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The threat of transboundary plant pathogens to agricultural trade in Southern Africa: a perspective on Zimbabwe's plant biosecurity – A review

Mudada N[1,2], Mapope N[1] and Ngezimana W[1]

[1]Crop Science Department, Faculty of Agricultural Sciences and Technology, Marondera University of Agricultural Sciences and Technology. Cold Storage Company (CSC) Complex, Plot 15, Longlands Road, Marondera, P.O. Box 35, Marondera, Zimbabwe
[2]Plant Quarantine Services Institute, 33 km Peg, Harare to Bindura Road, P. Bag 2007, Mazowe, Zimbabwe

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Abstract

The high frequency of cargo, passengers and movement of goods across borders increases the chances of pest invasions and spread in a geographical area. This paper reviews the biosecurity concerns associated with cross border traffic in international trade, using Zimbabwe as a case study. It reviews the threats of transboundary plant pathogens due to cross border traffic and trade of agricultural products in Southern Africa. The importance of plant biosecurity in agriculture through institutions of plant quarantine measures in crop protection and plant biosecurity will be highlighted. The paper has related the importance of pathways of plant pathogens and their threats to agriculture systems through accidental introductions amongst other anthropogenic related pathways of pests' introduction and spread. The review also addresses the relationship between pest risk analysis, human aided pests' pathways, and bioterrorism threats. It explained how entry point quarantine officials must behave in so far as minimising the chances of new introductions, establishment and spread of exotic pests by employing modern conformity assessments test especially rapid testing techniques. There are many pathogens threatening production of staple and strategic crops in Southern Africa if no extra care is given to cross border management of pathogen pathways. The list of pathogens threatening the block of countries in Southern Africa is long. Zimbabwe and other Southern African countries should have a critical watch and improve cross border quarantine inspections, constantly reviewing quarantine laws and procedures as well as exploiting the gains in the science of the use of rapid pest testing techniques for pest pathways in cross border to improve on easy of doing business and trade.

Keywords – accidental introductions – conformity assessments – pest risk analysis – rapid testing

Introduction

The exchange of goods through international and regional trade has enhanced the movement of plant-insect pests and pathogens in pathways both from human aided perspectives and natural dispersal (Zhang 2012). The increased frequency of cargo, passengers and movement of goods across borders increases the chances of pest invasions and spread (Meissner 2009). The movement

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Corresponding Author: Nhamo Mudada – e-mail – mudadan@gmail.com

of these goods and people across regions has come with challenges of biological security (Jannace & Tiffany 2019). The Southern African countries, particularly Zimbabwe, have not been spared in this globalization effect, which has come with challenges, including plant and biodiversity security threats. Fig. 1 shows the geographical position of Zimbabwe amongst the other 16 Southern African Development Community (SADC) members states.

Fig. 1 – Map of SADC Region showing the 16 Member States (Source: SADC (2020))

The outbreaks of new pathogen races of various crop species including cereals, fresh fruits and vegetables is exacerbated by cross border traffic aided by anthropogenic activities. The attack of maize and tomato crops by equally damaging *Spodoptera frugiperda* and *Tuta absoluta* respectively in Southern African countries in 2016 to 2017 is good example of how anthropogenic behaviour is linked to plant biosecurity challenges (CABI 2016, FAO 2017, Mujaju et al. 2021, PQSI unpublished). *Spodoptera frugiperda* and *Tuta absoluta* are pests originating from the Americas (Guedes & Picanco 2012), and their introduction to Africa (Campos et al. 2017, Biondi et al. 2018, Mujaju et al. 2021) is associated with the breaking of the geographic, physical barriers of the oceans of which without human interference, such invasion would never occur through natural means of pest dispersal.

Globally losses due to plant diseases range from 10-16% (Zadoks 1994, Pinstrup-Anderson 2001, Agrios 2005, Kan-Rice 2019, Savary et al. 2019); if cascaded to Southern Africa, this a huge loss in crop yields for food and feeds especially in a region ravaged by food insecurities and hidden hunger (FAO 2016). These losses can be avoided with improved developed biosecurity mechanisms mostly centred on pest exclusion and plant quarantine regulations.

Globalisation has supported the growth in international travel, tourism, and immigration, raising the risks of local outbreaks to affect many countries within a short space of time (Trunina et al. 2020, Anderson & Westcott 2020). In 2013, Kenya and other Eastern Africa countries imported maize grain from Southern Africa due to a maize lethal necrosis outbreak in these countries

(Mahuku et al. 2015). Though not directly related to plant biosecurity, in human health, COVID 19 (WHO 2020) and SARS (WHO 2003) spread from the areas of the outbreak to other places and countries within 24 hours after outbreak from Wuhan Meat Market (2019) and from rural China (2003) respectively. Interestingly the same challenges were recorded for H1N1 diseases, which spread as far places in six weeks (Garten et al. 2009, WHO 2009) for agricultural animal biosecurity related issues. This review gives the threats of transboundary pathogens to the trade of agricultural commodities in Southern Africa, outlining the biosecurity concerns associated with cross border traffic in the SADC region. The review marries the importance of plant quarantine regulations to reduce the accidental introduction of exotic pathogens due to trade, and it also summarises the importance of employing modern rapid testing techniques in conformity assessments of cross border consignments.

Importance of Plant-Biosecurity in the SADC region Agriculture

In SADC countries, agriculture sectors contribute between 4% to 27% of Gross Domestic Product, about 13% of total export earnings, and 66% in intra-regional trade, creating foreign currency (SADC 2020a). Though exports of agricultural consignments bring foreign currency, political stability, and macro-economic growth in SADC, they present and exacerbate old and new pathways for introducing and spreading transboundary pathogens (SADC 2020b) brought about through various forms of pathways (Meurisse et al. 2019). These pathways include the host as a carrier; inert materials such as packing material that carries resting stages of the organism; insect vectors and birds transporting pests; air or by deliberate illegal introductions as bioweapons. While human-assisted pathways offer themselves to curtailment by quarantine measures (Way & Emden 2000), natural disposal is beyond human control and is a major limitation in controlling pest by exclusion (Webber 2010). SADC member states, therefore, must institute extra alertness on the quarantine laws to prevent the unintentional introduction of pathogens harmful to the SADC agriculture system (Forestry Research 2021).

SADC should implement plant biosecurity, policy and regulatory framework mechanisms to analyse and manage risks in the sectors of plant life (FAO 2007a) and to ensure that cross border movement of transboundary pathogens is minimised. Whilst biosecurity considers the importance of protecting nations from transboundary pests that are brought about by the cross border movement of people, goods and commodities which act as pathways of pest movement (Waage & Mumford 2008, Department of Primary Industries 2019); “the SADC (2014) Protocol on trade requires that member states must base their plant quarantine standards on the international standards, guidelines, and recommendations of the World Trade Organization’s Agreement on the Application of Sanitary and Phytosanitary Measures”. In a view to cover delicate issues of the cross-border movement of pathogens in risks of biological warfare (Koblentz 2010), SADC protocol on trade allows member states to practice sovereignty in protecting plants. This sovereignty implies possibilities of trade barriers of the movement of plants within the region. As the countries within the region remain watchful and alert on cross border movement to protect their territories from the ingress or access of exotic pathogens during import, unjustified measures hindering the trade of plants and plant products unnecessarily should also be watched.

In general, critical issues regarding the threats of pathogens to agriculture trade in the SADC region include strengthening of the pest risk analysis mechanism and monitoring pathways of cross border movement of pathogens, development of pathogens database, and the development of pathogen management options for high impact pest incursions that threatens plant life (EFSA 2011). Monitoring of pathogen pathways calls for highly specific and rapid diagnosis systems that provide for efficient customs clearing systems and procedures and give thorough consignment inspections for quarantining purposes (Augustin et al. 2012). Such procedures must have minimal inconveniences to the cross-border traffic for both goods and passengers whilst at the same time providing for due diligence of cross border traffic quarantine inspections.

Importance of crop species as pathways of transboundary pathogens in SADC

Due to trade, maize, a staple food for most SADC countries, is being threatened by the exotic introduction of pathogens, such as Maize Lethal Necrosis. In Southern Africa, food security feeds and industrial crops are the ones mainly traded across borders. These plant products are mainly traded as dry crops, including grains, feeds, flours and dried timber and, these can act as potential carriers of transboundary pathogens. Trade of drugs and ornamental crop products within the SADC region, including tobacco and flowers, is also rising (Lester & Allen 2012, Mbekeani 2013). Within SADC, not only grains for feed and food or industrial use are being traded; seeds and planting material trade is on the rise (SADC 2020a). The number of inspected consignments of plant and plant products, injurious organisms and other regulated articles that were subjected to entry quarantine inspections in the last six years by the Zimbabwe Quarantine officials is given in Table 1.

Important crop species to the Zimbabwean economy and Southern Africa include maize, tobacco, sorghum, wheat, timber, and rice (FAO 2006). Fruits and vegetables such as potatoes, tomatoes, citrus, stone fruits, bananas and apples etc., are also a daily portion of the food systems within the SADC region and these are found in cross border trade of plant and plant products within Southern Africa countries. From the cultivated plant species traded within SADC and beyond SADC, the importance of staple cereals fruits and vegetables including those in the *Solanaceae* family from various parts of the world; for their roles in hosting pathogens or diseases of cultivated plants; should never be omitted (Ormeno et al. 2006) regarding transboundary movement of pests. A good example is *Datura* spp. and *Solanum tuberosum*, which play host to various virus types that are later transmitted to other cultivated crops. However, pest pathways are many, propagative materials, especially those in *Solanaceae* plant species, host many pathogens of diseases of the cultivated plants.

Potential pathways of pest introduction in SADC region

Different pathways for pest movement across borders exist in the Southern African region. According to the International Standards for Phytosanitary Measures (ISPMs) of the International Plant Protection Convention (IPPC 2016a), "pest-pathways" refer to how pests are carried from one geographical location to the next. It is "the combination of processes and opportunities resulting in the movement of pest propagules from one area to another, including aspects of the vectors involved, features of the original and recipient environments, and the nature and timing of what exactly is moved" (Richardson et al. 2010, Ministry for Primary Industries 2013). About five main pathways are existing in the transboundary movement of pests from one place to another in the SADC region, which are: 'pests-host as carriers; inert materials including packing material carrying resting stages of pests; insect vectors, birds and mammals; winds trajectories; and deliberate illegal introductions (bio-terrorism and bio-weapons)' (Webber 2010, Zhang 2012). SADC states have exit and entry points that are characterised by smuggling and porous entry and exit. This results in pathways escaping quarantine inspection procedures hence increasing the threats of transboundary pathogens threats.

New plant pathogens, apart from threatening trade, biodiversity and plant life, and animal and human life, are also threatened due to the nature of diseases they cause (Lovett et al. 2016). Considering one critical example of the introduction of soybeans rust (*Phakopsora pachyrhizi*) in the early 2000 in Zimbabwe and other SADC states, phytosanitary conditions to the trade of soybean into Zimbabwe were strengthened. Pest risk personnel need to understand pathway pest risk associations, together with type of entry point for better control of pathogens introductions (Douma et al. 2016). Where knowledge and experience is lacking, first line of pest defense which we also call quarantine is compromised. That's, new pests' introduction is exacerbated and as such, countries and or regions are affected resulting in endangering of the environment and agriculture. In countries where strong biosecurity laws are well enforced such as China, America, Japan Australia and European Union, few new pests' invasions are encountered (David 2007, Palmer 2017). If encountered, vigilant quarantine regulations are enacted and well enforced for containment and eradication of the invasion and high costs are always incurred on these operations (Florec et al. 2010).

Table 1 Total number of consignments of plants and plant products, injurious organism and other regulated articles inspected at points entry and exit points by the Zimbabwe Quarantine officials from 2015 to 2020.

Consignment type	**Numbers of consignments inspected each year from 2015 to 2020**						
	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**Numbers of consignments inspected in six years**
Imported commercial consignments	9,399	26013*	16,975	22,127	9,530	20,591	95,105
None commercial consignments	2,238	**	**	**	**	**	2,238
Transit commercial consignments	10,494	*	15,106	9898	8,893	9,874	54,265
Exported consignments	21,109	21210	29267	32,294	34,043	25,865	163,788
Bio-control agents (number of vial filled with injurious organisms)	**	**	**	**	3,515,585	8,000, 000	11,515,585

Source: PQSI (2020). *summed with imported commercial consignments ** data not available

The SADC region experiences pathways of pest that are either by natural means or due to anthropogenic behaviour or artificial means (FAO 2007b). Under natural pathogen dispersal within SADC, winds, cyclones; storms, tornadoes; pest as fliers; birds; wild animals; rainfall and water move pathogens from one state to another (Ghosh et al. 2019). There are no barriers to halt movement of animals such as baboons between Botswana and Zimbabwe from the Hwange national parks or between Mozambique and Zimbabwe from Gonarezhou national parks. In artificial movement, human activities which are intensified by trading across borders, aid transboundary pathogen’s movement between states and hence trading of plants gets restricted through justified phytosanitary measures. Recently, trade of wheat from Zambia to other SADC states including Zimbabwe have been compromised by the strengthening of the phytosanitary measures due to the accidental introduction of wheat blast into Zambia in 2020.

Artificial pathways can be broken down to two modes where one involves plant materials and the other involve inanimate materials (Webber 2010). It is critical to note that both affects trade within SADC as entry and exit quarantine procedures are executed. Pathways from plants segment include fresh produce, nursery stocks, cut flower and foliage, seed for sowing, grain or seed for consumption, seed for feed and seed for processing. It also includes processed plant material in the form of growing media. Pathway for inert material includes inorganic materials, vehicles and machinery, inorganic fertilisers, containers, packaging materials and debris from used vessels (Forestry Research 2021). Thus, at entry or exit, phytosanitary procedures must be performed to facilitate trade.

Transboundary movement of pest from one point to another by natural activities is referred to as natural pest pathways (Douma et al. 2016). Despite man’s intervention, such pathways are not influenced by human activities. These pathways have been in existence since the evolution of organisms. Managing natural pest pathways in the SADC region is almost impossible since no quarantine regulations can be instituted for this form of pathogen movement (Meurisse et al. 2019). Where geographical, physical barriers (Manrique-Poyato et al. 2015, IPPC 2019a, c) exist, natural pathways fail, not all SADC states are separated by physio-geographical pathways that exclude dispersal of pathogen across borders. Geographical barriers for natural pest movement include oceans, seas, climatic conditions (The Expert Consultation 2008), topography, vegetation, availability of pests' hosts and pest vectors.

The artificial pests' pathways greatly threaten SADC region. Under artificial pathways, activities by human beings make pests move from one place to the next, whether across political, geographic or economic boundaries. With artificial pest pathways, cross border pathogens' movement are determinants of cross border traffic in both passengers, mail, craft and cargo (Stanaway et al. 2001, EFSA Panel on Plant Health et al. 2018, Long et al. 2021). All these scenarios are consistent with the SADC region.

The most probable various pest's pathways exacerbated by human activities in the SADC region includes movement of plants and plants products for food, growing media for the production of highly economic crops such as blues berries; injurious organisms for use as biological control agents and for use as experimental organism in research; hitch hiker pathogens carried on passenger baggage: vectors traded as food such as the mopane worms and termites: packaging material; animals feeds and food from cross border traffic. The pathways also including cargo from passengers, vehicles, debris from empty vessels and containers (Stanaway et al. 2001). Multiple cargo pathway segments including inorganic risk materials, new or used vehicles and machinery, building materials, fertiliser, shipping containers; debris of soil and plant material can pose a risk in plant biosecurity (Brockerhoff et al. 2016, Brockerhoff & Liebhold 2017). These pathways are high potential threats to the movement of pathogens across borders of the SADC region. These pathways threaten trade due to the countermeasures coming from phytosanitary regulations within the region.

The region is also not spared by artificial pest pathways that can be transport stowaways and transport contaminants. Transport stowaway includes containers and packaging material; debris and waste from human activities; floating plant matter and debris; hitchhikers in or on the plane, cargo, vessels, vehicles, ships, boats, machinery and equipment; mail; mulches and plant media; passengers and luggage; ship bilge water; ship ballast water and sediment; ship hull fouling; and soil, sand, and gravel. Transport contaminants include contaminated aquaculture stock; contaminated bait; food contaminant; germplasm; hides, trophies and feathers; host and vector organisms; livestock; pets and aquarium species; and plants or plant parts.

In the years 2016 and 2017 in Zimbabwe and other Southern African countries, for instance, new races of pathogens and strains of insect pests were recorded (FAO 2017, CABI 2016). New Potato Virus Y (PVY) races (Dimbi et al. 2017, PQSI 2017) suspected to have been introduced through seed potato imports, attacked Zimbabwe tobacco crop and the diseases has been considered one of the culprits for the reduced 2017 annual total tobacco yield output of 189 million tonnes in comparison to the 202 Million kilograms that was harvested in 2016 (TIMB 2017). Within the same period, some Southern African countries crops were attacked by equally damaging *Spodoptera frugiperda*, *Tuta absoluta*, *Phenacoccus solenopsis* (CABI 2016, FAO 2017, PQSI 2017). Such pest invasions associated with breaking geographic physical barriers from pests' areas of origin is greatly linked to anthropogenic behaviours. Losses due to plant diseases alone are estimated at least 14.1% (Agrios 2005), which is an enormous loss in crop yields for food and feeds. Such crop and feed losses are a significant threat to food security. With well-developed biosecurity mechanisms, losses from increased spread of pests can be minimised within the Southern African countries: a sure way of protecting crops from pest's damage.

Though not well established, contamination of human bodies and clothes are also potential good pathways for agricultural pests. In 2020, the government of Zimbabwe introduced statutory instrument 77 of 2020 to prevent and control the spread of COVID 19 (WHO 2020) diseases (SARS Cov-2). Though the COVID 19 causing virus is a human disease, it indicates how important it is to note the importance of human body contaminants as pathways of pests and even those for agriculture and the environment.

The accidental introduction of *Fusarium oxysporum pv cubence tropical race* 4 (FocTR4) to Mozambique is suspected to have been aided by contaminated farm protective clothing from Phillipines (IPPC 2013, Miguel et al. 2018). The accidental introduction of *Tuta absoluta* in Zimbabwe is suspected to have caused by the smuggling of tomato (Tengeru variety) from Zambia to Chinhoyi, Mashonaland West Province in July 2016 (Anonymous, personnel interview, August 2016). These new introductions of *Tuta absoluta,* and *Spodoptera frugiperda,* into Zimbabwe and also *Fusarium oxysporum* pv *cubence* Foc TR4 into Mozambique, (which infected half a million plants within 3 years) are examples of new pest introduction associated with cross border traffic (CABI 2020a). Foc TR4 in Nampula province of Mozambique poses a peril to food security in Sourthen African, where banana is augment staple food and is a source of income to millions of especially the rural people. The trade of banana plantlets within SADC is also significantly threatened. The other members of SADC region have restricted the importation of banana planting material from Mozambique Nambula province. This means a reduced business from that country. Restriction that were imposed following the introduction of Foc TR4 in Mozambique Nambula province included the use of expensive foot and water bath, restriction on the free movement of people and animals and reduced market of not only bananas but used equipment from that region.

There are various components of cross border traffic that exists and affects exotic pathogens introduction. These components include commodity type, type of processing, the volume of commodity, and ambient conveyance conditions, including temperature and humidity. The introduction probability is higher when such components are at optimum levels (FAO 2007a, IPPC 2016a, Dirk et al. 2019). Whilst value addition benefits more in trade and with the system management of pathogens associated with cross border traffic, the type of commodity comes with it the merits or demerits of being a host pathway or a hitch-hiking carrier.

Hosts are much more risk as pathways of specific biological security threats in agriculture than non-host commodities (Webber 2010, IPPC 2019b). Processing affects the biophysical appearance of the commodities and any unprocessed plant products are good pathways of pests as these provide undisturbed host status for the biosecurity threats. This means that SADC states may restrict cross border trade of certain plants or plant products to escape phytosanitary restriction brought by pathogens threat yet at the same time affecting some other primary industries that require the use of unprocessed raw plant materials. For example, to reduce the threats of maize lethal necrosis viruses such as the Maize Chlorotic Mottle Virus, the trade of mealie-meal is preferred to the trade of the maize grain, and in such circumstances, the millers' business in the importing state is threatened.

Processing of plant and plant products alters the host biophysical properties, and in such instance, a processing application that changes the end plant product not to be re-infested by a specific pest are better phytosanitary measures that support the objectives of plant quarantine (EFSA Panel on Plant Health 2010). Where processing leaves the end product in a state that can be re-infested by a pest, extra phytosanitary measures will be necessary (IPPC 2019d).

Commodity volumes affects the border quarantine inspection procedures at points of entry during commodity integrity checks and verifications. The higher the volumes, the higher are the chances of pests escaping the border inspections process due to the requirements involved in commodity sampling and inspections (IPPC 2019d). SADC states have enacted barriers to trade volumes traded across borders not to enforce trade barriers but to reduce threats of new pathogens introductions. Such measures impact heavily on the volumes of trade within the region. The conveyance ambient conditions of commodities affect the living conditions of the pests. If the ambient conditions of temperature, food and humidity support the life of the pests in pathways, then the likeliness of invasion increases (FAO 2007a, Dirk et al. 2019). Such conditions come with some effects on the original quality of products and goods under transit. This can be explained by how low temperature treatment and the use of cold chain in conveyance to reduce pest threats such as False Codling Moths to apples affect trade costs. For pathogens; moist conditions and with optimum temperature leads to their proliferation. Arthropods can succumb to the cold temperature if cold chain is used, but pathogens may germinate post transiting conditions.

Anthropogenic behaviour and pest incursions due to cross border traffic

Globe-trotting due to trade and tourism have improved physical connections and contacts between countries and continents (Trunina et al. 2020). Daily, the atmosphere and the high waters are filled with vessels moving cargo and passengers with baggage from one place to other (UNCTAD 2019). The restriction to cross border movement of people due to SAZ Cov2 has come with advantages of reduced cross border traffic. These movements are designed and desired to improve economies and through sharing via trade, materials, food and raw materials for industrial use. Some of the cargo move with them, unwanted passengers in the form of agricultural threats of pests. The behaviour by men exacerbated by global trade and need for the growing of economies has led to sharing of goods between countries and economies. Some of the goods in international trade and cross border traffic include food; important for food security, and equipment and machinery (Jeschke 2011) for the construction industry and agriculture. These are goods moved by passengers and crew across borders, a human aided pest pathway between different states.

In Sourthen Africa the incursion of maize pests after the importation of maize grain from the Americas in recent years is critical consideration point regarding the threats of transboundary pests in trade. The maize grain imports from the Americas are correlated with the introduction of pests including Fall Armyworm (FAW) (*Spodoptera frugiperda*) (Nagoshi et al. 2018, Nagoshi 2019) and Maize Chlorotic Mottle Virus (MCMV) (Boddupalli et al. 2020). Although FAW is a natural flier capable of moving over hundreds of kilometres a day, it could only manage to cross the Atlantic Ocean barrier through mankind. The same for the MCMV, it could only cross the oceans through human aided pathways. For natural pathways such as for wind trajectories and storms; safe passage of the pests will never likely to occur, hence the most probable pathway includes human aided activities such as germplasm exchange. Pests like MCMV, (recorded in Kenya, Tanzania (Mahuku et al. 2015)), Wheat blast (recorded in Zambia (Tembo et al. 2020)) and Banana Panama diseases (recorded in Mozambique Nambula province (Dita et al. 2018)) have only human aided movement as the best probable pathway of spread.

Plant pathogens misuses as bioweapons in bioterrorism and agricultural plant biosecurity

'Bioterrorism is the use of biological agents by an individual or group not acting as official agents of a government to achieve a political or ideological objective' (Edward 2018). Microbial and biological agents found in cross border traffic within SADC states and beyond are elements for biosafety and biosecurity for agriculture, environment and medicine (Artika & Ma'roef 2017). The security breaching of biosafety regulations, plant quarantine and border safety regulations for importing bio-hazards is considered a kind of threat to humanity, food security, environment and agricultural biosecurity (WHO 2004, Oludairo et al. 2015). Whilst entry points staff put all their effort to enhance biosecurity and reduce agricultural plant biosecurity threats through cross border traffic control, un-cleared deliberate pest's introductions in the form of biological terrorism must not be forgotten.

The importation of biological agents or smuggling of such injurious organisms in biological research such as bacteria, fungi and viruses requires assessments for biodefense (Carus 1998, Das & Katarina 2010, Oludairo et al. 2015). Pathogens involved in cross border traffic like viruses, mycoplasma, fungi and bacteria, can be used dangerously as weapons in terrorisms and these subjects cause serious harm in cases of unauthorised introductions and releases (Das & Kataria, 2010). Even though there are global security agreements on prohibitions of biological weapons and bioterrorism, humans have hated the use of disease-causing agents for hostile purposes for both in food safety, agriculture, environment or human safety (National Research Council 2006).

Whilst a number of insect's pests and diseases emerged unexpectedly in some countries especially SADC and other African states with examples of the Panama banana wilt diseases that was reported in Mozambique in 2013 (IPPC 2013, Miguel et al. 2018), it becomes so difficult to distinguish between accidental introduction and deliberate introductions as acts of bioterrorism or economic sabotage. SADC states need to remain vigilant in cross border traffic control and screening and profiling of persons at points of entry and exits. With such ideas in mind, the National Research Council (2006) cited that the National Intelligence Council of the USA predicted a major terrorist attack employing biological agents by 2020, a year where human COVID 19 (SAZ-Cov2) diseases were reported (WHO 2020). In such instances, bioterrorism, though it is challenging to distinguish with accidental introductions, pathways of pest introductions especially the pathogens, requires extra alertness during entry inspection of cross border traffic.

Considering the geographical barriers between SADC states; other African countries and continents, bioterrorism is prevalent and thus, point of entry agricultural biosecurity control needs a cooperative effort from all cross-border agents. Reducing the exchange of biological and microbial organisms in scientific research should be a sure way to reduce the risk of bio-terrorism in agriculture. Apart from the above, awareness, strengthening capacities of cross border officials and improved infrastructure in the SADC region can improve challenges associated with bioterrorism in agriculture.

Agricultural biosecurity threats through bioterrorism date back to history and it must not be underestimated in this 21st century. In 1917 German spies were caught attempting to spread *Bacillus anthracis* to Norway and during World War I, German scientist attempted to ship horses and cattle inoculated with anthrax pathogen *Bacillus anthracis* from United States (US) to the Aliens (Wheelis 1998). The US offensive biological weapons programme focused on the causative agents of anthrax, botulism and other human, animal and plant pathogens during the World War II in 1942 (Seth 2015). In 1927, Hall observed that Bushman hunting arrows were poisoned with *Bacillus histolticus, B. welchii and B. novyi.* During the 6th century, Assyrians were believed to have contaminated the wells of their enemies with rye ergot, (*Claviceps purprea*), a plant parasitic fungus that produces hallucinogenic alkaloids (Detrick 1996). In 1971 to 1973, the US destroyed their un-weaponised anti-crop agents; rye blast, wheat stem rust, and rye stem rust, which were designed as plant biosecurity threats (Edward 2018).

Within the SADC member states, the Rhodesian forces inoculated *Vibrio cholerae* in water bodies and *B. anthracis* for the local black people during the second Chimurenga as bio-threats (Gould & Folb 2002, Bule 2006). Seth (2015) suggested that due to biological threats from bioterrorism, given the widespread belief that a taboo against intentional infection is a significant barrier against the use of biological weapons, it would be helpful to obtain a better understanding of the emergence of such views. There are no actual explicit acts of bioterrorism on plant pathogens documented, but the risky need to be considered carefully by governments. Crops and plants are critical sources of food security and backbones of economies.

Review of accidental pest introductions in SADC region and beyond the Southern African States

Webber (2010) cites examples of the accidental introduction of plant pathogens having been documented over 100 years with some of the introductions like *Phytophtora infestans* that caused great famine of Ireland in 1840s having serious impacts on the economies of affected regions where over a third of the population was killed from hunger. Other examples of accidental introduction of pathogens includes the introduction of soya beans rust (*Phakopsora pachyrhizi*) which affected the production of soybeans in Zimbabwe (Mudada 2006) in the early 2000s after the disease was reported in Uganda (Kawuki et al. 2003, CABI 2015). In 2013, Kenya was invaded by the Maize chlorotic mottle virus, resulting in severe crop losses in Kenya and the eastern African community (Boddupalli et al. 2020) and Tanzania (Jumbo et al. 2015). In 2013, Mozambique was invaded by *Fusarium oxyporum pv, cubense* tropical race 4 (Fusarium wilt of bananas or panama banana disease) (Dita et al. 2018). The recent invasion of Zambia (Tembo et al. 2020) by wheat blast diseases may lead to serious regional damage to the wheat production of the SADC countries if not carefully managed. Citrus greening diseases caused by *Liberibacter asiatica*, a serious diseases of citrus fruit trees was accidently introduced in Kenya, Uganda and Ethiopia (Ajene et al. 2020) and the vector *Daiphorina citri* introduced in Tanzania (Shimwela et al. 2016). Coffee berry diseases, introduced in Zimbabwe from Kenya (Masaba & Waller 1992, Belachew & Teferi 2015) resulted in the inauguration of the Plant Pest and Diseases coffee regulation (1971) by Zimbabwe to stop the movement of coffee from Mashonaland west province to any other parts of the country as a way of curbing its spread.

Any future pest/pathogens threats need to be monitored. Any introduction of diseases of important crops like the golden tobacco leaf diseases such as *Perenospora hyoscami* and *P. tabacina* poses serious threats in the tobacco production industry for Zimbabwe and Southern Africa. Quarantine measures should be implemented to make sure that economically important diseases of this nature are kept away. *Ralstonia solanacearum* (Peeters et al. 2013) in potatoes and, *Thecaphora solani* (Chalkley 2012) for tomatoes joins the list of the major economically important crop pathogens accidental introduced in other countries including SADC due to cross border traffic.

The accidental introduction of pathogens has been a threat since a long time ago. As mentioned on the example of the Ireland famine and as given in Tables 2a, b, c, a lot of devastating accidental introduction of pathogens have been recorded in history between 18^{th} and 20^{th} century worldwide. Table 3 shows pathogens recorded in Zimbabwe between the year 2000 and the year 2021.

Table 2a Examples of accidental introduction of fungal pathogens that were disastrous between 18^{th} and 20^{th} centuries in SADC and across the continents.

Pest/Pathogen	Suspected pathway of introduction	Geographical origin	Reference cited
Fusarium oxysporum f. sp. Cubense Tropical Race 4	planting material and soil (Mozambique, 2013)	Phillipines	Dita et al. (2018)
Magnaporthe oryzae pathotype Triticum (Fungus) (Wheat blast)	grain or seeds (Zambia in 2020)	Americas	Tembo et al. (2020)
Phytophtora cinnamon (Rands)	Live plants 1800s to 1900s	South West Pacific	Europe: Day (1938), North America: White (1937), Australasia: Podger at al. (1965)
Cronartium ribicola (JC Fisch)	Live plant 1900s	Asia	Europe: Fries (1815) North America: Spaulding (1909)
Cryphonectria parasitica (Murril) M.E.Barr	Chestnut plants, wood 1880s	Japan, China, Korea	North America: Merkel (1905) Europe: Biraghi (1950)
Ophiostoma ulmi (Buisman) Nanff.	Elm logs 1900s to 1940s	Eastern Asia	Europe: Guyot (1921), North America: May (1934), Asia: Afsharpour & Adeli (1974)
Phytopthora lateralis (Tucker and Milbrath)	Live plants 1940s	Taiwan, China, Japan	North America: Tucker & Milbrath (1942), Europe: Meffert (2006)
Ceratocytis plantain (JM Walter), Engelbr and TC Harr	Wood packaging and plants	North America	North America: Jackson & Sleeth (1935), Europe: Panconesi (1972)
Dothstroma septosporum. (Dorog). M Morelet.	Live plants, 1940	Himalayas or South America	Europe: Murray & Batko (1962), Africa: Gibson (1962), South America: Dubin & Staley (1966), Australia: Gilmour (1967)
Ophiostoma novo-ulmi (Brasier)	Elm logs, 1960s	Eastern Asia	Europe: Gibbs et al. (1972), Asia: Brasier & Afshapour 1979), Australasia: Cooper (1991)

Table 2a Continued.

Pest/Pathogen	Suspected pathway of introduction	Geographical origin	Reference cited
Phytopthora alni (Brasier and SA Kirk)	Live plants 1970s to 1990s	Interspecific hybridization event	Europe: Brasier et al. (1995), North America: Adams et al. (2008)
Phytopthora ramorum (Werres, De Cock and Man in t'Veld)	Live plants 1990s	Eastern Asia	Europe: Werres et al. (2002), North America: Garbelotto et al. 2001, Hepting & Roth (1946)
Fusarium circinatum (Nirenberg and O'Donnell)	Seeds, live plants	Mexico	Asia (Japan): Muramoto & Dwinell 1990, Africa: Viljoen et al. (1994), South America: Wingfield et al. (2002), Europe: Lander et al. (2005), Asia: Durgapal (1971)
Phytopthora kernoviae (Brasier, Beales and SA Kirk)	Live plants199s	Asia or possibly New Zealand	Australasia: McAlonan (1970), Europe: Brasier et al. (2005)

Source: (CABI 2021a, Webber 2010)

Table 2b Examples of accidental introduction of viral pathogens that were disastrous between 18th and 20th centuries in SADC and across the continents.

Pest/Pathogen	Suspected pathway of introduction	Geographical origin	Reference cited
Cassava brown streak ipomoviruses (Virus)	planting material DRC in 1973		Hahn & Williams (1973), Mulimbi et al. (2012), Casinga et al (2019).
Maize chlorotic mottle virus –	Planting material and grains (Tanzania 2014, Mozambique 2021)	Americas	Mahuku et al. 2015

(Source: CABI 2021a, Webber 2010)

Table 2c Examples of accidental introduction of bacterial pathogens that were disastrous between 18th and 20th centuries in SADC and across the continents.

Pest/Pathogen	Suspected pathway of introduction	Geographical origin	Reference cited
Pseudomonas syringae pv. Aesculi (ex Durgapal and Singh) Young, Bradbury et. al.	Possibly live plants, 1990s	Himalayas	Europe: Webber et al. 2008
Ralstonia solanacearum (bacterial wilt of potato).	Many SADC countries, including Zimbabwe (2005).	Portugal	Shutt et al. (2018), CABI (2005), Masuka et al. (1998).

(Source: CABI 2021a, Webber 2010)

Table 3 List of pathogens accidental introduced into Zimbabwe between 2000 and 2021.

Kind	Pests/pathogen	Suspected route/pathway of introduction	Geographical origin	Cited References / Source
Bacteria	*Pectobacterium brasiliense (Pectobacterium carotovorum* subsp. *Brasiliensis)* (soft rot and blackleg of ornamentals and potato)	Potato tubers	South Africa	Ngadze et al. (2012).
Bacteria	*Pectobacterium parmentieri* (black leg disease of potato)	Potato tubers	South Africa	Ngadze et al. (2012).
Fungi	*Pythium myriotylum* (brown rot of groundnut)	Not known	-	Sigobodhla et al. (2010)
Fungi	*Nattrassia mangiferae* (branch wilt of apple)	Plant material	North Africa	CABI/EPPO (2000), Gumbo et al. (2002)

The rate of the accidental introduction of pathogens is increasing in Africa and this calls for vigilant actions to improve biosecurity control strategies. Graziosi et al. (2019) indicated that thirty tree pathogens invaded African states between 1900 and 2013, a very large number of accidental introductions. This increased invasion was attributed to climate change and poor biosecurity control at points of entry. The identified invaders included *Armillaria* root rot in the 1600s (Coetzee et al. 2001), *Erythricium salmonicolor* (Roux & Coetzee 2005), *Chrysoporthe* spp. (Nakabonge et al. 2006), *Phakopsora pachyrhizi* in 2009 and *Puccinia psidii* in 2013 (Jarvie 2009, EPPO 2014, Graziosi et al. 2019).

The neighbouring country to Zimbabwe and with more advanced economy, South Africa is one of the regional gateway for exotic pathogens to Southern Africa due to its hive of economic activities and availability of sea ports connected to the outside continents especially tree pests (Graziosi et al. 2019) and this invasion route tend to use Zimbabwe as a transit to other African countries up the corridor. This calls for stricter or emergency biosecurity corrective measures at ports of entry for Zimbabwe and other third world countries in the like scenarios. There is the need for capacitation and strengthening port of entry quarantine officials in pathogens diagnosis and detection in all suspected pathways. This also calls for farmers to be provided with tools that reduce the impact of accidental pest invasions so as to minimise the risk that could also be exacerbated by climate change (Faulkner et al. 2017).

Phytosanitary measures to mitigate pathogen’s introductions in the SADC region

Once an introduced organism is considered a biosecurity threat, means to destroy the organisms must be considered in cross border traffic control. The measures may include the use of heat treatment, curation and inspection to detect and destroy such organism in cross border traffic (FAO 2007b, IPPC 2019d). The (SPS) Annex VIII to the SADC Protocol on trade gives detailed regulations for the member states to consider in plant protection (SADC 2008). In 2020, Zimbabwe, through the Zimbabwe Seeds company, pioneered the use of SADC guidelines on the trade of seeds developed under the SADC seed rules, which consider specific phytosanitary protocols to be followed.

In crop protection, the best ways to protect plants from pests is through pest exclusion, a function of plant quarantine regulations for pest control. Webber (2010), denotes that the management of the risk posed by exotic pathogens is a function of plant health regulations, which have their basis in the International Plant Protection Convention (IPPC) and the World Trade Organisation (WTO) Sanitary and Phytosanitary Standards (SPS). “Regulatory tactics are designed to prevent introductions of exotic pests and diseases, and to prevent their spread once established”, (FAO 2001). The

SADC SPS guidelines and SADC regulations on seed harmonization have been developed with the responsibilities of protecting plants from exotic pests between the SADC member states and with states outside the SADC block.

The use of pest control methods such as chemical curation and use of crop immunity through the development of pest-resistant varieties comes in with high costs. As SADC community, such costs are not good for the block's development. This is the reason why the member states have agreements on the use of plant protection and plant health laws when trading across borders.

Introducing new pathogens into a geographical area is generally via germplasm, and despite other pathways, methods to improve quarantine guidelines are handy (Michael et al. 2001). The SADC Plant health regulations assist member states in keeping at bay exotic pests which can undoubtedly be very invasive. The regulations used include pathway management that avoids the accidental introduction of these exotic pests by these different pest pathways. Thus, plant quarantine laws are fundamental in managing risks associated with pest incursions, especially those pests coming through cross border traffic. Pathways can be management at the place of origin, in transit, at the port of entry and during post-entry, also called after entry quarantine.

The protection of entry points through monitoring and inspecting cross border traffic or pathways is one of the surest ways SADC member states should consider in managing agricultural and environmental biosecurity threats. These border mediations can be in the form of risk profiling; which entails those specific phytosanitary standards for specific pathways must be considered. The mediations can also be in the form of port of entry inspections and verification processes for cross border traffic in which pre-determined management options for risk consignments is available. In such instances, treatment, returning of consignment to place of origin, or destruction of risk goods can be considered (PQSI unpublished, FAO 2007b, IPPC 2016e). The fifteen-member states SADC block have variegated regulations regarding this critical consideration in plant quarantine and in as far as my opinion is concerned, a regional plant health approach may be a good approach to protect this region from exotic pests; such as the case of the European Union Plant Health community structure where the EU is one block in so far as quarantine measures are concerned (Council Directive 2000).

The Plant Quarantine facilities should also guarantee post entry risk management in cases of accidental spillage for transit consignments. In cases of the deliberate introduction of risk goods in the member states, quarantine officials must implement the good culture of post entry quarantine, including, surveillance, inspection, testing and monitoring even during the in or off-season production in cases where seeds and planting material are introduced. Pest diagnosis infrastructure is a requisite in such scenarios. Both passive and active surveillance must be done (Honhold 2007, IPPC 2016b).

In all situations, SADC must have good emergency response mechanisms and plans to take care of emergencies such as containment and eradication as a block. This will definitely will mask the unavailability of resources to its other member states where emergencies occur. As such, polices to allow internal plant health officers; those who do not work at entry points; must be vigilant in plant health extension and internal plant biosecurity surveys to avert the dangers of exotic pest invasions misses or mistakes occurring from the entry quarantine inspections. When considering the use of regulation to control pest menace, though member states have the liberty to use their sovereignty laws in cases of pests' insurgence of very high economic importance, a regional approach service stitches. Given in Table 4 are some examples of regulations introduced to control exotic pests in Zimbabwe.

Product inspections at places of origin

The first critical phytosanitary measure in pathway management requires cooperation with the trading partners (OECD/WTO 2019). Some pests risk requires that phytosanitary measures at the place of origin manages the pest threat so that is it is excluded in the end product or pathway to be exported. In such cases, pest freedom is the expected result of such a phytosanitary measure. As SADC, the use of pest free areas, pest free places of production, areas of low pest prevalence or the use of systems approach in market access is one sure way of pathway management at places of production and origin (IPPC 2016c, 2019a). SADC member states carry out pest risk analysis and develop phytosanitary measures which the exporting member must certify by issuing a plant passport that accompanies the commodities and certifying its health status. In some cases, members' states consider pre-shipment inspections at the place of origin and production sites for market access as a pathway management measure (WTO 1986). The pre-shipment inspectors look at all facilities that deal with excluding the pests in the pathway, such as the production systems, pests' management methods, commodity storage, packing systems, and shipment strategies. The SADC member states, like Zimbabwe, does pathway management at place of origin through product inspections for the purpose of issuance of a plant passport. The exporting government authorities have always done pathway management at place of origin under the provisions of the International Plant Protection Convention's International Standards for Phytosanitary Measures (IPPC-ISPMs).

Table 4 Regulations introduced to control exotic pests in Zimbabwe between 1970 and 2021.

Regulation	**Remark**	**Outcome**
Plant Pests and Diseases (Tobacco) regulation, 1979	It was enacted to reduce the carryover of viral disease from season to season by creating a dead period that reduces the incidence of vectors transmitting viral diseases.	The spread of tobacco virus diseases remained masked due to the effective use of these regulations.
Plant Pests and Diseases (Coffee) Regulations, 1971. Statutory Instrument 738/1971	Was enacted to stop further spread of coffee berry disease (*Colletotrichum kahawae*) introduced in Mashonaland West province to the rest of the country.	A survey needs to be carried out in Mashonaland West to confirm a possible eradication of the disease following a deliberate move to remove all coffee plants from Mashonaland West Province.
Plant Pests and Diseases (Cotton) Regulations, (amendment)1988 Statutory Instrument 340/1980	Was enacted to reduce the spread of the pink boll worm (*Pectinophora gossypiella*) on cotton production	The pink boll work remains confined only in the South - East low-veld and Northern party of the country.
Plant Pests and Diseases (Importation) Regulations, 1976. Statutory Instrument 154/1976	Enacted to reduce accidental introduction of exotic pests into the country through trade and cross border traffic.	
Plant Pests and Diseases (Nursery) Regulations, 1972. Statutory Instrument 834/1972	Was enacted to reduce spread pests in the country through exchange of nursery stocks.	Reduced spread of pest in the country through nursery exchange.
Plant Pests and Diseases (Seed Potato Protection) Regulations, 1982 Statutory Instrument 679/1982	Enacted to protect potato planting material from bacterial blight (*Pseudomonas solanacearum*) and hence the development of potato quarantine area in the Manicaland province of country.	No new threats of potato pathogens were recorded since the enactment of the regulation.
Plant Pests and Diseases (Common Market for Eastern and Southern Africa) Regulations, 2016 Statutory Instrument 141 of 2016.	Enacted for Zimbabwe to exchange seeds with the COMESA block through the harmonised COMESA seeds and phytosanitary regulations.	-

Consignments conformity assessments at the point of entry

The procedure for the inspection of cargo that are pathways to pests normally follows a general inspection process (PQSI unpublished) and this procedure is almost consistent with the SADC member states. The consignment verification process starts with the checking of the documents accompanying the consignment. In this case, the importer presents documents accompanying consignments to the quarantine official, also called plant passports and plant visas. These documents include phytosanitary certificates, invoices, bills of laden or airway bills (PQSI unpublished, KEPHIS unpublished). The purpose of the quarantine official at this point is to check the accuracy of the information as presented for the specific commodities under import. When information presented complies with the phytosanitary import requirements as determined by the pest risk analysis process, record of the consignment is made in the import register and copies of the import documents are retained (PQUMAB 2014).

When documentation does not comply with the import requirements, the missing documents will be requested to initiate the consignment integrity verification process (Devorshak 2012). If the product is a prohibited good, or when documentation does not comply with the phytosanitary import requirements, a notification order is sent to the exporting state (IPPC 2016d). In such cases, the cargo may be detained pending the availing of missing documentation; the cargo returned to the country of origin or the cargo may be destroyed if the cargo is considered a threat to agricultural plant biosecurity (EU-2019/523 2019). Apart from the above decisions, where the cargo has missing documentation, some regulations may consider inspecting the consignment for agricultural biological hazards (Schrader & Unger 2003). If hazards are not detected, entry maybe be granted under post entry monitoring system by quarantine official.

The next critical activity done following import documentation checks by the quarantine officials is ensuring that the consignment is accurately described by its accompanying documents. Integrity of consignments is critical in reducing chances of smuggling and tempering while in transit which may jeopardises the transit conditions and integrity of phytosanitary certification system. Quantities or volumes, seals of the packaging materials or containers, safety conditions and other physical features of the consignment is physically checked. These features are expected to comply with the phytosanitary import requirements of the specific’s commodities.

The quarantine official carries out a physical inspection of goods in the form of plants, plants products and regulated articles in accordance with the standard operating procedure and regulations regarding agricultural plant and environmental biosecurity process. Most countries inspect in accordance with the international standard for phytosanitary measures numbers 23 and 31 (IPPC 2008, 2019d). An inspection that meets the set phytosanitary measures of imports is allowed entry. Where a consignment is inspected under special import authorisation, the inspection process maybe done post entry. Non-compliant consignments may be intercepted and an interception notification notice is sent to the exporting country according to ISPM 13, 20 (IPPC 2019e). The inspecting quarantine official keeps a sample and reports the inspection process and findings for each consignment for further use where necessary.

Inspection at entry point always accompanies sampling and pests’ diagnosis and identification (PQSI unpublished). Mostly, visual consignment inspection is done to check for presents of pest eggs, diseases symptoms and live insects. When an unknown arthropod or organism is found, the pest samples are sent to the central laboratories for identification. When this happens, entry of the pest if halted and the consignment is put into quarantine. It is easier to diagnose insects’ pest at entry point using the simple inspection tools of hand lenses, low-resolution microscopes, sieves, and augur, especially in developing countries. In the developed world, rapid test kits for pests are being employed, and screening of import consignments is easier. Many interceptions are made when consignment’s move from third world countries to first world countries because of high technological advancement at cross border entry inspections. However, identification of diseases where symptoms are not seen is difficult especially at the point of entry. Consignments that do not show disease symptoms always find their way into the country without proper diagnosis. In most developing countries like the SADC block, the risk of entry of pathogens is higher due to the unavailability or poor rapid detection tools and kits. Fig. 2 is a schematic diagram for the general procedure at points of entry in Zimbabwe.

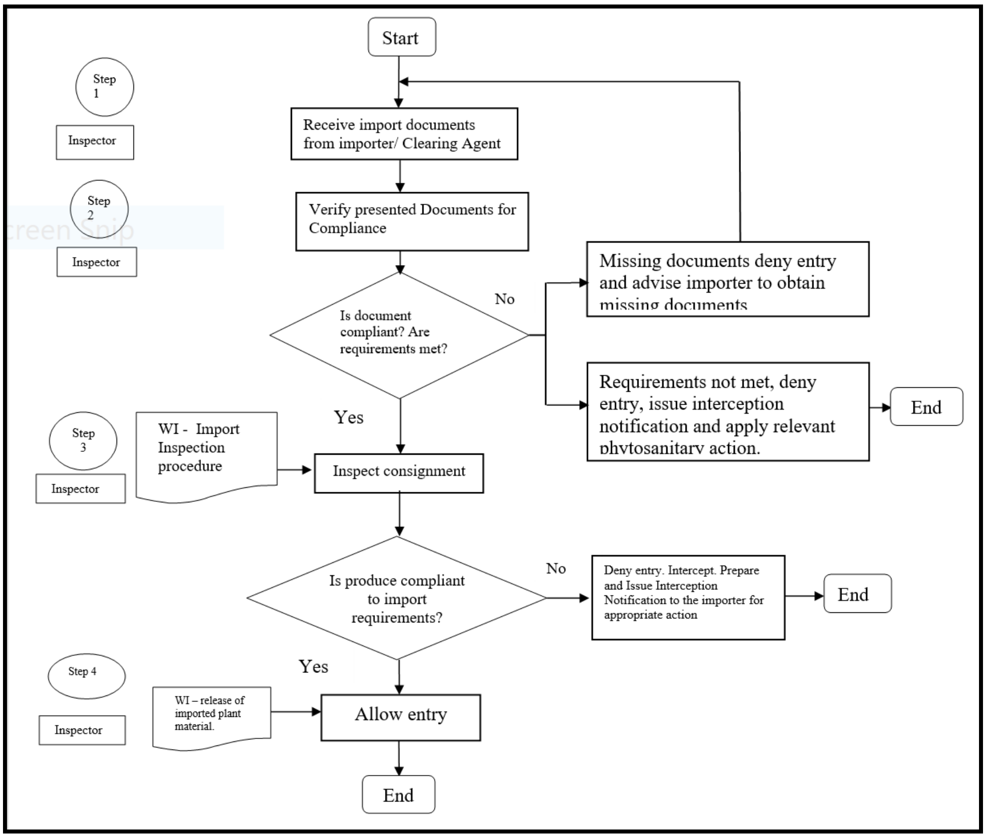

Fig. 2 – General procedure for phytosanitary Inspection of imported plants, plant products and regulated articles (Source: PQSI unpublished, KEPHIS unpublished).

Interception of consignment due to presents of pest at points of entry

Where a consignment is not accepted because of its failure to meet the phytosanitary measures for imports due to presents of pests, an interception report is produced. The intercepted consignment is either detained, returned or destroyed. A detained consignment can be subjected to treatment so that pest can be eliminated and entrance allowed. This can be done where the treatment provides a sufficient cover to alleviate the pests' risk.

The second decision is entry rejection. The consignment may be rejected and is returned to the place of origin. This decision is made if the consignment's return path or transit route will not cause further risk to the environment and agriculture biosecurity of the transit countries(s).

The third decision that can be made is commodity destruction. This decision is considered when the intercepted commodity is too risky if it is allowed to remain living. Pests subjected to this decision are of very high economic importance and any further delay in keeping them alive may lead to serious pest outbreaks and high economic injury and threatening of environment and agricultural plant bio-security systems.

Pathway interceptions in cross border trade

In plant biosecurity systems, commodity pathways are sampled for the purposes of inspection and for further tests. Samples are kept in storage for a period equivalent to the life span of the intercepted consignment. Samples are taken to verify consignment integrity, detect a pest, verify if a treatment measure was effective, and further test at the laboratories. Sampling procedures used at entry points include random sampling, stratified sampling and biased sampling if symptoms of diseases are observed (Heiberger & Holland 2009). Most first world countries have updated data bases regarding interception of pathways with pest (CABI 2021a, EPPO 2021) unlike our SADC member states including Zimbabwe. Such important databases are good for better control and preparedness in plant biosecurity (Florec et al. 2010, David 2007, Palmer 2017).

Importance of rapid pathogen detection techniques in international trade and customs procedures

Most point-of-entry quarantine inspections have been based on visual symptoms (Melanie & Sidhu 2015, Balodi et al. 2017) checks, especially in Zimbabwe and SADC countries and other third-world countries. Not all borders of SADC member states have essential inspection equipment such as microscopes, fungal spore traps, growth chambers or incubators, and other laboratory facilities (Riley et al. 2002). If available, the laboratories facilities are not equipped enough to counter the risky of pathogens escaping the point of entry inspections. Pathogen detection in pathways in cross border traffic is critical as it provides for proper planning to reduce pathogen escapes at entry points (Narayanasamy 2011).

SADC member states, including Zimbabwe, have an excellent eye considering visually identifiable pests such as some insects and some weed seeds but not on asymptomatic consignments. As such, pathogen testing, which normally takes between 24 hours to 21 days to be completed (Boddupalli et al. 2020) is critical. Such long normal pathogen testing affect trade turnover time in situations where consignment are detained pending pathology examinations.

The current global economic activity trends require fast decision that supports trade in line with the word bank 'easy of doing business initiative' and 'trading across borders' (World Bank 2020, Ministry of Finance 2018). To shorten customs clearance turnover time in cross border quarantine inspection, rapid detection techniques in pest diagnostics are critical. Results are obtained within a short period of time, ranging from as little as fifteen minutes for (lateral flow kits for Maize Chlorotic mottle virus to 48 hours for Some Enzyme-Linked Immunosorbent Assay (ELISA) tests (Jose 2017, Boddupalli et al. 2020). In the 21st century, ELISA has taken centre stage in the detection of plant pathogenic fungi and bacteria, employing monoclonal and polyclonal antisera (Jain et al. 2015, Balodi et al. 2017, Dayarathne et al. 2020). Examples of lateral flow-ELISA rapid testing were testing for *Phytophthora infestans* and *Ralstonia solanacearum* (Danks & Baker 2000, Narayanasamy 2011).

Rapid diagnostic tests (RDT) have also been done using the PCR methods. When used correctly and consistently, Rapid Diagnostic Technique (RDT) provides decision-making information for quarantine officials taking care of cross border traffic faster and improving the easy of doing business in international trade. Other rapid testing technologies include the Flow cytometry normally used for cell counting and sorting, biological markers detection, and protein production by the bio-systems of concerned organisms (McKinnon 2018). Flow cytometry can be applied in phytopathology to identify and assess bacterial and fungal plant pathogens with bacteria being the main subject of concern (Narayanasamy 2011, Dayarathne et al. 2020).

In 1985, Kary Mullis pioneered the use Polymerase Chain Reaction (PCR) to detect pathogens especially bacteria in plant biosecurity systems. PCR comes with the advantage of not isolating pathogens in pure culture, resulting in time and resources savings. (Mullis 1985)

Some other available RTDs include those that involve nucleic acid, more solely Deoxyribonucleic acid (DNA). DNA involving methods include fluorescence in situ hybridization (FISH); nested PCR (nPCR), cooperative Polymerase Chain Reaction (Co-PCR), multiplex Polymerase Chain Reaction (M-PCR), real-time Polymerase Chain Reaction (RT-PCR), and Deoxyribo Nucleic Acid fingerprinting (Narayanasamy 2011, Balodi et al. 2017, Rajapaksha et al. 2018, Dayarathne et al. 2020).

DNA pathogen detection methods are time savers, reliable, and highly specific than traditional serological assays that requires artificial propagation of test molecules (Prasad & Vidyarthi 2009, Law et al. 2015). Apart from these merits, in cross border quarantine consignments integrity assessments; rapid sequencing of nucleic acids, biomarkers such as volatile chemical and blends coupled with information networks provides for real time (Lucas 2011) monitoring and surveillance of pests including pathogens. Surveillance is very important activity in cross border quarantine inspections for plant biosecurity.

Some literature has cited "Bacterial Fermentation Kit (Juliana 2006)" as alternate methods to differentiate species of bacteria for cross border consignments conformity assessments or the general pathogen detection and identification. The "Bacterial Biochemical Identification Kits" employs the ability of some species of bacteria to hydrolyse starches, lipids etc as a characterisation method for specific strains. The use of high-throughput sequencing (HTS), (Olmos et al. 2018) i.e. next-generation sequencing (NGS); (deep sequencing) has also came in as a handy to advances in the research of pathogen-host associations in phytopathology. The HTS technique allows for the detection of very distant isolate of the same pest in samples and it respectably reveal any biological threat in any plant sample during consignments integrity conformity checks.

Nanotechnology where enzyme based biological sensors normally glazed with nano-material such as copper, silver, and gold may also influence the sensitivity of diagnostic probes for plant pathogens in samples (Khan et al. 2019). Nano-materials-based diagnosis techniques are either used by directly applying nano-particles of suitable antimicrobial chemical or by encapsulating anti-microbial by a nanomaterial.

Rapid diagnostics system is a very positive development in cross border quarantine and international/regional trade. It provides for reduced inconveniences from quarantine conformity checks of cross border traffic. Rapid diagnostic systems have been used in agriculture, human medicine and veterinary services. RDTs reduce the cost (Abingdon Health PLC 2020) of disease screening at ports of entry without carrying samples to central laboratories, which is a laborious and costly activity to the traders, crew and passengers in cross border traffic. Rapid tests kits are an easy-to-use and efficient testing tool. At an on-spot testing is achieved within minutes to hours.

The use of the RDTs by SADC and Zimbabwe is limited to few occurrences. If fully employed, quarantine systems in delaying border clearance procedures will be a think of the past.

Threats associated with the introduction of new exotic pathogen species from regional and international trade

Crop pests cause an estimate of 20 to 40 percent of crop loses annually worldwide (Zadoks 1994, Savary et al. 2012, CABI 2020b), of which some of the pests cause 100% yield losses on certain crop species. About USD70 billion and USD 220 billion is lost yearly due to invasive species and plant pest respectively with the invasive species accounting for thirty-two per cent of the annual losses (FAO 2021) globally. In SADC, not less than half a billion dollars in crop yields is lost due to pests annually. Zimbabwe loose not less than US300 million dollars annually due to plant pests. Disease crop losses account for not less than 15% reduction of the exportable produce per annum (FAO News bulletin 2019). Exotic pathogens and insect's pests threaten agricultural biosecurity, biodiversity and the environment disturbing the natural ecosystems. Due to these challenges and the need to protect the environment, the agricultural biosecurity systems and biodiversity, governments budgetary planning and allocation of resources is affected. Governments especially the third world countries like Zimbabwe, face resources allocation challenges in prioritising emergencies considering food, animal health, human health, and natural disaster (Moffitt & Osteen 2006). All this is related to the devastating effects of exotic pathogens and pests whether for animal, plant and human health. The United Nations declared 2020 the international year of plant health to raise awareness of the importance of protecting the world plant resources from pests (FAO 2020).

The introduction and establishment of invasive pest species lead to loss of plant life, loss of grazing lands leading to soil erosion and land degradation. The loss of plant life brought in by exotic pests leads to loss of feed and food, resulting in food insecurity. Exotic species, in cases of weeds, threaten other species through extraneous competition of resource, as pest's hosts and or pathways. The environment is threatened with habitats displacement, leading to landscape damages and paving way for invasive weed species to have niche habitats. Socially, pest have a nuisance behaviour: cases of *Prostphanus trancatus*, (Nyagwaya et al. 2011) which destroys wood material by feeding on them; and cases of wood rots by the *Armillaria* spp. (honey fungus) and *Serpula lacrymans* (true dry rot), *Fibroporia vaillantii* (mine fungus), and *Coniophora puteana* (cellar fungus), which attack timber in structures (Dutkiewicz 1989, Stamets 2005).

Variances in crisis preparedness and designing of proficient controlling of aggressive exotic species present different economic concerns due to the risk management tactics put on the table in cases of incursions. Thus, development of a risk management model that ease risk of invasion while allocating scarce resources equitable to all sectors of the economy suffice these challenges (Shogren 2000). Here, risks are reduced by mitigation and reduction of ruthless occurrence. In responding to pest's threats, governments are forced to make decisions even when there is no baseline information, and as such, the need to research to ascertain the threats, develop measures for prevention and control as well as carrying out a pest risk analysis for economic consequences is critical (Ben-Haim 2006, Moffitt & Osteen 2006).

Based on the increased international movement of cross border traffic, Zimbabwe is threatened by many pathogens and other pests. These pathogens do not only have biosecurity challenges on staple food crops only, but a wide range of cultivated and non-cultivated plant species. Tables 5, 6, 7 lists pathogens threatening Zimbabwe strategic crops and the trade of plant and plant products in Southern African countries.

Potential pathogens biosecurity threats listed in Tables 5-7 have resulted in the institution of quarantine measures as the first line of defense by SADC member states. Some of these measures are trade restrictions that seriously impact the free movement of people and goods, resulting in delayed customs clearance at ports of entry and exit. Though phytosanitary measures are allowed if scientifically justified and without unnecessary trade restrictions, the easy of doing business across borders is compromised, including the trade of plants and plant products within SADC and other Sourthen African countries. Trade of goods and services across the border is greatly affected by the measures instituted by governments to address plant and agricultural biosecurity threats to nations. Such regulations though they are restrictive to trade, they succor in protecting plant life and agriculture biosecurity. Trading across borders of various crops and other plant products in Sourthen Africa requires vigilant biosecurity controls to guard against unwanted exotic pest introductions within the boundaries of each state from all potentials pathways of pest spread.

Quarantine pathogens threatening the production and trade of strategic crops of the Zimbabwean economy and Southern African countries

Important cereal crops of Zimbabwe include maize, which is a key source of carbohydrates and the staple food crop for Zimbabwe (Alumira & Rusike 2005, Global Africa Information Network 2018) Maize accounts for 80% of cereal crops in Sourthen Africa which is a regional staple crop (SADC 2020c). Other important cereal grains cereals in SADC include wheat, (a key grain for serving the baking industry), sorghum and millets (good sources of traditional carbohydrates for Zimbabweans). Important vegetable tubers include the potato crop and cassava (WFP 2017, Mupakati & Mazarura 2017, MLARR 2018). The strategic crops also include tomatoes (*Lycopersicon esculentum* L.) and other leafy vegetables. Apart from the above, tobacco and cotton cash crops are very critical in Zimbabwe's economy (Zimtrade 2021).

Maize is a key staple food for Zimbabwe. Wheat and potatoes provide alternative sources for food security for the Zimbabweans people. Potato is almost found in every dish as carbohydrates served as fries, crisps or as table potato. Due to high crop demand, importation of the crops into Zimbabwe has been going on uninterrupted. Importation of seeds including vegetative propagating material like those for seed potato to improve the productivity of table potato has subsequently increased and thus the importation of seed potato tubers has taken sharp increases since 2010 to 2020 (Seed Services 2010-2020). Wheat is a key confectionary product in the Zimbabweans baking industry. Tomatoes are served as a vegetable or mixed as an ingredient and portions for the foods in the daily dishes. Sorghum and millets like maize, are critical alternatives of the staple foods for the Zimbabweans and other Southern Africana states. Tobacco is a key export crop for foreign currency earning by the Zimbabwean economy. Cotton is a key export crop for foreign currency earning also used in the country textile and medical sanitary industry. All these plant products are crossing the borders frequently into and out of Southern African states. Tables 5, 6, 7, is a list of threatening transboundary pathogens Zimbabwe and SADC have to worry of as far as plant biosecurity for strategic crops for food and industrial purposes is concerned.

Table 5 Some transboundary bacterial pathogens threaten strategic crops biosecurity in Zimbabwe and Southern African countries. (Source: CABI 2021a, b, c).

Preferred scientific name	**International common name**	**Taxonomic group**
Clavibacter michiganensis subsp. *sepedonicus*	Potato ring rot	Bacteria
Dickeya dadantii	bacterial wilt and soft rot of ornamentals and potato	Bacteria
Liberibacter asiaticus	Asian greening disease	Bacteria
maize bushy stunt phytoplasma	maize bushy stunt	Bacteria
Pantoea stewartii	bacterial wilt of maize	Bacteria
Pseudomonas marginalis pv. *pastinacae*	brown rot	Bacteria
Pseudomonas syringae	bacterial blast	Bacteria
Pseudomonas viridiflava	bacterial leaf blight of tomato	Bacteria
Ralstonia solanacearum race 3	brown rot of potato	Bacteria
Spiroplasma kunkelii	corn stunt spiroplasma	Bacteria
Xanthomonas campestris	black rot of crucifers	Bacteria

Table 6 Some transboundary fungal pathogens threaten strategic crops biosecurity in Zimbabwe and Southern African countries. (Source: CABI 2021a, b, c).

Preferred scientific name	**International common name**	**Taxonomic group**
Cochliobolus hawaiiensis	leaf spot: maize	Fungi/Chromista
Corynespora cassiicola	target leaf spot of tomato	Fungi/Chromista
Fusarium sporotrichioides	kernel rot of maize	Fungi/Chromista
Gibberella acuminate	stalk rot of maize	Fungi/Chromista
Harpophora maydis	late wilt of maize	Fungi/Chromista
Helminthosporium carposporum	fruit rot of tomato	Fungi/Chromista
Khuskia oryzae	cob rot of maize	Fungi/Chromista
Magnaporthe oryzae Triticum pathotype	wheat blast (already in Zambia, 2020)	Fungi/Chromista
Monilinia fructigena	brown rot	Fungi/Chromista
Mycosphaerella zeae-maydis	yellow leaf blight of maize	Fungi/Chromista
Penicillium notatum	storage rot of cereals	Fungi/Chromista
Peronosclerospora maydis	downy mildew of maize	Fungi/Chromista

Table 6 Continued.

Preferred scientific name	International common name	Taxonomic group
Peronosclerospora philippinensis	Philippine downy mildew of maize	Fungi/Chromista
Peronospora hyoscyami f. sp. *tabacina*	blue mould of tobacco	Fungi/Chromista
Phaeosphaeria avenaria f. sp. *triticea*	speckled: wheat leaf blotch	Fungi/Chromista
Phoma andigena	black blight of potatoes	Fungi/Chromista
Phyllachora maydis	black spot of maize	Fungi/Chromista
Phytophthora erythroseptica var. *erythroseptica*	pink tuber rot	Fungi/Chromista
Polyscytalum pustulans	skin spot of potato	Fungi/Chromista
Pseudocochliobolus verruculosus	post-harvest rot	Fungi/Chromista
Puccinia pittieriana	common rust of potato	Fungi/Chromista
Pyrenochaeta lycopersici	brown root: tomato rot	Fungi/Chromista
Pythium arrhenomanes	cereals root rot	Fungi/Chromista
Sclerophthora rayssiae var. *zeae*	brown stripe downy mildew of maize	Fungi/Chromista
Septoria lycopersici var. *malagutii*	annular leaf spot of potato	Fungi/Chromista
Sphacelia sorghi	ergot of sorghum	Fungi/Chromista
Synchytrium endobioticum	wart disease of potato	Fungi/Chromista
Thecaphora solani	potato smut	Fungi/Chromista
Tilletia controversa	dwarf bunt of wheat	Fungi/Chromista
Tilletia indica	Karnal bunt of wheat	Fungi/Chromista
Trametes versicolor	wood decay	Fungi/Chromista
Trichothecium roseum	fruit rot of tomato	Fungi/Chromista
Typhula incarnate	snow blight: cereals	Fungi/Chromista
Typhula ishikariensis	speckled: cereals snow mould	Fungi/Chromista
Ulocladium atrum	Ulocladium blight of potato	Fungi/Chromista
Urocystis agropyri	flag smut of wheat	Fungi/Chromista
Ustilago nuda f. sp. *tritici*	loose wheat smut	Fungi/Chromista
Waitea circinata	root rot of maize	Fungi/Chromista

Table 7 Some transboundary viral pathogens threaten strategic crops biosecurity in Zimbabwe and Southern African countries. (Source: CABI 2021a, b, c).

Preferred scientific name	International common name	Taxonomic group
Andean potato mottle virus	Andean mottle of potato	Viruses
Maize chlorotic dwarf virus	Maize and other cereal viral disease	Viruses
Maize chlorotic mottle virus	Maize and other cereal viral disease	Viruses
Maize lethal necrosis disease	Maize and other cereal viral disease	Viruses

Table 7 Continued.

Preferred scientific name	International common name	Taxonomic group
Maize mottle/chlorotic stunt virus	Maize and other cereal viral disease	Viruses
Potato deforming mosaic virus	deforming mosaic of potato	Viruses
Potato spindle tuber viroid	spindle tuber of potato	Viruses
Potato virus X	potato interveinal mosaic	Viruses
Potato yellow dwarf virus	yellow dwarf of potato	Viruses
Potato yellow vein virus	yellow vein of potato	Viruses
Tomato chlorosis virus	yellow leaf disorder of tomato	Viruses
Wheat yellow mosaic bymovirus	wheat spindle streak mosaic	Viruses

General state of cross border plant quarantine systems for Zimbabwe and Southern Africa

The Zimbabwe entry point quarantine inspection meets the minimum requirements for phytosanitary entry inspections according to the operational standards depicted by the international standards for phytosanitary measures (ISPMs) (IPPC 2019e, FAO 2015a, b). Like some other countries in Southern Africa, Zimbabwe has National Plant Protection Organisation Frameworks, which execute duties in accordance to IPPC provisions (ISPM 1 2006, Molins et al. 2009, Vapnek & Manzella 2007). The entry quarantine officials, also called plant health inspectors to have a minimum qualification of at least a diploma in pest related science such as agricultural and or biological sciences. Such a qualification gives strength to the inspectors to visually identify disease symptoms in pathways and consignments including insects' pests' stages during inspections. Where basic inspection equipment is present, qualification officials with at least diploma can screen quarantine pests faster, facilitating the easy of doing business.

Highly developed quarantine systems such as those from the first world countries have entry quarantine officials possessing at least a master degree in pest-related sciences. Such skills give the officers enough confidence to detect and identify pathogens or pests with little challenges or difficulties, especially when enough testing materials are available.

Zimbabwe quarantine system has at least the basic inspections tools at each point of entry. Visual identifiable pests' stages can easily be screened during cross border quarantine inspections without the need to wait for referral laboratory results from the central diagnostic facility for the NPPO. Minimum information management equipment for information dissemination are found at each entry point. Internet is accessible for each entry point to facilitate efficient data and information exchange. Quarantine officials are uniformed for easy of identification by stakeholders.

The quarantine officials use a number of official documents to execute their duties. These documents include import and export certificates, interceptions notification forms, receipt book, invoice books, statutory instruments, standard operating procedures, or standard operational manuals. The availability of such documents are key in NPPO operations of entry points. The Zimbabwe NPPO like any other contracting parties of the IPPC are encouraged to have such official documents and useful documents to facilitate trade.

One of the main challenges affecting cross border inspection in Zimbabwe trade and in some other countries in Southern Africa is the unavailability of rapid pest detection kits at ports of entry. These kits are critical provisions for the detection of pathogens in pathways during cross border quarantine inspections. By their nature, plant pathogens are not easily detected by naked eyes unless there are symptomatic cases of the pathogens in consignments. To identify pathogens from sample, culturing may need to be done where diseases symptoms are absent. This culturing process requires at least some time to be finalized. Trade requires efficiency in terms of turn over time in delivery of inspection results and where rapid testing tools are missing, the easy of doing business in international trade is compromised and hence trade is threatened through these justified restrictions.

Though comparable and having a better plant quarantine system to other countries, Zimbabwe should continue to strengthen the skills of the quarantine officials on testing procedures at points of entry as well as data storage, probably through the development of online data stores which are easily accessible when required. Data on interceptions and notification is not easily accessible in Zimbabwe. Unlike countries like the EU, such data is important for the development of emergency responses regarding accidental pest introduction and emergency responses to pests' outbreaks. It also takes care of the requirements of the ISPM 13 for the contracting parties of the IPPC. Such data is critical in coming up with emergency responses and also surveillance plans, eradication plans or even containment plans in cases of accidental introductions.

Information regarding the types of harmful organisms intercepted, sources of origin and types of pathways causing biosecurity risks come from such interception databases. For example, the EU in 2019 intercepted 6,990 consignments from third world countries with 1,734 of the interceptions being harmful organisms. From the 2019 EU Europhyte report (Europhyte Report 2019), Zimbabwe consignments submitted to the EU were intercepted 31 times due to wrong documentation and 24 times due to insect pests (*Liriomyza huidobrensis, Spodoptera littoralis, Spodoptera frugiperda, Liriomyza trifolii, Bemisia tabaci, Thaumatotibia leucotreta*). This type of interception, if it was the reverse, it could have been helping Zimbabwe more in terms of preparedness on transboundary pests' insurgence.

General conclusion

Plant biosecurity in agriculture requires the introduction of a new pest in a territory to remain minimal. New pests in a territory cause a lot of losses in both yield and quality of produce. This usually leads to severe economic losses due to applying of wrong emergency control strategies for such biosecurity threats. Considering how Zimbabwe quarantine systems are structured and how it operates, considerable changes are critical to reduce the impact of transboundary pathogens in trade of strategic crop and crop products in the Southern Africa region.

The list of pathogens threatening the block of counties in Sourthen Africa is long. Escape or accidental introduction of one pathogen for the Sourthen African strategic crops could result in a serious threat on the production of crops and trade. Due to porous borders and non-geographic barriers, what happened to Mozambique following the detection of Panama banana wilt, maize lethal necrosis diseases in Tanzania, *Bactrocera dorsalis* in Zimbabwe and the outbreak of soybeans rust in Zimbabwe to mention but a few transboundary pest introductions; left a trail of trade restrictions and productions losses. This calls for Zimbabwe and other Southern African countries to have a critical watch and improve cross border quarantine inspections, constantly reviewing quarantine laws and procedures as well as exploiting the gains in the science of the use of rapid pest testing techniques for pest pathways in cross border.

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