



# Pathogens threatening agriculture and biodiversity in South Africa: A horizon scanning approach

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## Abstract

There is mounting evidence that invasive alien species (IAS) have adverse effects on plant health and the global economy, posing a significant threat to biodiversity and ecosystem functioning. Identifying and assessing emerging IAS, such as plant pathogens, is a proactive approach that might assist in prioritising potential pathogen threats before they become established or widespread, negatively affecting plant health, crop production, animal production, animal health by affecting pastures and food security in South Africa. We collected information from the CABI Invasive Species Compendium and Crop Protection Compendium on plant pathogens that are present in neighbouring countries and are likely to be introduced throughout the Republic of South Africa using an expert-elicitation horizon scanning study. Pathogens with the highest score were determined based on their strong capability on the chance of entry, establishment, economic impact, and biodiversity destruction. The current study revealed that only 17 pathogens (6 fungi, 7 viruses, 2 bacteria and 2 phytoplasma) had been prioritised due to their potential to enter the country and have been reported in the neighbouring countries. Maize lethal necrosis disease, *Candidatus Liberibacter asiaticus*, *Candidatus Phytoplasma palmae*, *Fusarium oxysporum* f.sp. *cubense* tropical race 4, and Maize chlorotic mottle virus have the highest potential to enter and establish in the country. The most effective phytosanitary actions for the high scoring pathogen were to conduct surveillance for their potential presence in South Africa and risk analysis, especially for organisms recorded in neighbouring countries.

**Keywords** Pathogens · Pathogen Risk Analysis · Viruses · Bacteria · Phytoplasma · Invasive Alien Species · Quarantine

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## Introduction

World Trade Organization's (WTO) Sanitary and Phytosanitary Measures (SPS) Agreement and International Plant Protection Convention (IPPC) acknowledge the harmful effects of pests and diseases to represent worldwide concerns. The IPPC seeks to prevent the introduction and spread of regulated pests while fostering safe trade for the planet's plant resources (FAO 2011). The WTO-SPS Agreement enables members to establish their guidelines and measures for food safety and the welfare of plants and animals, and these guidelines must be founded on science and international principles (WTO 1995). Species introduced or transported outside their natural ecological range or current distribution by anthropogenic or natural activities and that may result in economic or environmental damage or negatively impact human health are considered invasive alien species (IAS) (Hesketh and Roy 2015).

As with natural disasters, early warning of the risks associated with such events is crucial for preventing, controlling, and mitigating invasion threats and may lessen environmental and fiscal harm (Ricciardi et al. 2017). Plant diseases negatively impact crop production and the international trade of plants and plant commodities. Despite technological advancements in controlling and detecting plant pathogens, nations still experience the emergence of plant diseases (Brooks et al. 2022). The introduction and spread of IAS are regarded as one of the most significant drivers of global change in biodiversity and ecosystem services (Hesketh and Roy 2015; Roy et al. 2023). A risk arising from a newly identified hazard to which significant exposure may occur or from an unanticipated new or increased significant exposure and/or susceptibility to a known hazard may be described as an emerging risk to plant health (EFSA Scientific Committee 2007).

As worldwide connectivity and trade among countries grow, plant pathogens are dispersed to new geographic areas more frequently (Barwell et al. 2021). The pressure on the food supply will likely increase due to climate change, which may also create favourable conditions for invasive pests and pathogens (Richardson et al. 2016). Without in-depth knowledge of their characteristics, distribution, and spread, predicting the danger they pose to plant health and biodiversity can be challenging. It is, therefore essential to identify invasive alien species and evaluate their potential effects so that the species can be prioritised for the adoption of effective control strategies and steps to manage invasion pathways (Roy et al. 2017). Management of new threats to biodiversity requires international/ regional cooperation and financial investment (Sutherland et al. 2023). In recent years, Sub-Saharan Africa (SSA), a region dominated by resource-poor farmers, has suffered from a growing number of invasive plant pathogens (Kenis et al. 2022).

CABI developed the beta versions of its invasive species, the Horizon Scanning Tool, to assist pest risk analysts in identifying potentially invasive species (Coles 2018). The potential for arrival, establishment, and probable effects on ecosystem function, economies, and human health is considered when identifying high-risk species (Dawson et al. 2022). Management of invasive alien species is thought to require horizon scanning to prioritise the threat presented by potentially new IAS that have not yet become established in a region (Roy et al. 2011). In order to plan and carry out measures to avoid the introduction of IAS, it is essential to scan the horizon for high-risk invasive non-native species (INNS) (Gallardo et al. 2016).

The list of invasive species is narrowed down using a variety of criteria (such as pathways, habitats and taxonomy), allowing researchers to concentrate on groups of potential invaders that may need a more thorough risk assessment, surveillance, public education, or direct intervention measures to stop their introduction and spread. Species from all main taxonomic groups of animals, plants, and microorganisms are included in horizon scanning (Hesketh and Roy 2015).

Invasions by alien pathogenic species are a growing threat to crop production. The Agricultural Pests Act, 1983 (Act No.36 of 1983) and its relevant regulations, namely, National Control Measures R.110 of 27 January 1984 as amended, Import Regulations R.111 of 27 January 1984 as amended, and Government Notice R.1013 of 26 May 1989 as amended, are used to administer the plant health regulatory framework in South Africa. In essence, these phytosanitary measures restrict the movement of plant commodities from infested to non-infested regions, as well as the issuance of an official order and the application for removal permission. The current study is aimed at using horizon scanning first to compile a list of potentially invasive alien pathogenic pests, which include bacteria, fungi, viruses and phytoplasmas that are thought to be absent from South Africa but could harm the country's forestry, agriculture, and environment if they were to be introduced and established. To limit the negative consequences of introduced alien invasive species, this study also focused on the possibility to prioritise efforts such as pest risk assessments, prevention, surveillance, and contingency planning by ranking these pathogens based on their potential hazard.

## Material and methods

### Assembling the list of plant pathogens

The Horizon Scanning Tool was used to identify and categorise species that might be threats and have enter South Africa from other countries, especially the neighboring countries. It uses CABI data to generate a list of pathogens that are not recorded as present in South Africa but are

reported from ‘source areas’ i.e. geographic areas with similar climates to South Africa, neighbouring areas or selected trading partners. The CABI's Crop Protection Compendium (CPC), Invasive Species Compendium (ISC) (CABI 2021) were used for assessing their likelihood of arrival, likelihood of establishment, and the likelihood of influence on biodiversity. In the initial stage of horizon scanning, we generated a list of species, refined the data by pathways, organism types, impact outcomes and habitats, and accessed linked open-access species datasheets in the CABI Compendium. A list of species that are absent from South Africa but present in specific source areas was created using data from the CPC datasheets. Initially, all countries in and outside of Africa served as the source locations, leading to a list of more than 2165 species. The Subject Matter Experts (SMEs) reviewed the list and eliminated all pathogens that were already known to exist in South Africa (despite not having been reported as present, so appearing as absent in the CPC) and pathogens that were generally agreed upon as not being significant plant pests in South Africa, such as species that are unique to a plant genus that does not exist in the country. The list was reduced by limiting it to only those species that had complete datasheets in the CPC (in order to identify the most significant pests) and that were listed in the ISC (CABI 2021) in order to remove any species that were in the CPC but had not been identified as invasive anywhere and, therefore, did not exhibit any invasive traits. Through this exercise, we found 149 pathogens. A lot of pathogens that were deemed unnecessary for this exercise were eliminated during discussions. These included pathogens that were thought to be unimportant for plants in South Africa, such as species specific to a genus of plants that do not occur in the country or those that were known to occur in the country but were not included in the CPC's list of pathogens. The Agricultural Pests Act, Act No. 36 of 1983, and the National Environmental Management: Biodiversity Act 10 of 2004 authorize the official management of 15 pathogens, including species not yet found in Africa but are recognized as quarantine pests. Although they had not yet reached Africa, some of these infections have lately moved quickly to other continents. A final shortlist of fifty pathogens was presented for additional evaluation and prioritization.

### Study region and description of scoring criteria

The data included the following variables: taxon, common name(s), taxonomic group, functional group, native distribution, presence/absence in South Africa and thematic group. On a scale of 1 (extremely rare) to 5 (very likely), the likelihood of arrival, likelihood of establishment, and likelihood of influence on biodiversity were all scored by the SMEs. Based on the methodology outlined by Roy et al. (2019), a risk scoring system was employed.

The following formula obtained the overall score:

$$\begin{aligned} & \text{Likelihood of entry} \times \text{likelihood of establishment} \\ & \times (\text{potential of socio – economic impact} \quad (1) \\ & + \text{potential of environmental impact}) \end{aligned}$$

The likelihood of arrival, influence on biodiversity, and overall score for each species were added together and the confidence in the entire score was expressed as low, medium, or high. To determine confidence scores: Low (L) indicates the absence of direct observable evidence, the difficulty of interpreting the evidence, or the low caliber of the evidence; Medium (M): Some direct observational data are present, but they may be confusing or challenging to scale in the particular geographic setting; High (H): Direct observational evidence that is readily available, uncomplicated to comprehend, and of high caliber. Fig. 1 displays a flow diagram of the horizon-scanning workflow that is used to determine the non-native pathogens in South Africa.

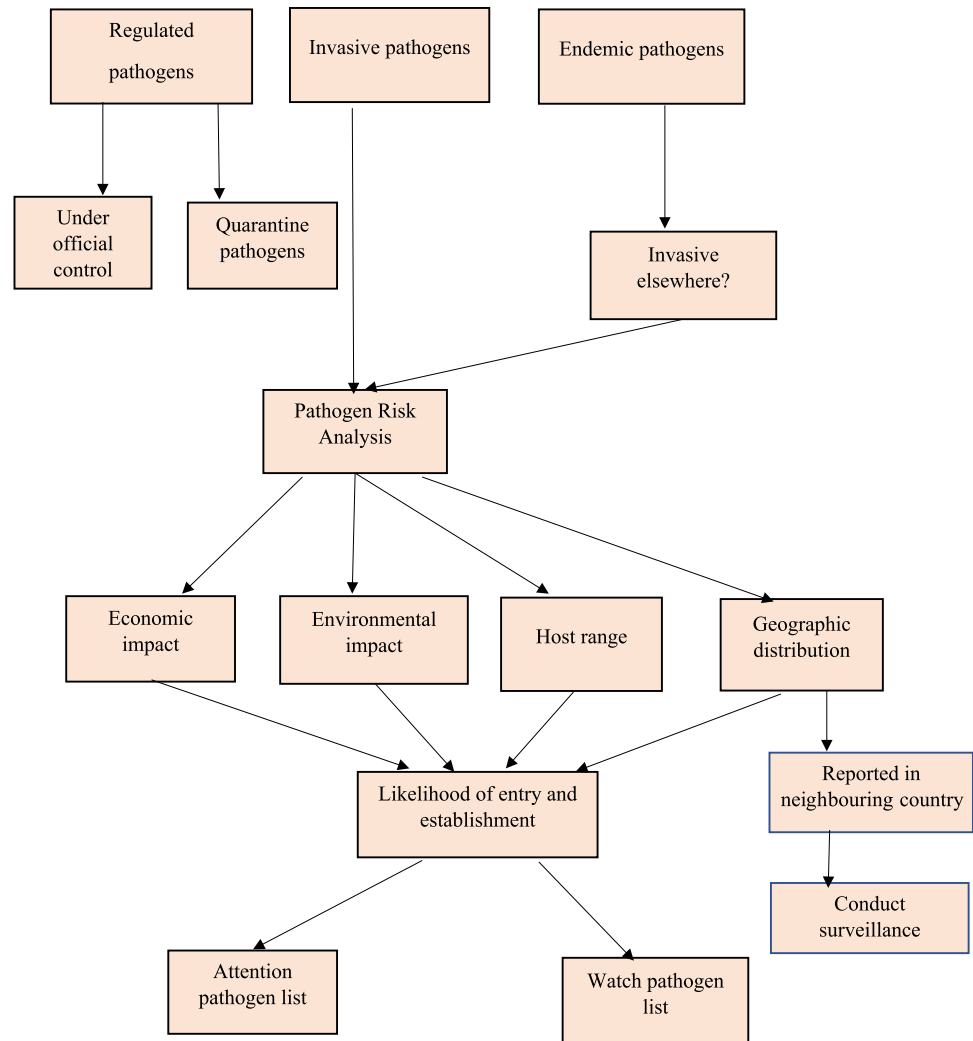
Compendia (CPC and ISC), published (journal articles and reviews), and grey literature (conference papers and proceedings, dissertations and theses, government documents and reports, and newspaper articles) provided the data that supported the scores, confidences, and likely pathways. This information also covered the likely pathways of arrival, different economic impacts, mechanisms affecting other species, mechanisms affecting ecosystem function, impact on human well-being, socio-economic impacts, additional comments, and references, specifically in the context of South Africa.

In order to determine the probability of entry, the following suggestions were made: 1, present in Africa (not in neighboring countries) and spreading slowly; 2, present in Africa (but not in nearby nations) and spreading quickly, or in a nearby countries and spreading slowly; and 3, present in a nearby nation and spreading. Three potential routes of entry-unaided (UN), which consisted mainly of natural dispersal; commodity (CO), which consisted of intentional introduction as a commodity or with a commodity or unintentional introduction with a commodity (contaminant); and stowaway/hitchhiker (ST), were taken into consideration when assessing the likely pathways of arrival.

### Expert panel and pathogen risk assessment

Subject Matter Experts (SMEs) from the South African National Plant Protection Organisation, research institutions, academic and regulatory environments performed the prioritization. The SMEs had knowledge and experience in bacteriology, mycology, and virology. A ranked list of pathogens that are detrimental to plants and may eventually

**Fig. 1** Flow diagram of horizon-scanning of non-native pathogens in South Africa



invade South Africa was created using an adaptation of the consensus technique created for ranking IAS (Sutherland and Woodroof et al. 2009; Roy et al. 2014a, 2019).

The current study's authors form part of the expert panel for pathogens. Pathogens listed in the relevant legislations (Agricultural Pests Act, 1983 (Act No.36 of 1983) and National Environmental Management: Biodiversity Act 10 of 2004) were considered during data assembly and data analysis. The authors conducted pest risk assessments on pathogens.

### Scoring of pathogens

The species that were chosen from among the SMEs were scored remotely and independently. Every expert evaluated a minimum of seven pathogens.

### Reaching consensus

A final risk score was obtained for all assessed species by calculating the median score for the final score, which the

group validated through consensus. Pathogens were then ranked according to their potential threat to South Africa.

## Results

A total of 149 taxa, which are primarily agricultural pathogens, were assessed. The current study revealed that only 17 pathogens (six fungi, seven viruses, two bacteria and two phytoplasma) had been prioritized and have been reported in the neighbouring countries (Table 1). According to our scoring/assessment system, maize lethal necrosis disease, *Candidatus Liberibacter asiaticus*, *Candidatus Phytoplasma palmae*, *Fusarium oxysporum* f.sp. *cubense* tropical race 4, and *Maize chlorotic mottle virus* have the highest potential to enter and establish in the country (Table 1). The most suggested phytosanitary actions identified by experts for the high scoring pests were to conduct surveillance for their potential presence in South Africa and full Pest Risk

**Table 1** Prioritized pathogens, which are a potentially invasive alien pest, their distribution in the neighboring and suggested actions. These species have the highest priority rankings in terms of their presence in neighbouring countries, likelihood of entry, likely path-

way of arrival, likelihood of establishment, and potential of socio-economic and environmental impacts. Prioritization was done by the experts in the field of plant pathology

Scientific name	Taxonomic group		Mozambique, Tanzania, Kenya	Score	Suggested phytosanitary actions
Maize lethal necrosis disease	Virus		Mauritius, Réunion, Kenya, Ethiopia	120	Conduct a full PRA and surveillance
<i>Candidatus Liberibacter asiaticus</i>	Bacterium		Mozambique, Tanzania, Kenya	105	Conduct a full PRA and surveillance
<i>Candidatus Phytoplasma palmae</i>	Phytoplasma		Mozambique	105	Conduct a full PRA and surveillance
<i>Fusarium oxysporum</i> f.sp. <i>cubense</i> tropical race 4	Fungus		Tanzania, Mozambique, DRC, Kenya	105	Conduct a full PRA and surveillance
Maize chlorotic mottle virus	Virus		Angola, Botswana, Comoros, Kenya, Nigeria, Togo, DRC, Mozambique, Tanzania, Zambia, Zimbabwe	105	Conduct a full PRA and surveillance
<i>Pseudocercospora angolensis</i>	Fungus		Seychelles	90	Conduct a full PRA and surveillance
Tomato leaf curl New Delhi virus	Virus		Zambia, Zimbabwe	90	Conduct a full PRA and surveillance
<i>Bipolaris victoriae</i>	Fungus		Mozambique, Tanzania, Zambia, Morocco, Algeria, Tunisia, Zimbabwe	84	Conduct a full PRA and surveillance
<i>Cassava brown streak virus</i>	Virus		DRC, Malawi, Mozambique, Tanzania, Zambia, Zimbabwe, Nigeria, Ethiopia	72	Conduct a full PRA and surveillance
<i>Coniothyrium glycines</i>	Fungus		Comoros, DRC, Madagascar, Malawi, Mauritius, Reunion, Tanzania, Zambia	72	Conduct a full PRA and surveillance
<i>Mycosphaerella fijiensis</i>	Fungus		Comoros, DRC, Madagascar, Malawi, Mauritius, Reunion, Tanzania, Zambia	64	Conduct a full PRA and surveillance
<i>Cowpea mild mottle virus</i>	Virus		Mauritius, Tanzania	64	Conduct a full PRA
<i>Cucurbit aphid-borne yellows virus</i>	Virus		Mozambique, Tanzania, Kenya	60	Conduct a full PRA and surveillance
<i>Phytoplasma oryzae</i>	Phytoplasma		Kenya	60	Conduct a full PRA and surveillance
<i>Magnaporthe oryzae</i> Triticum pathotype	Fungus		Zambia	60	Conduct a full PRA
<i>Xanthomonas oryzae</i> pv. <i>oryzicola</i>	Bacterium	Madagascar, Uganda, Kenya		50	Conduct a full PRA
<i>Pseudocercospora angolensis</i>	Fungus	Angola, Botswana, Comoros, DRC, Mozambique, Rwanda, Tanzania, Uganda, Zambia, Zimbabwe		50	Conduct a full PRA and surveillance
Wheat streak mosaic virus	Virus	Zambia		50	Conduct a full PRA

Note: PRA=pest risk analysis

Analysis (PRA), especially for organisms recorded in neighbouring countries (Table 1).

Supplementary material lists pathogenic species that were evaluated in total, that is, 8 bacteria, 3 phytoplasmas, 26 fungi, and 13 viruses. Sixty-two percent of harmful organisms were found in neighbouring countries (including SADC countries), compared to 38.77% of pathogenic species that were not found in the continent. These pathogens were highly unlikely to enter South Africa were very likely to establish themselves and have a significant socio-economic impact. The majority of organisms (73.46%) had a higher probability of arriving in South Africa as stowaways or contaminants than as commodities (26.53%), which was followed by those that could only arrive as contaminants.

While all viruses may enter South Africa as contaminants on commodities, all bacteria, fungi, and phytoplasmas were likely to come as commodities and stowaways. Regarding the likelihood of entry, the majority of pathogens had a medium probability of entry, while 36.73% had a lower probability of entering South Africa. Only 8.16% had a higher probability of entry. Most pathogens had a high likelihood of establishment in South Africa, whereas 20.40% had a medium probability of establishment in the country. Only 2.04% had a lower likelihood of establishing in the country. In contrast, 30.60% had a high potential socio-economic impact, whereas most pathogens had a medium potential of socio-economic impact. Only 12.24% had a lower potential of causing socio-economic impact. Regarding environmental impact, the majority of pathogens (83.66%) had a lower potential for causing ecological impact. In comparison, only

16.32% had a higher possibility of causing environmental impact after entry and establishment in the country, as suggested by the experts. The most suggested actions for the high scoring species were to survey their potential presence in South Africa, especially for species recorded in neighbouring countries and full PRAs (Table 2).

## Discussion

Horizon scanning is a methodical strategy for investigating new trends, problems, opportunities, threats, and events that can help scientists and policymakers take proactive measures (Sutherland and Woodroof 2009). This strategy is essential in integrated disease management (IDM) as it guides other pest and pathogen monitoring and surveillance activities. Invasion threats can be detected using horizon scanning, combining a data-driven strategy with quick risk assessment and/or expert consensus building (Kendig et al. 2022). Using information from CABI datasheets, a list of invasive species that are found in the continent and neighboring countries but absent from South Africa was generated. These "source areas" may be pertinent because they are close by, connected by trade or transit routes, or have similar climates to the area potentially at risk. Horizon scanning can support and influence local, state, and foreign decisions in terms of preparedness for potential threats due to emerging diseases (Sutherland et al. 2018). According to Branquart et al. (2016) and Vanderhoeven et al. (2015), impacts on crop production were evaluated following their dispersal potential

**Table 2** Possible pathways of entry into South Africa

Species	Taxonomic group	Pathways
Maize lethal necrosis disease	Virus	CO
<i>Candidatus Liberibacter asiaticus</i>	Bacterium	ST
<i>Candidatus Phytoplasma palmae</i>	Phytoplasma	ST
<i>Fusarium oxysporum f.sp. cubense</i> tropical race 4	Fungus	ST
Maize chlorotic mottle virus	Virus	CO
<i>Pseudocercospora angolensis</i>	Fungus	CO
Tomato leaf curl New Delhi virus	Virus	CO/ST
<i>Bipolaris victoriae</i>	Fungus	CO/ST
Cassava brown streak viruse	Virus	CO/ST
<i>Coniothyrium glycines</i>	Fungus	CO/ST
<i>Mycosphaerella fijiensis</i>	Fungus	CO
Cowpea mild mottle virus	Virus	CO/ST
Cucurbit aphid-borne yellows virus	Virus	CO/ST
<i>Phytoplasma oryzae</i>	Phytoplasma	CO/ST
<i>Magnaporthe oryzae</i> Triticum pathotype	Fungus	CO/ST
<i>Xanthomonas oryzae</i> pv. <i>oryzicola</i>	Bacterium	CO/ST
<i>Pseudocercospora angolensis</i>	Fungus	CO/ST
Wheat streak mosaic virus	Virus	CO/ST

Note: CO=commodity; ST=stowaway/hitchhiker

(signifying potential for spread), colonisation of habitats with high conservation values, negative impacts on native species (predation/herbivory, competition, transmission of pathogens and parasites to native species, genetic effects), and alteration of ecosystem functions (modification to nutrient cycling, physical modifications to the habitat, modifications of natural successions, disruption of food webs).

Similar approach was used by Kenis et al. (2022) who scanned the horizon for invasive alien species that were not yet recognized as being legally present in Ghana. They discovered that 64 pathogenic species had been evaluated using a streamlined pest risk assessment. Additionally, they found that two infections had not been identified on the African continent. There were 46 pathogenic species that have previously been identified in Togo, Côte d'Ivoire, and Burkina Faso, three neighboring countries. The primary recommendations made for species that received high scores were comprehensive pest risk assessments and, for species. However, in Kenya, Kenis et al. (2022), a total of 41 harmful species were evaluated, including 15 bacteria, 3 Chromista (water molds), 16 fungi, one viroid, and six viruses. The majority of pathogens (85%) were likely to enter commodities as contaminants, particularly if they were seed-borne diseases.

Additionally, 68% of pathogens that may be transported in soil or by a vector (virus and viroid) were likely to arrive as stowaways. According to Roy et al. (2014b), ten important areas require further study and intervention. These include the introduction and establishment of alien pathogens as well as the forecasting of their spread and subsequent effects on native biota and ecosystems. To address the knowledge gaps in this case, it was thought that multidisciplinary capability, coordination, and expertise development were essential for identifying and managing threats. To identify high-risk Invasive non-native species (INNS) across the United Kingdom Overseas Territories (OTs), taking into account the possibility of introduction, establishment, and impacts on biodiversity and ecosystem function, economies, and human health, Dawson et al. (2022) used horizon scanning for potential invasive non-native species throughout the OTs. They also identified the introduction pathways that pose the highest risk of introducing INNS to the territories. The analysis discovered that shipping containers, which were linked to the greatest number of species. Other isolated islands and archipelagos can use the same high-risk species and pathways found as a roadmap to concentrate their ongoing biosecurity and surveillance efforts in order to stop further intrusions. Global shifts in food production, distribution, and consumption have raised the danger of pest and pathogen introduction. Food supplies are anticipated to be more scarce due to climate change, creating new, favourable environments for invading diseases and pests. Human population displacement brought on by political, economic, and humanitarian

crises is another possible cause of new problems (Richardson et al. 2016).

A significant threat to biodiversity, ecosystem services, local economy, and public health comes from invasive alien species invasions. Currently, invasive alien species are present in most major taxonomic groupings, occur in many ecosystems, and are introduced both accidentally and on purpose for cultivation. For example, *Fusarium oxysporum* f. sp. *cubense* (Foc R4) (Hypocreales: Nectriaceae) is a soil-borne fungus that is difficult to control (Yuan et al. 2012). This pathogen is regarded as a quarantine pest for bananas (*Musa* spp.) in South Africa and is regulated in terms of the Agricultural Pests Act, 1983 (Act No.36 of 1983) (Table 3). Although Foc R4 was originally identified in Australia in 1876, before 1960 it primarily affected export plantations in the western tropics. The current spread of this disease in Asia poses a severe danger to Cavendish banana growers (Molina et al. 2007). Dita et al. (2014) recommended that countries free of Foc TR4 should apply preventative phytosanitary measures to prohibit the risk of entry- of infected plants from the countries where the Foc TR4 stain is present. The most effective disease management strategy is to employ pathogen-free planting material in combination with disease-free soils (Ploetz 2006).

A highly contagious viral maize disease, known as Maize lethal necrosis disease (MLN), has been reported in eastern Africa and is a significant threat to the countries' maize-based agri-food systems, with losses expected to reach US\$261 million in Ethiopia and US\$198 million in Kenya (Marenja et al. 2018). Maize lethal necrosis disease was first identified in Kenya in 2010 and has since expanded to nearby countries. Maize chlorotic mottle virus (MCMV) and Sugarcane mosaic virus (SCMV) were discovered to interact synergistically to cause MLND in eastern Africa (Gowda et al. 2015; Mbenga et al. 2016). From seedling to maturity, maize plants are vulnerable to MLND at every stage of growth, causing chlorotic mottling of the leaves, necrosis developing from the leaf margin to the midrib, and a dead heart are the diagnostic signs of MLND (Gowda et al. 2015). Later stages of infection may result in sterile pollen, small cobs with weak seed sets, or plant mortality. All the countries in eastern Africa and most of those in sub-Saharan Africa are currently under threat due to MLN disease (Lukanda et al. 2014; Gowda et al. 2015). The disease was also recorded in Uganda, the Democratic Republic of the Congo, Tanzania, Uganda, South Sudan, and Rwanda (Adams et al. 2014; Lukanda et al. 2014). In South Africa, MLND has been listed as a quarantine pest for maize and it is not known to occur within the country. The presence of maize thrips (*Frankliniella williamsi*), numerous crops of maize per year, and maize crops that are particularly susceptible are all factors that contribute to MLN disease emergence (Redinbaugh and Stewart 2018). Isabirye and

**Table 3** Regulated pathogens under official control in South Africa, in terms of the Agricultural Pests Act, 1983 (Act No.36 of 1983)

Scientific name	Common name	Regulatory year	Occurrence in South Africa
Banana bunchy top virus	Bunchy top of banana	2017	Yes*
<i>Cacosceles newmannii</i> (Thomson)	Longhorn beetle	2022	Yes*
<i>Candidatus Phytoplasma asteris</i>	Aster yellows phytoplasmas	2009	Yes*
<i>Clavibacter michiganensis</i> subsp. <i>michiganensis</i> (Smith 1910; Davis et al. 1984)	Bacterial canker of tomato	2022	No
<i>Fusarium oxysporum</i> f. <i>cabense</i> (TR4)	Panama disease of banana	2022	No
<i>Liberibacter africanus</i> (Garnier et al. 2000)	Citrus greening (African strain)	1984	Yes*
<i>Liberibacter asiaticus</i> (Jagoueix et al. 1994)	Citrus greening (Asian strain)	2014	No
Pepper ringspot virus	Pepper ringspot virus	2022	Yes*
<i>Phyllosticta citricarpa</i> Kiely	Citrus black spot	2002	Yes*
Potato spindle tuber viroid	Spindle tuber of potato	2022	No
<i>Ralstonia solanacearum</i>	Bacterial wilt	1984	Yes*
Sugarcane fiji disease fijivirus	Fiji disease of sugarcane	2021	No
Sugarcane white leaf phytoplasma	White leaf disease of sugarcane	2021	No
<i>Synchytrium endobioticum</i> (Schilb.) Percival	Wart disease of potatoes	1984	No
<i>Tilletia indica</i> Mitra	Karnal bunt of wheat	2001	Yes*
<i>Xylophilus ampelinus</i> (Panagopoulos 1969)	Bacterial blight	2009	Yes*

NB: Yes\*= not in all areas

Rwomushana (2016) also indicated that the warm arid, semi-arid, and sub-humid tropics of eastern and southern Africa are at risk of the potential distribution of this disease.

Citrus greening or huanglongbing caused by *Candidatus Liberibacter asiaticus* is a serious bacterial disease of citrus (Kim and Wang 2009; Hu et al. 2021). The citrus psyllid species *Diaphorina citri* and *Trioza erytreae*, which feed on the phloem, are the vectors of Citrus greening (Fan et al. 2010). *Diaphorina citri* is the most proficient vector of citrus greening disease caused by *Candidatus Liberibacter asiaticus* (Tsai and Liu 2000). *Diaphorina citri* has never been reported in South Africa. Because the citrus psyllid is a sucking insect, it feeds by inserting its mouthparts into plant tissue (Tayyab et al. 2022). *Candidatus Liberibacter africanus* has been introduced to the Caribbean, West Indies, North and Central America. The African strain has been reported in Limpopo, Gauteng, North West, Free State, Northern Cape, Mpumalanga, KwaZulu-Natal and other parts of the Western Cape. The Eastern Cape is the only province where African strain is not reported or declared in the legislation in South Africa (Garnier et al. 2000; Pietersen et al. 2010). In South Africa, both *Candidatus Liberibacter asiaticus* and *Candidatus Liberibacter africanus* are regarded as quarantine pests for citrus (*Citrus* spp.) planting and are regulated in terms of the Agricultural Pests Act, 1983 (Act No.36 of 1983) (Table 3). For many years, citrus greening has been endemic in many Asian citrus growing regions (Manjunath et al. 2008). Citrus orchards with the disease are typically destroyed or rendered unproductive in 5 to 8

years (Li et al. 2009). Citrus greening is difficult to control, and infected groves become economically unviable 7 to 10 years after severe symptoms start (Schneider et al. 2005); it is regarded as the citrus disease that causes the most severe global damage.

Maize chlorotic mottle virus (MCMV) causes serious disease in maize (*Zea mays* L.). This virus was originally identified in maize in Peru and the United States (Xie et al. 2011). In South Africa, MCMV are regarded as quarantine pests for maize (*Zea mays*). Six species of chrysomelid beetles, including the cereal leaf beetle (*Oulema melanopa*), the corn flea beetle (*Chaetocnema pulicaria*), the flea beetle (*Systema frontalis*), the southern corn rootworm (*Diabrotica undecimpunctata*), the northern corn rootworm (*D. longicornis*), and the western corn rootworm (*D. virgifera*), transmit the MCMV (Nault et al. 1978). There have been reports of the MCMV in corn from Kenya, Rwanda, Tanzania, and Uganda (Lukanda et al. 2014). Corn plants with MCMV infection exhibit stunted development and chlorotic mottling on leaves (Cabanas et al. 2013).

Citrus Phaeoramularia foliage and fruit spot disease, a fungal disease caused by *Pseudocercospora angolensis*, first appeared in 1952 in Angola and Mozambique (De Carvalho and Mendes 1953). Citrus plants with pseudocercospora leaf and fruit spot disease can lose up to 100% of their production (Yesuf 2013). *Pseudocercospora angolensis* is listed on phytosanitary import requirements for Citrus (*Citrus* spp.) as a pest of quarantine significance to South Africa. The disease's most significant effects are the premature

abscission of young fruit and leaves and the development of fruit lesions that make the fruit unmarketable (Harling et al. 2010). About 22 African countries have a high prevalence of *P. angolensis*, severely hindering citrus output in tropical Africa, especially in Sub-Saharan Africa (Yesuf 2013). All citrus species' fruits and twigs are susceptible to varying degrees.

In East African coastal regions, Cassava brown streak disease (CBSD) is presently regarded as the most destructive viral disease. The disease was first discovered in all areas where the crop is grown. It was reported from Kenya and Mozambique, in 1936 from Tanzania and in 1950 from Malawi (Winter et al. 2010). In South Africa, CBSD is listed as a quarantine pest for cassava (*Manihot* sp.). The earliest accounts identified CBSD as a virus disease spread by a whitefly vector and through infected cuttings (Bigirimana et al. 2011). In 2004, a significant CBSD outbreak near Kampala quickly expanded throughout Uganda (Alicai et al. 2019). Similar CBSD outbreaks were reported in several eastern and central African countries in the years that followed, and the disease is currently a threat to West Africa. According to recent estimates, CBSD costs could reach up to \$100 million yearly in economic losses (Mohammed et al. 2012). In cassava, CBSD symptoms include leaf chlorosis, which frequently has a distinctive feathering pattern along the veins, and stem necrosis in cases of serious infection (Maruthi et al. 2005). The disease's primary effect on the product is the development of root necrosis (Hillocks et al. 2001).

Dry bean bacterial wilt and tan spots are caused by *Curtobacterium flaccumfaciens* pv. and is a serious emerging disease that poses a danger to the global edible legume industry (Osdaghi et al. 2020). *Curtobacterium flaccumfaciens* pv. *flaccumfaciens* is a quarantine pest for South Africa, listed on phytosanitary import requirements for common beans (*Phaseolus vulgaris* L.). It was first identified as the cause of bacterial wilt on common beans in the state of South Dakota (USA) in 1920. Since then, it has been found in various geographic locations around the globe, including parts of East and South Europe, Africa, Australia, Asia, North and South America (Soares et al. 2013). Common beans are susceptible to *C. flaccumfaciens* pv. *flaccumfaciens*, causes yellowing, wilting, vascular browning, and death of the shoots (Júnior et al. 2012). The pathogen color variants of *C. flaccumfaciens* pv. *flaccumfaciens* are varied both phenotypically and genotypically (Agarkova et al. 2012).

Wheat streak mosaic virus (WSMV) is a disease of grains and grasses that threatens the world's wheat production. The WSMV causes it (Singh et al. 2018). WSMV is the type strain of the *Tritimovirus* genus in the Potyviridae family (Tatineni et al. 2010). The yield loss due to *Wheat streak mosaic virus* infections can exceed 60%, depending on the weather (wet, dry, chilly, or hot). *Aceria tosichella*, a wheat

curl mite, is a vector of the wheat streak mosaic virus (Hadi et al. 2011). Wheat streak mosaic virus is regarded as a quarantine pest on *Zea mays* for export to South Africa.

The Pepper ring spot virus (PepRSV) has been discovered to infect potato crops in South Africa within the past four years (Esterhuizen 2020). The PepRSV only has reports from Brazil as far, infecting weed species including as tomatoes, peppers, artichokes, and Bidens. In 2023 PepRSV was discovered in a number of production regions, including the Northern Cape, KwaZulu-Natal, North West, and Limpopo (Uys and Esterhuizen 2024). In South Africa it is regulated in terms of the Agricultural Pests Act, 1983 (Act No.36 of 1983) (Table 3).

Potential invasive pests that are probably not yet present in South Africa but already in neighbouring countries or spreading fast on the African continent may require the implementation of surveillance programmes, which could either be based on visual surveys or trapping campaigns. Numerous activities are supported by surveillance, such as: early detection of newly arrived pests; establishment and maintenance of pest-free zones, pest-free places of production, pest-free production sites, or areas of low pest prevalence; reporting pest activity to foreign countries; measuring changes in the characteristics of a pest population or pest incidence (for example, for areas of low pest prevalence or for research); delimiting a pest population in an area; eradication and pest management; etc.

The horizon-scanning may be used to establish a quarantine pests list that could be applied on a South African scale. For species that are unquestionably, high-risk pests necessitate quarantine measures that can only be supported by comprehensive PRAs completed in accordance with international standards, pest risk analyses may also be necessary. Using biological or other scientific and economic data, pest risk analysis assesses the likelihood of a pest's entry and spread as well as the potential of its economic impact in South Africa. This can be done to identify pests and/or pathways of quarantine concern and evaluate their risk, identify endangered areas, and, if needed, identify risk management strategies for identified possible pathogens of quarantine significance. It may also be necessary to conduct pest risk analyses for species that are unquestionably high-risk pests. Any pests not on the quarantine pests list would require pest risk analysis before importing any host material to South Africa.

The study revealed the top priority pests using the combination of horizon scanning and expert elicitation approach. This will help inform South Africa to allocate resources to high-priority pests and diseases and ensure that contingency plans and response strategies are developed to effectively deal with potential pathogen incursions. Horizon scanning is an essential tool in integrated disease management (IDM) as it complements other disease monitoring and surveillance

activities. Staying ahead of potential threats allows for a more proactive and timely response, e.g. border control, reducing the risk of large-scale pathogen outbreaks and their associated impacts. This research can be used as a guide for upcoming initiatives on prioritising plant pathogens, especially in the neighbouring states. It could be used to evaluate the threat posed by invasive plant pests in any nation or neighbouring states. The current study can serve as a model for future projects on plant pathogen prioritisation in Africa and elsewhere.

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## Declarations

**Conflict of interest** None.

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