis* subsp. sepedonicus Fire blight of apple and pear *Erwinia amylovora* Soybean downy mildew *Peronospora manshurica* Blue mold of tobacco *Peronospora hyocyami* subsp. Tabacina Tropical rust of maize *Physopella zeae* Barley stripe mosaic virus Mexican cotton boll weevil *Anthonomus grandis* Russian wheat aphid-*Diuraphis noxia* Mediterranean fruit fly *Ceratitis capitata*
Against plantation Crops	Black pod of cocoa *Phytophthora megakarya* Powdery rust of coffee *Hemelia coffeicola* Sudden death of oak *Phytophthora ramorum* South American leaf blight of rubber *Microcyclus ulei* Vascular wilt of oil palm *Fusarium oxysporum f. sp. elaeidis* Coconut cadang cadang viroid Palm lethal yellowing Phytoplasma Pine wood nematode *Bursaphelenchus xylophilus*

10. CONCLUDING REMARKS

A country that has a stringent surveillance system and is capable of rapidly detecting and mitigating disease outbreaks is less likely to be targeted. Unlike disease outbreaks in human and animals, due to presence of very large numbers of plants in agricultural area, surveillance and monitoring is comparatively difficult and disease spreads significantly before being visible or detected. Unfortunately, surveillance system, especially for agriculture sector in most of the developing countries, including India, is not so stringent. Besides, plant pathology and disease detection methods being used at present are largely based on classical techniques, which are time-taking and less sensitive as compared to molecular techniques. Development of rapid diagnostic kits for field detection of plant disease is given least priority as compared to human or animal diseases, precluding early and accurate detection of outbreaks in agriculture. Thus, increasing surveillance, capability for accurate and early detection using molecular tools, is of utmost importance to effectively prevent and contain an act of agroterrorism.

Adoption of new sensitive, specific, and rapid diagnostics to detect potential pathogens are therefore urgently needed. Perhaps, next generation sequencing technologies and remote sensing-based technologies have immense applications in agro-surveillance and agrothreat mitigation.

In addition to stringent surveillance and monitoring mechanisms, there is also a need for enactment of strict legislation, having provisions for considerable punishment for aggressive acts against agriculture. An important area of surveillance is commercial biotech facilities that have capabilities of culturing and genetically modifying microbial organisms. In this aspect, plant pathogens being under research even in government and private R&D organisations/universities/institutions need to be properly scrutinised and secured from theft and accidental release in the environment. Finally, as with other forms of warfare, ground intelligence remains the key factor to deter any act of agroterrorism. Specific measures should be taken to educate farmers and other stakeholders involved in agricultural sector towards suspecting and reporting any unusual event to appropriate authorities. Simultaneously, periodic review of disease outbreaks occurring in neighbouring countries and assessment of their scientific and technological capabilities through research literatures is also necessary for prevention of any natural or deliberate outbreaks.

REFERENCES

1. Kadlec, R.P. Biological weapons for waging economic warfare. *In* Battlefield of The Future 21st Century Warfare Issues, edited by Grinter, L. & Schneider, B.R. US Government Printing Office, Washington, D.C., USA, 1998, pp. 251-266. https://www.airuniversity.af.edu/CSDS/Display/Article/1612675/battlefield-of-the-future-21st-century-warfare-issues-1998/ (Accessed on 26 June 2019).
2. Monke, J. Agroterrorism: Threats and preparedness. *In* CRS Report for Congress, RL32521. The Library of Congress, Congressional Research Service, Homeland Security Digital Library, 2007. https://www.hsdl.org/?abstract&did=472158 (Accessed on 29 June 2019).
3. Phillips, R.L. Communitarianism, the Vatican, and the New Global Order. *Ethics International Affairs*, 1991, **5**, 135-47.
   doi: 10.1111/j.1747-7093.1991.tb00235.x
4. Guidelines for management of agroterrorism. *In* National Disaster Management Guidelines—Management of Biological Disasters. National Disaster Management Authority, Government of India, New Delhi, India, 2008. Pp. 93-107. ISBN 978-81-906483-6-3.
5. Suffert, F.; Latxague, E.; & Sache, I. Plant pathogens as agroterrorist weapons: Assessment of the threat for European agriculture and forestry. *Food. Sec*., 2009, **1**(2), 221-32.
   doi:10.1007/s12571-009-0014-2
6. Thielecke, F. & Nugent, A.P. Contaminants in Grain—A major risk for whole grain safety? *Nutrients*, 2018, **10**, 1213.
   doi:10.3390/nu10091213
7. Carus, W.S. The history of biological weapons use: What we know and what we don't. *Health. Secur*., 2015, **13**(4), 219-55.
   doi: 10.1089/hs.2014.0092
8. Barras, V. & Greub, G. History of biological warfare and bioterrorism. *Clin. Microbiol. Infect.* 2014, **20**(6), 497-502.
   doi: 10.1111/1469-0691.12706
9. Roffey, R.; Tegnell, A. & Elgh, F. Biological warfare in a historical perspective. *Clin. Microbiol. Infect*. 2002, **8**(8), 450-454.
   doi:10.1046/j.1469-0691.2002.00501.x
10. Robinson, J.P. The rise of CB weapons (Volume I). *In* The problem of chemical and Biological warfare. Almqvist & Wiksell AB, Uppsala, Stockholm, 1971. 395 p. https://www.sipri.org/publications/2000/problem-chemical-and-biological-warfare (Accessed on 29 June 2019).
11. Riedel, S. Biological warfare and bioterrorism: A historical review. *Proc. (Bayl. Univ. Med. Cent.),* 2004, **17**(4), 400-406.
    doi: 10.1080/08998280.2004.11928002
12. Geissler, E. van Courtland Moon, J.E. Biological and toxin weapons: Research, development, and use from the Middle Ages to 1945. Oxford University Press, Oxford, UK, 1999. pp. 114-116. https://global.oup.com/academic/product/biological-and-toxin-weapons-9780198295792?cc=in&lang=en& (Accessed on 26 June 2019).
13. Falkenrath, R.A.; Newman, R.D. & Thayer, B.A. America's Achilles' Heel: Nuclear, biological, and chemical terrorism and covert attack. MIT Press, Cambridge, USA, 1998. 380 p. https://www.jstor.org/stable/j.ctt1fq9wk8 (Accessed on 20 June 2019).
14. Goldberg, J. & Mangold, T. Plague Wars: A true story of biological warfare. Macmillan, London, UK, 1999. 402 p. ISBN-13: 978-0330367530
15. Alibek, K. & Handelman, S. Biohazard: The chilling true story of the largest covert biological weapons program in the World-Told from the Inside by the man who ran it. Random House Inc., New York, 1999. 319 p. ISBN 0-385-33496-6
16. Whitby, S & Rogers, P. Anti□crop biological warfare □ implications of the Iraqi and US programs. *Def. Analy*., 1997, **13**(3), 303-18. doi:10.1080/07430179708405739
17. Belvadi M. "*Agent Green*"-The US Leads efforts to use biological weapons in the war on drugs. 2001. http://www.greens.org/s-r/26/26-14.html (Accessed on 30 June 2019).
18. Risks of using biological agents in drug eradication- A brief paper with emphasis on human health. The Sunshine Project, USA, 2001. https://www.google.com/url? sa=t&rct=j&q=&esrc=s&source=web&cd=6&cad=rja&uact=8&ved=2ahUKEwid_qGBkf3mAhX0heYKHcopD3oQFjAFegQIAhAC&url=http%3A%2F%2Fwww.mamacoca.org%2Fdocs_de_base%2FFumigas%2Fnr_04.pdf&usg=AOvVaw1BrHrSjoUpVQPaZIfs7Jnd (Accessed on 30 November 2019).
19. Wheelis, M. Agricultural biowarfare and bioterrorism. *In* Annual Meeting of the Association of Politics and the Life

Sciences in Atlanta, Georgia, USA, 1999. https://www.iatp.org/sites/default/files/Agricultural_Biowarfare_and_Bioterrorism.htm (Accessed on 30 November 2019).

20. History of plant pathology, causes of plant disease, bacteria, fungi, viruses and viroids. https://science.jrank.org/pages/5300/Plant-Diseases.html (Accessed on 30 June 2019).
21. Trewyn, R. National bio and agro defense Facility: Protecting livestock and people from foreign animal diseases and bioweapons. Kansas State University, 2018. https://www.k-state.edu/nbaf/documents/ (Accessed on 30 June 2019).
22. Kranthi, K.R. Cotton Leaf Curl Virus Time Bomb. *Cotton statistics & News*, 2014. http://cicr.org.in/pdf/Kranthi_art/CLCuD_Time_Bomb_ap_2014.pdf (Accessed on 30 June 2019).
23. Zhao, Y.; Zhang, S.; Luo, J.Y.; Wang, C.Y.; Lv L.M.; Wang, X.P.; Cui, J.J. & Lei, C.L. Bt proteins Cry1Ah and Cry2Ab do not affect cotton aphid *Aphis gossypii* and ladybeetle *Propylea japonica*. *Sci. Rep.*, 2016, **6**, 20368. doi:10.1038/srep20368
24. Hagenbucher, S.; Wäckers, F.L.; Wettstein, F.E.; Olson, D.M.; Ruberson, J.R. & Romeis J. Pest trade-offs in technology: Reduced damage by caterpillars in Bt cotton benefits aphids. *Proc. R. Soc. B., 2013,* **280**, 20130042. doi: 10.1098/rspb.2013.0042
25. Mittre, V. Origins and history of agriculture in the Indian sub-continent. J. Hum. Evol., 1978, **7**, 31-36. doi:10.1016/S0047-2484(78)80033-5
26. Fuller, D.; Korisettar, R.; Venkatasubbaiah, P.C. & Jones, M.K. Early plant domestications in southern India: some preliminary archaeobotanical results. *Veget. Hist. Archaeobot.*, 2004, **13**(2), 115–129. doi:10.1007/s00334-004-0036-9
27. India at a glance. http://www.fao.org/india/fao-in-india/india-at-a-glance/en/ (Accessed on 10 Jan 2020).
28. Economy of India. https://en.wikipedia.org/wiki/Economy_of_India#cite_note-WTTCBenchmark-146 (Accessed on 9 January 2020).
29. World Economic Outlook October 2018. International Monetary Fund (IMF). *https://www.imf.org/en/publications/weo* (Accessed on 7 July 2019).
30. Sharma, V.P. India's agrarian crisis and smallholder producers' participation in new farm supply chain initiatives: A case study of contract farming. Indian Institute of Management, Ahmedabad, India, 2007. http://agris.fao.org/agris-search/search.do?recordID=GB2013202158 (Accessed on 10 Jan 2020).
31. Sunder, S. India economic survey 2018: Farmers gain as agriculture mechanisation speeds up, but more R&D needed. The Financial Express, 2018. https://www.financialexpress.com/budget/india-economic-survey-2018-for-farmers-agriculture-gdp-msp/1034266/ (Accessed on 8 January 2019).
32. India's agricultural exports climb to record high. USDA-FAS, 2014. https://www.fas.usda.gov/data/india-s-agricultural-exports-climb-record-high (Accessed on 10 January 2020).
33. Agriculture and food industry and exports. India Brand Equity Foundation, Ministry of Commerce & Industry, Government of India, 2019. https://www.ibef.org/exports/agriculture-and-food-industry-india.aspx (Accessed on 10 January 2020).
34. Statistical Yearbook of the Food and Agricultural Organization, 2014. Asia and the Pacific Food and Agriculture. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific Bangkok, 2014. *www.faostat.fao.org.* (Accessed on 17 September 2019).
35. India outranks US, China with world's highest net cropland area. India Water Review, 2017. http://www.indiawaterreview.in/Story/Features/india-outranks-us-china-with-worlds-highest-net-cropland-area/2096/2#.XhtSwSNS8aE (Accessed on 17 November 2018).
36. Manjunath, T.M. Bt-Cotton in India: Remarkable adoption and benefits. Foundation for biotechnology awareness and education, Bangalore, 2008. https://fbae.org/2009/FBAE/website/our-position-bt-cotton.html (Accessed on 20 December 2018).
37. State of agriculture in India. PRS Legislative Research 2020, http://prsindia.org/policy/discussion-papers/state-agriculture-india (Accessed on 10 January 2020).
38. Dey, T.; Saville, A.; Myers, K.; Tewari, S.; Cooke, D.E.L.; Tripathy, S.; Fry, W.E.; Ristaino, J.B. & Roy, S.G. Large sub-clonal variation in *Phytophthora infestans* from recent severe late blight epidemics in India. *Sci. Rep*., 2018, **8**, 4429. doi:10.1038/s41598-018-22192-1
39. Fry, W,E. *Phytophthora infestans*: New tools (and old ones) lead to new understanding and precision management. *Annu. Rev. Phytopathol*., 2016, **54**, 529–47. doi: 10.1146/annurev-phyto-080615-095951
40. Ceresini, P.C.; Castroagudín, V.L.; Rodrigues, F.Á.; Rios, J.A.; Aucique-Pérez, C.E.; Moreira, S.I.; Croll, D.; Alves, E.; de Carvalho, G.; Maciel, J.L.N. & McDonald, B.A. Wheat blast: From its origins in South America to its emergence as a global threat. *Mol. Plant. Pathol.* 2019, **20**, 155-172. doi: 10.1111/mpp.12747.
41. Mottaleb K.A; Singh, P.K; Sonder, K; Kruseman, G; Tiwari, T.P; Barma, N.C.D; Malaker, P.K; Braun, H.J. & Erenstein, O. Threat of wheat blast to South Asia's food security: An ex-ante analysis. *PLoS ONE*, 2018, **13**, e0197555. doi: 10.1371/journal.pone.0197555
42. Mottaleb, K.A.; Singh, P.K.; Sonder, K.; Kruseman, G. & Erenstein, O. Averting wheat blast by implementing a 'wheat holiday': In search of alternative crops in West Bengal, India. PLoS ONE 2019, 14, e0211410. doi: 10.1371/journal.pone.0211410
43. Bhattacharya, R. & Pal, S. Deadly wheat blast symptoms enters India through the Bangladesh border, Bengal govt burning crops on war footing. 2017. https://www.hindustantimes.com/kolkata/deadly-wheat-blast-symptoms-enters-india-through-the-bangladesh-border-bengal-govt-burning-crops-on-war-footing/story-

3zoWQ0H7sdMU4HxQyzWUsN.html (Accessed on 10 Jan 2020).

44. GoI (Government of India). (2017). Pre-Rabi 2017 DAC & FW- ICAR Interface: Group Recommendations. New Delhi: Directorate of Extension, Department of Agriculture Co-Operation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare. http://agricoop.nic.in/sites/default/files/Prerabi_Kharif_Booklet_2017.pdf (Accessed on 10 Dec 2019).
45. Sangomla, A. & Kukreti, I. Fall armyworm attack: The damage done. Down to Earth, 2019. https://www.downtoearth.org.in/coverage/agriculture/fall-armyworm-attack-the-damage-done-63445 (Accessed on 10 November 2019).
46. Fall armyworm attack caused Rs 20 cr crop loss in Mizoram. The Hindu, Business Line, 2019. https://www.thehindubusinessline.com/economy/agri-business/fall-army-worm-attack-caused-rs-20cr-crop-loss-in-mizoram/article27056315.ece (Accessed on 10 November 2019).
47. Sattar, M.N.; Iqbal, Z.; Tahir, M.N. & Ullah, S. The prediction of a new CLCuD epidemic in the Old World. *Front. Microbiol., 2017* **8**, 631. doi: 10.3389/fmicb.2017.00631
48. Saleem, H.; Nahid, N.; Shakir, S.; Ijaz, S.; Murtaza, G.; Khan, A.A.; Mubin, M. & Nawaz-ul-Rehman, M.S. Diversity, mutation and recombination analysis of cotton leaf curl Geminiviruses. *PLoS One.,* 2016, **11**, e0151161. doi:10.1371/journal.pone.0151161
49. Nawaz-ul-Rehman, M.S.; Briddon, R.W. & Fauquet, C.M. A melting pot of Old World begomoviruses and their satellites infecting a collection of *Gossypium* species in Pakistan. *PLoS. One.,* 2012*,* **7**, e40050. doi: 10.1371/journal.pone.0040050
50. Cotton Corporation of India. Statistics of state wise cotton area, production and productivity, 2016. http://cotcorp.gov.in/statistics.aspx?pageid=4#area1 (Accessed on 10 Jan 2020).
51. Varma, S. & Bhattacharya, A. Whitefly destroys 2/3rd of Punjab's cotton crop, 15 farmers commit suicide. The Times of India, 2015. http://timesofindia.indiatimes.com/india/Whitefly-destroys-2/3rd-of-Punjabs-cotton-crop-15-farmers-commit-suicide/articleshow/49265083.cms (Accessed on 02 Jan 2020).
52. Vasudeva, V. GM cotton: Whitefly attack raises anxiety among farmers. The Hindu, 2015. http://www.thehindu.com/sci-tech/agriculture/gm-cotton-whitefly-attack-raises-anxiety-among-farmers/article7775306.ece (Accessed on 02 Jan 2020).
53. Datta, S.; Budhauliya, R.; Das, B.; Gopalakrishnan, R.; Sharma, S.; Chatterjee, S.; Vanlalhmuaka., Raju, P.S. & Veer, V. Rebound of *Cotton leaf curl Multan virus* and its exclusive detection in cotton leaf curl disease outbreak, Punjab (India), 2015. *Sci. Rep,* 2017, **7,** 17361 doi:10.1038/s41598-017-17680-9
54. Zubair, M.; Zaidi, S.S.; Shakir, S. Farooq, M. Amin, I.; Scheffler, J.A.; Scheffler, B.E. & Mansoor, S. Multiple begomoviruses found associated with cotton leaf curl disease in Pakistan in early 1990 are back in cultivated cotton. *Sci. Rep.,* 2017, **7**, 680. doi: 10.1038/s41598-017-00727-2
55. Shakir, S.; Zaidi, S.S.; Atiq-ur-Rehman; Farooq, M.; Amin, I.; Scheffler, J.; Scheffler, B.; Nawaz-Ul-Rehman, S.M. & Mansoor, S. Non-cultivated cotton species (*Gossypium* spp.) act as a reservoir for cotton leaf curl begomoviruses and associated satellites. *Plants (Basel)*., 2019, **8**(5), E127. doi: 10.3390/plants8050127

ACKNOWLEDGEMENT

Authors acknowledge the Defence Research & Development Organisation (DRDO) for supporting their laboratories through intramural research funding.

CONTRIBUTORS

Dr Sibnarayan Datta, Sc 'D' is presently working in the Entomology & Biothreat management division in DRDO-Defence Research Laboratory, Tezpur. His research interests focus on virology, molecular microbiology, diagnostics, genomics and biothreat management.
He conceptualised the article and wrote the draft of this manuscript.

Dr Vanlalhmuaka, Sc 'E' is the Head of Entomology & Biothreat management division in DRDO-Defence Research Laboratory, Tezpur. His research interests focus on entomology, vector borne infections, molecular diagnostics, biothreat management.
He contributed in critical revision and editing of the manuscript.

Dr S.K. Dwivedi is presently the Director of DRDO-Defence Research Laboratory, Tezpur. His research interests focus on biothreat management, protected agriculture, high-altitude agriculture and hydroponics.
He contributed in critical revision and editing of the manuscript.