frontiers in Agronomy

TYPE Original Research
PUBLISHED 04 September 2026
DOI 10.3389/fagro.2026.1897049

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OPEN ACCESS

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RECEIVED 01 June 2026
REVISED 28 July 2026
ACCEPTED 18 August 2026
PUBLISHED 04 September 2026

CITATION
Mulema J, Uzayisenga B, Hakizamungu L, Waweru B, Murekeyimana P, Bahunde E, Mutumwinka M, Ingabire P, Berababyeyi C, Nzaire P, Mutoni T, Masereri SA, Harerimana JC, Habanabakize T, Gasumba E, Rurangwa L, Nambazimana A, Mukeshimana B, Mukamana D, Bigirimana VdP, Ocheing V, Tuyishime O, Hategekimana A, Umugwaneza AN, Hakirumurame S, Oronje M, Karanja D, Akiri M, Onkendi E, Ochillo W, Uwamahoro F, Mbabazi A, Rwomushana I, Niragire I and Hagumimana P (2026) Assessing the threat: risk assessment of non-native plant pests likely to threaten livelihoods if introduced in Rwanda. *Front. Agron.* 8:1897049. doi: 10.3389/fagro.2026.1897049

Assessing the threat: risk assessment of non-native plant pests likely to threaten livelihoods if introduced in Rwanda

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The lack of information on potential invasions by alien species is a major contributor to the prevalence of invasions in sub-Saharan Africa. A rapid risk assessment was conducted to prioritise high-risk species not yet reported in Rwanda that could be introduced and become invasive. The CABI Horizon Scanning Tool identified 9,155 species (including 641 invasive species) that have not yet been reported in Rwanda but are present in other likely trading countries. The 9,155 species comprised 5,860 arthropods, 319 bacteria, 174 chromists, 1,762 fungi, 34 molluscs, 261 nematodes, 10 protists, 33 viroids, and 712 viruses. The 9,155 species were reduced to 1,972 (392 arthropods, 147 bacteria, 79 chromists, 784 fungi, 21 molluscs, 134 nematodes, nine protists, 18 viroids, and 388 viruses) identified as affecting major crops grown in Rwanda. An additional 127, which included 14 from the list of regulated pests, four deemed of phytosanitary concern, 18 identified in other risk assessment studies, and species vectored by (14) or vectors (77) of assessed species were added, raising the total to 2,099. Of the 2,099, 1,081 were reported outside Africa and 1,018 within Africa, with 381 reported in a neighbouring country. The 2,099 (including 212 reported invasives) comprised 468 arthropods, 152 bacteria (including 24 phytoplasmas), 79 chromists, 810 fungi, 21 molluscs, 136 nematodes, four plants, nine protists, 18 viroids, and 402 viruses. The highest risk score was 175, recorded for 185 species, and the lowest was two, recorded for 22 species. The assessed species could be introduced as contaminants (1,385), stowaways (211), or via multiple pathways (503). A no-action management option was suggested for 1,270 species, surveillance for 356, and regulation for 563 (521 quarantine and 42 regulated non-quarantine). Additional actions included developing a contingency plan, conducting publicity, managing the pest by industry, and conducting research, which were suggested for 18, 21, 4, and 20, respectively. This study proposes a new list of regulated pests and also aligns Rwanda with Target 6 of the Kunming-Montreal Global Biodiversity Framework, which aims to reduce the impacts of IAS on biodiversity and ecosystem services.

KEYWORDS

horizon scanning, invasive alien species, pest identification, pest risk analysis, pest risk management

Introduction

Agriculture, forestry, and biodiversity worldwide are increasingly threatened by non-native species that become invasive (hereafter referred to as invasive alien species, or IAS[1]) (Mota et al., 2009; Rossman, 2009, Youm et al., 2011; Graziosi et al., 2020). The economic costs of IAS to agriculture are estimated to amount to billions of United States Dollars, primarily due to reduced yields, lower product quality, increased management expenses, and loss of trade, particularly for IAS listed as pests[2] regulated[3] as quarantine[4] in trading partner regions (Margolis et al., 2005; EFSA et al., 2017; Bradshaw et al., 2024; Yaméogo et al., 2024). Invasive alien species have also significantly affected the forestry industry. For instance, the cypress aphid (*Cinara cupressi*) significantly affected the Mexican cypress (*Cupressus lusitanica*) industry in Eastern and South Africa. First recorded in Malawi in 1986, it was subsequently detected in Tanzania, Burundi, Rwanda, Kenya, Uganda, the Democratic Republic of the Congo, Zimbabwe, South Africa and Ethiopia (Obiri et al., 1994; Ciesla et al., 1995; Demeke, 2020). Other IAS recorded to affect the forestry industry in Africa include pine woolly aphid (*Pineus boerneri*), pine needle aphid (*Eulachnus rileyi*), and sirex woodwasp (*Sirex noctilio*) (Odendaal, 1980; Blackman et al., 1995; Hurley et al., 2012). Economic costs include reduced forest productivity, increased management costs, and damage to ecosystem services, all of which affect the value and supply of forest products (Vilà and Hulme, 2017; Rawat et al., 2024; Bradshaw et al., 2024). The impact of IAS on biodiversity cannot be overstated, as evidenced by habitat loss and degradation (Kumar Rai and Singh, 2020; Singini and Baso, 2025). Invasive species outcompete native species for resources, modify the physical and chemical properties of the environment, and displace native species (Seabloom et al., 2003; Michelan et al., 2018). A report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) highlights IAS as one of the five drivers of ecosystem biodiversity loss (Jaureguiberry et al., 2022; Hulme et al., 2023).

Rwanda has also experienced similar global impacts of IAS, which have severely affected agriculture, forestry, and biodiversity, ultimately harming livelihoods and the economy (Uzayisenga et al., 2018; Niragire et al., 2020; Azrag et al., 2023; Gaidashova et al., 2025). Agriculture is vital to the economy, contributing approximately 27% of Gross Domestic Product and accounting for 37% of foreign exchange earnings from exports (RDB, 2025). To promote economic development, improve agricultural productivity, strengthen food security, and enhance livelihoods, the Government of Rwanda (GoR) has prioritised the commercialisation of staple crops through land consolidation under the Crop Intensification Programme (CIP), with a focus on 10 strategic agricultural value chains. These value chains include Arabica coffee (*Coffea arabica*), avocado (*Persea americana*), beans (*Phaseolus vulgaris*), cassava (*Manihot esculenta*), maize (*Zea mays*), potato (*Solanum tuberosum*), rice (*Oryza sativa*), soybeans (*Glycine max*), tea (*Camellia sinensis*), and wheat (*Triticum aestivum*) (Nsabimana et al., 2021; Kim et al., 2022).

However, many of these value chains have been affected by the introduction of IAS, which, in phytosanitary terms, could be considered pests and should therefore have been regulated prior to introduction as quarantine pests to limit their introduction and spread. Some of the IAS that have devastated agriculture and livelihoods in Rwanda include maize lethal necrosis disease (MLND) reported in 2014 (Adams et al., 2014); tomato leaf miner (*Pthorimaea absoluta*), reported in 2015 (Ndereyimana et al., 2019); fall armyworm (*Spodoptera frugiperda*), reported in 2018 (Uzayisenga et al., 2018); and potato cyst nematodes (*Globodera rostochiensis*), reported in 2020 (Niragire et al., 2020). The MLND is mainly caused by co-infection with maize chlorotic mottle virus (MCMoV) and one of the cereal viruses from the

1 Invasive alien species (IAS) is any plant, animal, pathogen, or organism introduced by human action (either accidentally or intentionally) outside its natural, native range (CBD 2002).

2 A pest is defined as any species, strain, or biotype of plant, animal, or pathogenic agent injurious to plants or plant products (IPPC Secretariat, 2021).

3 A regulated pest is a quarantine pest or a regulated non-quarantine pest (IPPC Secretariat, 2021).

4 A quarantine pest is a pest of potential economic importance to the area that is endangered, and is either not yet present there, or present but not widely distributed and subject to official control (IPPC Secretariat, 2021).

Potyviridae family, such as *Johnsongrass mosaic virus*, *maize dwarf mosaic virus*, *sugarcane mosaic virus*, or *wheat streak mosaic* virus (Louie, 1980; Adams et al., 2013; Stewart et al., 2017). The MCMoV was first reported in South America (Braidwood et al., 2018) but has since been reported in other countries, such as China (Xie et al., 2011), Kenya (Wangai et al., 2012), where it was first reported in sub-Saharan Africa (SSA), and Uganda (Kagoda et al., 2016).

The most cost-effective management approach is to prevent the introduction and spread of IAS (Blackburn et al., 2014; Vilà and Hulme, 2017). This requires an efficient border biosecurity system to limit human-mediated pathways of entry and an effective early detection and rapid response (EDRR) mechanism to eradicate or contain introduced IAS (Reaser et al., 2020; Black and Bartlett, 2020). The increase in the prevalence of IAS across most of SSA could be attributed to porous borders, coupled with a lack of regulations or poor enforcement of existing regulations, resulting in inadequate border biosecurity, insufficient capacity to prevent IAS incursions, and limited information on high-risk IAS (Hulme et al., 2018; Mulema et al., 2022). However, while it may be unrealistic to rely solely on border biosecurity to prevent the introduction and spread of IAS in SSA, the situation could be improved by ensuring the availability and timely sharing of sufficient information at both national and regional levels regarding high-risk species. One approach to generating information on high-priority, high-risk IAS is horizon scanning (Peyton et al., 2019, 2020, Dobrzycka-Krahel and Medina-Villar, 2023).

Horizon scanning is a strategic process of systematically examining and prioritising potential future IAS threats based on their socio-economic impacts and effects on biodiversity (Sutherland et al., 2008, 2010a, 2010b, Roy et al., 2014). It is a proactive approach to IAS management that uses scientific data and expert opinion to compile lists of potential invaders and their pathways of introduction. This information can be used to restrict pathways by reducing entry and spread, intercepting movements at border points, and assessing the risk of planned imports. By prioritising risks and guiding biosecurity efforts, it helps governments and organisations develop preventive measures at national and regional levels, inform policy and practice, and develop early detection systems and contingency plans (Caffrey et al., 2014; Turner et al., 2024). In this study, horizon scanning was utilised to i) prioritise high-risk species not yet reported in Rwanda but could be introduced and become invasive; ii) analyse and update the list of regulated pests for Rwanda following the prioritisation process of high-risk species.

The approach has been utilised to achieve the first objective at national and regional levels (Weber and Gut, 2004; Sutherland et al., 2008; Gassó et al., 2009; Roy et al., 2014, 2019, Gallardo et al., 2016; Kenis et al., 2022; Mulema et al., 2022, 2024, 2025b, 2025a). The approach has been utilised in Burundi to achieve the second objective (analyse and update the list of regulated pests), resulting in the development of a new list of regulated pests (Mulema et al., 2025b). Horizon scanning was previously conducted through an extensive literature review by a panel of experts, who compiled information on potential high-risk species in a specific geographical or political region, followed by risk assessment to prioritise high-risk species for management (Weber and Gut, 2004; Sutherland et al., 2008; Gassó et al., 2009, Bayón and Vilà, 2019).

In this study, the Horizon Scanning Tool (HST) developed by CABI was utilised. The HST is used to generate a list of potential non-native pest species reported in a geographic jurisdiction (Country or Regional Economic Block) with which the area at risk may trade with but that are currently reported as absent. This tool, which is accessible through the CABI Compendium, is part of the CABI Digital Library. The HST utilises data present in the Compendium (https://www.cabi.org/HorizonScanningTool) to generate a list of species that are reported as not present (known not to occur) in a selected "area at risk" but are reported from "source areas", which are geographic regions with similar climates, neighbouring territories, or selected trading partners. It is important to note that the lack of a report indicating presence does not confirm absence, as this may result from gaps in reporting. The HST has previously been used to prioritise non-native pest species for which actions to prevent introduction and spread in Burundi (Mulema et al., 2025b), Ghana (Kenis et al., 2022), Kenya (Mulema et al., 2022), Uganda (Mulema et al., 2025a), the United States (Kendig et al., 2022; Lieurance et al., 2023), and Zambia (Mulema et al., 2024).

Materials and methods

Selection of non-native plant pest species

The premium version of the HST was used to compile a preliminary list of plant pests not yet reported in Rwanda. The HST parameters included specifying the area at risk (Rwanda) and selecting regions from which non-native pest species were likely to be introduced ("source areas"). The source areas included all geographical regions in Africa (excluding Rwanda), Asia, Europe, North America, Oceania, and South America. All parameters, except the organism type, were not modified. The considered pest organisms included arthropods, bacteria (including phytoplasmas), chromists, fungi, molluscs, protists, plant-parasitic nematodes, and viruses (including viroids). Following the scan, the list was exported as an Excel (.xlsx) file for further analysis.

The assessment workshops

The horizon scanning process was conducted in two workshops. The first workshop was held in Musanze, Rwanda, from 11th to 15th December 2023, and the second in Kigali, Rwanda, from 19th to 22nd November 2024. The team of 24 Subject Matter Experts (SMEs) drawn from Rwanda Agriculture and Animal Resources Development Board (RAB), Huye Rwanda; Rwanda Inspectorate, Competition and Consumer Protection Authority (RICA), the National Plant Protection Organisation (NPPO[5]) of Rwanda headquartered in Kigali; and University of Rwanda (UR), Kigali, Rwanda comprised experts in acarology, bacteriology, entomology, malacology, mycology, nematology, and virology. The assessment team

5 A national Plant Protection Organisation (NPPO) is an official service established by government to protect plant resources and discharge other functions specified by ARTICLE IV.2 of the IPPC.

was trained to utilise the HST to generate a list of pests not reported in the "area at risk," which, in this case, was Rwanda and other areas with which Rwanda may trade. This was conducted on the first day of the first workshop (held in Musanze).

Assessment of prioritised pest species

Following the HST training, the assessment team was also trained to conduct a rapid risk assessment. Assessment groups were formed according to the areas of expertise indicated above. The bacteriology group assessed bacteria, phytoplasmas, and protists; the mycology group assessed chromista and fungi; the entomology group assessed arachnids and insects; the nematology group assessed nematodes and molluscs; and the virology group assessed viroids and viruses.

Description of the scoring system

The rapid risk assessment was conducted using risk-scoring guidelines based on the framework outlined by Roy et al. (2019), which were later adapted by Kenis et al. (2022) and Mulema et al. (2022). Roy et al. (2019) evaluated the likelihood of introduction (entry), establishment, spread, and potential negative impacts on biodiversity and ecosystem services. However, this study focused on the possibility of introduction (entry), establishment (including spread), and potential socio-economic and environmental (biodiversity) impacts. A five-point scoring system was employed for the four parameters: entry, establishment, socio-economic impact, and environmental impact. The guidelines are also provided in Supplementary Material S1.

Assessment of the likelihood of entry

A score of one indicated that the organism was absent from Africa and unlikely to be found in an imported commodity; two indicated absence from Africa but likely to be infrequently imported on a commodity; three was ascribed to three scenarios: either present in Africa (excluding neighbouring countries to Rwanda) and spreading slowly; or absent from Africa but demonstrated to spread very quickly across several continents, or often associated with a commodity that is commonly imported, or frequently intercepted in Rwanda; four, indicated presence in Africa (excluding neighbouring countries) with rapid spread, or presence in a neighbouring country with slow spread; and five, indicated presence in a neighbouring country rapid spreads. Countries neighbouring Rwanda included Burundi, DR Congo, and Tanzania. The global pest distribution data were obtained from the CABI Compendium, European and Mediterranean Plant Protection Organisation (EPPO), and the Global Biodiversity Information Facility (GBIF).

Assessment of the pathways for introduction

Hulme et al. (2008) identified three mechanisms and their pathways through which an alien species might enter new geographical or political areas. These mechanisms include the importation of a commodity (via three pathways: contaminant, escape, and release), the arrival of a transport vector (through one pathway: stowaway), and natural spread from a neighbouring region (via two pathways: corridor and unaided). The contaminant pathway involves organisms unintentionally introduced with traded commodities, such as obligate pathogens, parasites, and commensals of traded plants and animals. The escape pathway covers organisms intentionally introduced that accidentally escape, such as feral crops, livestock, pets, garden plants, and live bait. The release pathway primarily involves the deliberate release of organisms, such as biocontrol agents, game animals, and landscape plants. Generally, only the contaminant pathway is considered in risk assessments, as comprehensive evaluations are typically conducted only for organisms intentionally introduced into countries or regions. The stowaway pathway, also examined in this assessment, refers to organisms unintentionally introduced when they are attached to or within a transport vector, such as a mollusc. The corridor pathway involves organisms unintentionally introduced through human infrastructure development, thereby connecting previously unlinked regions. This pathway was not considered because it generally does not apply to most pests. Finally, the unaided pathway includes organisms introduced via natural dispersal across political borders. Examples include flying insects, pollen, spores, and soil contaminated with pathogenic microorganisms, which wind currents may carry. Therefore, the contaminant, stowaway, and unaided pathways were included in this study because they are more relevant to the introduction, establishment and spread of pests.

Assessment of the likelihood of establishment

A score of one indicated that Rwanda was climatically unsuitable or that host plants were absent; two, that only a few areas in Rwanda were climatically suitable, or host plants were rare; three, that large regions of in Rwanda were climatically suitable, whilst host plants were rare; or that only a few areas in Rwanda were climatically suitable, but host plants were at least moderately abundant; four, that large regions of Rwanda were climatically suitable, but host plants were moderately abundant; and five, that large areas in Rwanda were climatically suitable, whilst host plants were very abundant. To ensure consistency in assessing the capacity for establishment, the SMEs weighted the likely hosts grown in Rwanda.

Assessment of potential socio-economic impact

A score of one indicated that the alien species did not attack plants that were cultivated or utilised; a score of two signified that the alien species damaged plants that were only occasionally cultivated or utilised; a score of three denoted that the alien species damaged plants that were regularly cultivated or utilised, but without threatening the cultivation, utilisation, or trade of this crop; a score of four meant that the alien species had the potential to threaten, at least locally, the cultivation of a plant that was regularly cultivated or utilised, or to periodically attack a crop that was key to the economy of Rwanda without posing a threat to the latter; and a score of five indicated that the alien species had the potential to threaten, at least locally, a crop that was essential to the economy of Rwanda.

Assessment of potential impact on the environment

A score of one indicated that the alien species would not affect any native species; two meant the alien species would impact individuals of a native species without affecting its population level; three signified that the alien species had the potential to reduce the population levels of a native species; four implied that the alien species could eradicate a native species locally or affect populations of a protected or one species; and five denoted that the alien species possessed the potential to eliminate a native species or to locally eradicate keystone species. Native species in this context include animals, plants, and other organisms, including pathogens.

Scoring of the prioritised pest species

The scores for each species attribute were thoroughly discussed, and any discrepancies were resolved until a consensus was reached, after which the final score was confirmed. As detailed in Blackburn et al. (2014), low-, medium-, and high-confidence ratings were provided for each of the four assessed attributes, the likely pathway of arrival (introduction), and the overall risk score. The vectors and vector-borne pathogens of prioritised pests were also evaluated.

Determining risk

Suppose the likelihood of entry is assigned a letter A, the likelihood of establishment is assigned B, the magnitude of socio-economic impact is assigned C, and the magnitude of impact on biodiversity is assigned D. The overall risk score is calculated using the following formula.

$$\text{Overall risk} = A \times B \times (C + D)$$

The highest expected score was 250, while the lowest was two.

Actions for management

An overall score of 54 was established as the threshold for recommending management actions. This score was selected because it can be reached only by species with a score of three across all assessable attributes, or by those exceeding three in at least three parameters. A score of three or higher indicates a greater likelihood of entry, establishment, and significant impact (socio-economic or biodiversity). Scores below three are considered low risk, as they suggest a reduced likelihood of entry, establishment, and impact; a score of three is deemed moderate, while scores above three (four and five) indicate an increased likelihood of entry, establishment, and impact (in contrast to scores of one and two). A no-action approach was recommended for species with an overall risk score below 54. Conversely, a management action was recommended for all pests with an overall risk score above 54. The suggested measures included pest detection surveillance for pests reported in a neighbouring country to determine pest status in Rwanda; regulation; contingency planning for preparedness; raising awareness; industry-led management (relevant value chain system); and research.

Detection surveillance was also considered if the assessment team confirmed a prior interception or if a pest frequently affects a host commodity imported from a country where the pest is endemic. Pest Risk Analysis (PRA) is essential for providing guidelines to manage pathways and limit the probability of the introduction and spread of a quarantine pest, along with its associated potential economic consequences. However, action was deemed necessary for particular species with an overall risk score below 54. These include species currently regarded by trading partners, such as the European Union (EU), as high-risk A1 or A2 quarantine pests, including subspecies of *Xylella fastidiosa*. The European and Mediterranean Plant Protection Organisation (EPPO) maintains the official EPPO A1 and A2 lists of pests recommended for regulation as quarantine pests in the EU, a key trading block for many countries in SSA, including Rwanda. These lists are updated annually based on PRA to safeguard agriculture, forestry, and plant health. Conversely, a no-action recommendation was made for some species with an overall risk score above 54, where the primary pathway of introduction was considered unlikely. This group includes pests transmitted by vectors rather than through seed (seed-borne or seed-transmitted), although the vectors were unlikely to have been introduced alongside a viable pathogen. Other species in this category include soil-borne pests unlikely to accompany the commodity, such as soil-borne fungi that are not seed-transmitted. Furthermore, a no-action recommendation was suggested when insufficient information was available to assess a particular species or its vectors, or to assess a pest vectored by a species already reported in Rwanda.

Results

Analysis of the horizon scanning output

Pests not yet reported in Rwanda ('area at risk') but present in other countries, from which Rwanda may source ("source areas") commodities (including plants, plant products, or other articles being moved for trade or other purpose), and could affect biodiversity as well as crop and forest productivity if introduced to Rwanda, were identified by the HST. The tool found 9,417 species comprising 6,030 arthropods, 338 bacteria (including 49 phytoplasmas), 179 chromista (oomycetes), 1,811 fungi, 34 molluscs, 280 nematodes, 10 protists, 33 viroids, and 712 viruses (Data not included). This initial list was filtered to include only species with complete names, resulting in 9,155 species: 5,860 arthropods, 319 bacteria (including 48 phytoplasmas), 174 chromists, 1,762 fungi, 34 molluscs, 261 nematodes, 10 protists, 33 viroids, and 712 viruses. The 641 reported as invasive comprised 506 arthropods, 48 bacteria (including 13 phytoplasma), 14 chromista, 107 fungi, 16 molluscs, 42 nematodes, two viroids, and 39 viruses. All data is presented in Supplementary Material S2 (Sheet: Horizon scanning data).

The 9,155 species were further evaluated to identify only those affecting major crops grown in Rwanda. This resulted in 1,972 species, comprising 392 arthropods, 147 bacteria (including 24 phytoplasmas), 79 chromists, 784 fungi, 21 molluscs, 134 nematodes, nine protists, 18 viroids, and 388 viruses (Table 1). This data is detailed in Supplementary Material S2 (Sheet: HS selected species). The 1,972 species which were subjected to rapid risk assessment included 211 species reported as invasive. They included 92 arthropods, 22 bacteria (including 24 phytoplasmas), five chromists, 39 fungi, nine molluscs, 22 nematodes, and 22 viruses (Table 1). This data is detailed in Supplementary Material S2 (Sheet: HS selected species).

Analysis of pests on the regulated list

One significant outcome of rapid risk assessment of pest species is either the development of a new list of regulated pests or the updating of an existing list, especially the quarantine pest section in both cases. The list of regulated pests comprises both the quarantine pests and the regulated non-quarantine pests (RNQPs). The current list of regulated pests for Rwanda, last revised in April 2022, comprises 255 pest species. These can be categorised into 241 quarantine pests (95%) and 14 RNQPs (5%). In phytosanitary terms, a non-quarantine pest is not a quarantine pest in an area; a quarantine pest is a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled; while a RNQP is a non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact and which is therefore regulated within the territory of the importing contracting party (IPPC Secretariat, 2021).

The quarantine pests on the refined regulated lists included 44 bacteria, three chromista, 103 fungi, 40 insects, one arachnid, 13 nematodes, one protist, two viroids, and 48 viruses. This data is included in Supplementary Material S3 (Sheet: Version 1). However, following a thorough evaluation, it was found that some pests were misclassified and that some were entered multiple times. The correction of these two anomalies resulted in 236 species, including 41 arthropods (40 insects and one mite), 39 bacteria, 11 chromists, 83 fungi, 12 nematodes, two protists, two viroids, and 46 viruses. Of the 236 species, 222 were categorised as quarantine pests and 14 as RNQP (Table 2). All 14 RNQP and 36 of the 222 quarantine pests affect a priority crop (Table 2). The summarised data can be accessed in Supplementary Material S3, Sheet 3.

According to the definition, the 14 RNQPs are known to be present in Rwanda; however, all 14, except for two, *Magnaporthe grisea* and *Ustilago maydis*, have been documented as present in the CABI Compendium and EPPO database. These two species are known to be ubiquitous, especially where hosts are highly abundant,

TABLE 1 Pest groups identified by the Horizon Scanning Tool.

Pest group	Number (Invasive)
Arthropod	
Outside Africa	183 (64)
In Africa	
Not in a Neighbouring country	103 (26)
In a Neighbouring country	106 (02)
Total	**392 (92)**
Bacteria	
Outside Africa	57 (10)
In Africa	55 (11)
Not in a Neighbouring country	35 (01)
In a Neighbouring country	
Total	**147 (22)**
Chromista	
Outside Africa	27 (00)
In Africa	
Not in a Neighbouring country	33 (05)
In a Neighbouring country	19 (00)
Total	**79 (05)**
Fungi	
Outside Africa	416 (20)
In Africa	
Not in a Neighbouring country	226 (19)
In a Neighbouring country	142 (00)
Total	**784 (39)**
Mollusca	
Outside Africa	12 (04)
In Africa	
Not in a Neighbouring country	08 (04)
In a Neighbouring country	01 (01)
Total	**21 (09)**
Nematodes	
Outside Africa	55 (06)
In Africa	
Not in a Neighbouring country	59 (16)
In a Neighbouring country	20 (00)
Total	**134 (22)**
Protista	
Outside Africa	07 (00)
In Africa	
Not in a Neighbouring country	10 (00)
In a Neighbouring country	00 (00)
Total	**09 (00)**
Viroids	
Outside Africa	07 (00)

(Continued)

TABLE 1 Continued

Pest group	Number (Invasive)
Viroids	
In Africa	
Not in a Neighbouring country	10 (00)
In a Neighbouring country	01 (00)
Total	**18 (00)**
Viruses	
Outside Africa	225 (07)
In Africa	
Not in a Neighbouring country	122 (15)
In a Neighbouring country	41 (00)
Total	**388 (22)**
Grand Total	**1,972 (211)**

The bold values indicate tolals for each section.

and are likely to be present in Rwanda. Further analysis demonstrated that 204 (87%) of the 236 species were reported in Africa, of which 58% (n=119; N = 204) were present in neighbouring countries, and 15% (n=32; N = 204) were reported in Rwanda (Table 2). The 32 species included 14 categorised as RNQPs. The 236 species also included 197 (83%) generated by the HST (Supplementary Material S3, Sheet: Version 4); however, the 39 species (17%) not part of the HST output were added to the 1,982 species (from the above section), increasing the total to 2,021. However, of the 39 species, only 13 were assessed, as the others had been reported in Rwanda, bringing the total to 1,995 (Supplementary Material S3, Sheet: Version 4).

Evaluation of vectors and vectored species

A total of 1,972 species identified by the HST were assessed to identify those capable of transmitting or being transmitted by other species. The species that could serve as vectors or be vectored but were not identified by the HST were also evaluated to assess their associated risks. This led to the identification of 100 vector species and 24 species that could be vectored. The 100 vector species included 95 arthropods, one fungus (*Olpidium bornovanus*), and four plants, all *Cuscuta* species (*C. campestris*, *C. ceanothi*, *C. europaea*, and *C. reflexa*). The arthropods belonged to the orders Acarida (3), Coleoptera (5), Hemiptera (81), Hymenoptera (4), Lepidoptera (1), and Thysanoptera (1). Most of the Hemiptera species were from the families Cicadellidae (40) and Aphididae (25). All this data is presented in Supplementary Material S15 (Sheet: Vector species). The 24 vectored species included three fungi (*Fusarium euwallaceae*, *Microbotryum succisae*, and *Ustilago violacea*), one nematode (*Angiostrongylus cantonensis*), and 20 viruses. One vector species, *Spongospora subterranea* (categorised as quarantine) and eight vectored species, two classified as quarantine (*Potato virus X* (*PVX*) and *tomato black ring virus* (*TBRV*)) and six as RNQPs (*bean common mosaic virus* (*BCMV*), *cassava brown streak virus* (*CSBV*), *African cassava mosaic virus* (*ACMV*), *cucumber mosaic virus* (CMV), *maize chlorotic mottle virus* (*MCMV*), and *sugarcane mosaic virus* (*SCMV*)), were added because they were

TABLE 2 Current list of regulated pests.

Pest group	Quarantine						Regulated non-quarantine pest						
	Abscent in Africa (A)	Present in Africa (B)	Present in a country neighbouring Rwanda	Present in Rwanda	Affects a priority crop	Total (C = A +B)	Abscent in Africa (D)	Present in Africa (E)	Present in a country neighbouring Rwanda	Present in Rwanda	Affects a priority crop	Total (F = D + E)	Total (G = C + F)
Arthropods	09	29	19		20	38		03	03	03	03	03	41
Bacteria	04	34	18	04	24	38		01	01	01	01	01	39
Chromista	01	10	08	02	04	11							11
Fungi	03	76	44	08	60	79		03	03	02	03	03	83
Mollusca													
Nematodes	01	11	02	02		12							12
Plants													
Protista		02	01	01	01	02							02
Viroids	01	01	01		01	02							02
Viruses	13	27	13	01	26	40		06	06	06	06	06	46
Total	**32**	**190**	**106**	**18**	**136**	**222**		**14**	**13**	**14**	**14**	**14**	**236**

The bold values indicate tolals for each section.

listed as regulated. All this data is presented in Supplementary Material S15 (Sheet: Vectored species).

Assessment of additional species

Additionally, pest species not included in the horizon-scanning output but considered to have phytosanitary consequences were added to the list of pests prioritised for assessment. The list consisted of pests whose species categories had recently been redefined. The category added included bacterial species belonging to the *Soft Rot Pectobacteriaceae*. Formerly called the *Soft Rot Enterobacteriaceae*, this group includes the genera *Dickeya* and *Pectobacterium*, both of which belong to the family *Pectobacteriaceae*. Species from these two genera are highly destructive in many value chains, especially within the Solanaceae.

The horizon-scanning output included seven *Dickeya* species and ten *Pectobacterium species*. Six of the *Dickeya* species (*D. chrysanthemi*, *D. dadantii*, *D. dianthicola*, *D. fangzhongdai*, *D. paradisiaca*, and *D. solani*) affect potatoes. The last *Dickeya* species, *D. zeae*, is known to affect maize. Although *D. zeae* was initially considered a single species, Hugouvieux-Cotte-Pattat and Van Gijsegem (2021) demonstrated diversity among its strains, resulting in two distinct clades, one of which was later elevated to *D. oryzae*.

Seven of the ten identified *Pectobacterium* species, including *P. aroidearum*, *P. atrosepticum*, *P. betavasculorum*, *P. brasiliense*, *P. carotovorum*, *P. parmentieri* and *P. polaris*, are known to affect potatoes. Recently, *P. carotovorum* subsp. *carotovorum* has been elevated to three species, *P. carotovorum*, *P. parvum*, and *P. peruviense* (Waleron et al., 2018; Portier et al., 2019; Pasanen et al., 2020). A new species closely related to *P. parmentieri* was recently delineated as *Pectobacterium punjabense* (Sarfraz et al., 2018). The four species, *D. oryzae*, *P. parvum*, *P. peruviense*, and *P. punjabense*, not included in the horizon-scanning output, were considered for the risk assessment. All this data is presented in Supplementary Material S5 (Sheet: Assessment of Bacteria).

Pests considered for *risk assessment*

The initial selection, based on the previously specified criteria, yielded 1,972 species, including 193 already on the regulated list (Supplementary Material S15; Sheet: HS selected species). The remaining 43 of the 236 regulated species included 29 species already reported in Rwanda and not considered for risk assessment (Supplementary Material S15; Sheet: Analysed regulated list). The remaining 14 species were added to the 1,972, bringing the total to 1,986 species considered for risk assessment. An additional four species, *D. oryzae*, *P. parvum*, *P. peruviense*, and *P. punjabense*, deemed of phytosanitary concern, were added, raising the number to 1,990 species.

An additional 18 species, comprising two arthropods, one bacterium, 13 fungi, and two nematodes, identified by the HST in Burundi, Kenya, or Uganda, or all these countries, but not Rwanda, were added, increasing the total number of species for assessment to 2,008. A total of 22 species not identified by the HST but vectored by assessed species were added. They comprised three fungi, one nematode and 18 viruses. The nematode was *A. cantonensis*, while the three fungal species were *F. euwallaceae*, *M. succisae*, and *U. violacea*. *Angiostrongylus cantonensis* is vectored by the molluscs *Pomacea canaliculata* and *Sarasinula plebeia* and affects humans, but was not considered for assessment. Of the 18 viruses, seven, including *banana bunchy top virus* (*BBTV*), *banana streak virus* (*BSV*), *pepper vein yellows virus* (*PeVYV*), *pepper veinal mottle virus* (*PVMV*), *potato virus M* (*PVM*), *PVX*, and *sweet potato chlorotic stunt virus* (*SPCSV*), were not assessed because they are known to occur in Rwanda. This left 11 viruses, which included *African cotton mosaic disease*, *Dichorhavirus coffeae*, *maize mal de Rio Cuarto virus*, *maize mottle/chlorotic stunt virus*, *okra leaf curl disease*, *papaya bunchy top agent*, *peanut green mosaic virus*, *raspberry leaf blotch virus*, *rose yellow leaf virus*, *tomato necrotic ringspot virus* (*TNRSV*), and *wheat yellow mosaic virus*. Adding 14 species raises the number of species considered for assessment to 2,022.

The last category of species added was those known to vector assessed species, but were not included in the HST output. This category included 100 species, of which 23 were already reported in Rwanda. The remaining 77 comprised 72 arthropods, one fungus (*Olpidium bornovanus*) and four plant species (*C. campestris*, *C. ceanothi*, *C. europaea*, and *C. reflexa*). This resulted in a total of 2,099 considered for assessment (Supplementary Material S15; Sheet: Final list for Evaluation). The 2,099 species comprised 468 arthropods, 152 bacteria (including 24 phytoplasmas), 79 chromists, 810 fungi, 21 molluscs, 136 nematodes, four plants, nine protists, 18 viroids, and 402 viruses. The 2,099 included 212 species reported as invasive, categorised into 92 arthropods, 22 bacteria (including 24 phytoplasmas), five chromists, 39 fungi, nine molluscs, 23 nematodes, and 22 viruses. All data are presented in Supplementary Material S15, Sheet: Final list for Evaluation.

Assessment of arthropods

A total of 495 species were selected for downstream analysis, including 41 regulated species, of which 38 were categorised as quarantine and three as RNQPs (Table 2). Of these, 392 (79%) were generated by the HST and included 92 (23%; N = 392) that had been reported as invasive (Table 3). The 392 species also included 36 that had been listed as regulated pests. The remaining 103 (21%) not generated by the HST included five species from the list of regulated pests, of which three (*Prostephanus truncatus*, *Spodoptera frugiperda*, *Thaumatotibia leucotreta*) had already been reported in Rwanda, leaving only two (*Archips podana* and *Helothrips haemorrhoidalis*) for risk assessment. The other 98 species (out of 103) were added because they were vectors of assessed pests, particularly bacteria (*Xylella fastidiosa* subsp. *fastidiosa*, *X. fastidiosa* subsp. *multiplex*, and *X. fastidiosa* subsp. *pauca*), as well as phytoplasma and fungi (*Amylostereum areolatum* and *Fusarium oxysporum* f.sp. *cubense* Tropical Race 4 (*Fo*CTR4), protists (*Phytomonas leptovasorum* and *Phytomonas staheli*), and viruses. The phytoplasmas included *Candidatus Liberibacter asiaticus* (*CLas*), *Candidatus Liberibacter solanacearum*, *Candidatus Phytoplasma asteris*, *Candidatus Phytoplasma rubi*, *Candidatus Phytoplasma solani*, *Candidatus Phytoplasma trifolii*, *cotton*

TABLE 3 All pest species selected for assessment.

Pest group	Number of selected species	Affects a priority crop	Quarantine	RNQPs	Present in Rwanda	Considered for assessment	Generated through horizon scanning	Invasive species	Vector	Vectored	Present outside Africa (A)	Present in Africa (B)	Present in a neighbouring country	Total (A+B)
Arthropods	495	204	38	03	27	468	392	92	296		249	219	110	468
Bacteria	157	71	38	01	05	152	147	22		33	60	92	35	152
Chromista	81	23	11		02	79	79	05			27	52	19	79
Fungi	823	240	79	04	13	810	784	39	04	15	427	383	151	810
Mollusca	21	10				21	21	09	02		12	09	01	21
Nematodes	139	82			02	136	134	23	17	05	57	79	20	136
Plants	04	01				04			04		03	01	00	04
Protista	10	04	02		01	09	09		03	03	03	06	00	09
Viroids	18	01				18	18			03	07	11	01	18
Viruses	418	125	40	06	16	402	388	22		376	235	167	43	388
Total	**2,166**	**761**	**208**	**14**	**66**	**2,099**	**1,972**	**212**	**326**	**435**	**1,081**	**1,018**	**381**	**2,099**

The bold values indicate totals for each section.

phyllody phytoplasma, *sugarcane grassy shoot phytoplasma*, *sugarcane white leaf phytoplasma*, *sugarcane yellow leaf phytoplasma*, and *sweet potato little leaf phytoplasma*.

The majority (49) of the species were virus vectors; however, up to 30 arthropod species were vectors of *X. fastidiosa*. The remaining two included *Aphis cuscutae*, a pest of *C. ceanothi*, and *Scrobipalpopsis solanivora*, a host of *Solanum tuberosum*. It was added because it was detected by the HST in other countries. The 103 species included 27 reported from Rwanda, which were excluded from the risk assessment, leaving 76 for the risk assessment. All these were vectors (n=72), except for four: *A. cuscutae*, *Archips podanus*, *H. haemorrhoidalis*, and *S. solanivora*. The majority of the 72 species vectored viruses, except for three, *Cosmopolites sordidus* (vector of *Fo*CTR4), *Nezara viridula* (vector of *P. leptovasorum* and *P. staheli*), and *Trioza erytreae* (vector of *Candidatus Liberibacter americanus* and *CLas*).

Of the 495 species, only 468 (95%) were included in the risk assessment (Table 3). The 468 included 219 (47%) species reported in Africa, of which 110 (51%, N = 219) were reported in neighbouring countries (Supplementary Material S5; Sheet: Assessment of Arthropods). A proportion of 47% (n=219; N = 468) of these species affected a prioritised crop. Furthermore, 273 species (58%) were vectors of the assessed pathogenic organisms. The majority (76%; n=355, N = 468) of the species were likely introduced solely as contaminants, and all were either not known to occur in Africa or reported in Africa but in countries other than neighbouring ones. The remaining 24% could be introduced through various pathways, with 4% (n=20; N = 468) entering as contaminants or stowaways and 20% (n=93; N = 468) as contaminants, stowaways, or unaided (Table 4). Species that could be introduced through the unaided pathway were all reported in a neighbouring country. The highest overall risk score was 175, attributed to 79 species, while the lowest was two, noted for two species (*Colladonus montanus* and *Myzus varians*). All data have been consolidated in Supplementary Material S4; Sheet: Assessment of Arthropods.

Assessment of bacteria

The number of bacterial species considered for downstream analysis was 81, including 39 regulated pests (38 quarantine and one RNQP); however, only 152 (97%) were included in the rapid risk assessment, with the five excluded because they had already been reported in Rwanda (Table 3). The excluded species, which included *Pseudomonas fuscovaginae*, *Pseudomonas savastanoi* pv. *phaseolicola*, *Ralstonia solanacearum*, *Xanthomonas campestris* pv. *musacearum*, and *Xanthomonas phaseoli* pv. *phaseoli* were all listed as currently regulated in Rwanda. Of the 152 species, 147 were generated by the HST, except for five (Table 3). The five included *cassava witches' broom*, which was part of the horizon scanning outputs and rapid risk assessments of Burundi (Mulema et al., 2025a) and Uganda (Mulema et al., 2025b), and four (*D. oryzae*, *Pectobacterium parvum*, *Pectobacterium peruviense*, *Pectobacterium punjabense*) were deemed to present a phytosanitary risk. Of the 152 species, 22 (14%) were reported as invasive (Table 3). In addition, 23% (n=34; N = 152) are currently regulated in Rwanda

10.3389/fagro.2026.1897049

TABLE 4 Likely pathways of arrival for assessed pests.

Pest group	CO	CO; ST	CO; ST; UN	CO; UN	ST	Blanks	Total
Arthropod	355	20	93			27	**495**
Bacteria	134	11			07	05	**157**
Chromista	60			19		02	**62**
Fungi	663	10		137		13	**823**
Mollusca					21		**21**
Nematode	91	28			17	03	**139**
Plants	3	1					**04**
Protista	10						**10**
Viroids	17	1					**18**
Viruses	53	183			166	16	**418**
Total	**1,385**	**254**	**93**	**156**	**211**	**67**	**2,166**

CO, Commodity; ST, Stowaway; UN, Unaided. The bold values indicate tolals for each section.

(Supplementary Material S5; Sheet: Assessment of Bacteria). The majority (61%; n=92; N = 152) were known to occur in Africa, of which 37% (n=34; N = 92) were reported in a neighbouring country (Supplementary Material S5; Sheet: Assessment of Bacteria). Furthermore, 44% (n=67; N = 152) affected a crop prioritised by the GoR. A proportion of 23% (n=34; N = 151) was included on the current list of regulated pests (Supplementary Material S5; Sheet: Assessment of Bacteria).

The highest overall risk score was 175, recorded for seven species, including *Burkholderia gladioli* pv. *gladioli*, *Candidatus Phytoplasma asteris*, *Dickeya chrysanthemi*, *D. dadantii*, *D. dianthicola*, *Pectobacterium carotovorum, and Pseudomonas syringae* pv. *garcae*. The lowest score was eight, recorded for six species, including *Candidatus Phytoplasma rubi*, *Erwinia persicina*, *Pseudomonas marginalis* pv. *alfalfae*, *Pseudomonas syringae* pv. *apii*, *Pseudomonas syringae* pv. *atropurpurea*, and *Xanthomonas melonis* (Supplementary Material S5; Sheet: Assessment of Bacteria). Of the 152 species, most (88%, n=134) were likely introduced solely as contaminants, while the fewest (5%, n=7) were likely introduced as stowaways (Table 4). The remaining 7% (n=11) could enter via either pathway, as contaminants or stowaways (Table 4). About one in five (22%; n=33; N = 152) of the species assessed could also be transmitted by vectors (Supplementary Material S5; Sheet: Assessment of Bacteria). The majority (61%; n=13; N = 33) of the vectored species were phytoplasma, except for 13, which included *Dickeya zeae*, *Pantoea ananatis*, *Pantoea stewartii* subsp. *stewartii*, *P. carotovorum*, *Rathayibacter rathayi*, *Rathayibacter toxicus*, *Rathayibacter tritici*, *Spiroplasma citri*, *Spiroplasma kunkelii*, *Sugarcane Ramu stunt disease*, *Xylella fastidiosa* subsp. *fastidiosa*, *X. fastidiosa* subsp. *multiplex*, and *X. fastidiosa* subsp. *pauca*. *Xylella fastidiosa* subspecies were the most vectored bacterial species among all assessed. All data have been consolidated in Supplementary Material S5; Sheet: Assessment of Bacteria.

Assessment of chromista

A total of 81 chromists were selected, including 11 regulated pests, all categorised as quarantine pests; however, only 79 were considered for the rapid risk assessment (Table 3). The two excluded species, *Peronosclerospora sorghi* and *Phytophthora infestans*, were added because they were listed as regulated but were known to occur in Rwanda and were therefore excluded from the risk assessment (Table 3). Five species representing 6% (N = 79) have been reported as invasive (Table 3). The majority (66%; n=52; N = 79) were reported in Africa, with 37% (n=19; N = 52) reported in a neighbouring country (Supplementary Material S6; Sheet: Assessment of Chromista). About 28% (n=23; N = 79) of the species considered for assessment were associated with a priority crop (Supplementary Material S6; Sheet: Assessment of Chromista). Nine of the 79 species are currently regulated in Rwanda, including *Albugo candida*, *Hyaloperonospora parasitica*, *Peronospora mandshurica*, *Phytophthora cactorum*, *Phytophthora palmivora*, *Phytophthora sojae*, *Plasmopara halstedii*, *Sclerophthora macrospora* and *Sclerospora graminicola* (Supplementary Material S6; Sheet: Assessment of Chromista). The main pathway, accounting for 76% (n=60; N = 79), by which these species could be introduced was through contamination of plants and plant products (Table 4). The remaining 19 species, accounting for 24% (N = 79), could be introduced through multiple pathways, either as contaminants or unaided as spores, since most of these species were also reported in a neighbouring country (Table 4). The highest overall risk score was 175, recorded for seven species, including *A. candida*, *H. parasitica*, *Peronosclerospora maydis*, *Peronospora destructor*, *Phytophthora nicotianae*, *Phytophthora phaseoli*, and *S. graminicola*, while the lowest was 10, recorded for three species, *Aphanomyces raphani*, *Peronospora dianthicola*, and *Phytophthora gloverana* (Supplementary Material S6; Sheet: Assessment of Chromista). All data have been consolidated in Supplementary Material S6; Sheet: Assessment of Chromista.

Assessment of fungi

The total number of selected species was 823, including 83 regulated species, of which 79 were categorised as quarantine and four as RNQPs; however, only 810 (approximately 98%) were included in the risk assessment. The remaining 13 species were included in the list either because they were listed as regulated in

TABLE 5 Actions suggested for assessed pests.

Pest group	No action	Surveillance	Regulation (Quarantine)	Regulation (RNQPs)	Contingency plan	Publicity	Management by industry	Research
Arthropods	295	103	94	05	06	05	03	02
Bacteria	62	47	58	05	07	13	01	17
Chromista	36	17	26	02				
Fungi	522	134	156	12	02	01		02
Mollusca	13	02	07		01	01	01	
Nematodes	53	19	66	02	02	01		01
Plants	03		01					
Protista	07		02	01				
Viroids	09	02	08		01	01		
Viruses	266	34	103	15				
Total	**1,266**	**358**	**521**	**42**	**19**	**22**	**05**	**22**

The total number of species selected for this study was 2,166. Of the 2,166, only 2,099 were considered for rapid risk assessment, excluding 67 species because they were reported as present in Rwanda. A no-action was suggested for 1,266 of the 2,166, leaving 900 species for the remaining actions. Of the 900 species, detection surveillance was suggested for 358, leaving 542. While the species for which regulation (quarantine) was suggested were 521; 21 of these species were also indicated for surveillance, which would leave 500 species. The last 42 species were what remained of the 67 excluded species. These species were present in Rwanda and were suggested for regulation (regulated non-quarantine). Adding the bolded figures accounts for the 2,166 species. Although additional actions, such as contingency plans, publicity, industry management, and research, were proposed, the species targeted for these actions had already been recommended for surveillance or regulation; thus, their numbers do not account for the final total. The bold values indicate tolals for each section.

Rwanda (9) or because the HST has identified them in assessments for Burundi, Uganda, or both (Supplementary Material S7; Sheet: Assessment of Fungi). However, all 13 species are known to occur in Rwanda and therefore not considered for rapid risk assessment. The nine regulated species included two RNQPs and seven quarantine pests. The two RNQPs were *Colletotrichum lindemuthianum* and *Sporisorium sorghi*, while the seven quarantine pests included *Colletotrichum graminicola*, *Colletotrichum sublineola*, *Glomerella cingulata*, *Phakopsora pachyrhizi*, *Sphacelotheca reiliana*, *Thanatephorus cucumeris*, and *Verticillium dahliae*. The additional four species included *Alternaria brassicae*, *Mycosphaerella cruenta*, *Puccinia sorghi*, and *Sphaeropsis sapinea* (Supplementary Material S7; Sheet: Assessment of Fungi).

The 810 species considered for risk assessment included 784 generated by the HST (Table 3). An additional 26 were included because they are currently regulated in Rwanda (nine species) or because risk assessments had been conducted on them in Burundi or Uganda (17 species) (Supplementary Material S7; Sheet: Assessment of Fungi). The nine regulated pests comprise *Berkeleyomyces basicola*, *Curvularia pallescens*, *Curvularia uncinata*, *Curvularia verruculosa*, *Diaporthe phaseolorum* var. *meridionalis*, *Fusarium oxysporum* f.sp. *vasinfectum*, *Gibberella avenacea*, *Harpophora maydis*, and *Macrophomina phaseolina* (Supplementary Material S7; Sheet: Assessment of Fungi). The total of 810 species includes 39 (5%) reported as invasive (Table 3), 28% (n=227; N = 810) known to affect a prioritised crop (Table 3), and approximately 9% (n=74; N = 810) listed on the regulated list (Supplementary Material S7; Sheet: Assessment of Fungi). A proportion of 47% (n=383; N = 810) had been reported in Africa, of which 39% (n=151; N = 383) were known to occur in a neighbouring country (Supplementary Material S7; Sheet: Assessment of Fungi).

The majority (82%, n=663; N = 810) of assessed fungal species were likely introduced solely as contaminants (Table 4). The remaining 18% (n=147; N = 810) were likely introduced through multiple pathways, with 10 (1%) introduced either as contaminants or stowaways, and 137 (17%) introduced as contaminants or unaided (as spores) (Table 4). The species introduced into Rwanda as stowaways or unaided were all reported in neighbouring countries. The stowaways were all soil-borne fungi and could be spread through contaminated soil. The highest overall risk score was 175, recorded for 60 species, while the lowest was two reported for 19 species (Supplementary Material S7; Sheet: Assessment of Fungi). Fifteen of the assessed fungal species were vectored by other assessed species, mainly arthropods, while four of the species were vectors, especially for viruses (Supplementary Material S7; Sheet: Assessment of Fungi). The vectors included *O. bornovanus* (vector for *melon necrotic spot virus*), *Olpidium brassicae* (vector for *lettuce big-vein virus*, *tobacco necrosis satellite virus*, and *tobacco necrosis virus*), *Olpidium radicale* (vector for *cucumber necrosis virus* and *melon necrotic spot virus*) and *Synchytrium endobioticum* (vector for *PVX*) (Supplementary Material S7; Sheet: Assessment of Fungi). All data have been consolidated in Supplementary Material S7; Sheet: Assessment of Fungi.

Assessment of molluscs

The HST detected all 21 molluscs considered for downstream assessment, and none were listed on the current list of regulated pests (Table 2). Nine (43%) of the 21 species were reported as invasive (Table 2). The nine species included *Arion vulgaris*, *Cornu aspersum*, *Deroceras laeve*, *Deroceras reticulatum*, *Limax* maximus, *Meghimatium pictum*, *P. canaliculata*, *Pomacea maculata*, and *Veronicella cubensis*. Ten species are known to affect a prioritised crop (Table 3). They include *Arion hortensis*, *A. vulgaris*, *C. aspersum*, *D. reticulatum*, *Diplosolenodes occidentalis*, *Pila dolioides*, *P. canaliculata*, *Pomacea glauca, S. plebeia*, and *V. cubensis* (Supplementary Material S8; Sheet: Assessment of Molluscs).

Nine of the species, representing 43%, were known to occur in Africa (Table 3). They included *Achatina fulica*, *A. hortensis*, *Bradybaena similaris*, *C. aspersum*, *D. laeve*, *D. reticulatum*, *L. maximus*, *P. canaliculata*, and *Rumina decollata*. Only one (*Limax maximus*) was reported in a neighbouring country (Uganda) (Supplementary Material S8; Sheet: Assessment of Molluscs). Two species, *P. canaliculata* and *S. plebeia*, are reported as vectors of the lungworm nematode. The highest overall risk score was 150, recorded for *P. canaliculata*, while the lowest was eight, recorded for *P. maculata* (Supplementary Material S8; Sheet: Assessment of Molluscs). All the assessed molluscs could be introduced exclusively as stowaways (Table 4).

Assessment of nematodes

The 139 nematode species selected for this study included 138 plant-parasitic nematodes and one other, *A. cantonensis*, also known as rat lungworm (Griffin et al., 2025). Two of the evaluated plant-parasitic molluscs, *P. canaliculata* and *S. plebeia*, are reported intermediate hosts of *A. cantonensis*. The 138 species included two (*Aphelenchoides besseyi* and *Globodera rostochiensis*) because they were listed as regulated pests, but were not considered for assessment because they were already reported in Rwanda. The remaining 136 species comprised 134 species generated by the HST (Table 3), and two species, *Macroposthonia onoensis* and *Peltamigratus luci*, were included because they were included in rapid risk assessments of Burundi (Mulema et al., 2025a) and Uganda (Mulema et al., 2025b), respectively. The 134 species included 22 (16%) that were reported as invasive (Table 3). In addition, 10 of the 134 species were listed on the regulated list, including *Anguina tritici*, *Ditylenchus angustus*, *Ditylenchus destructor*, *Ditylenchus dipsaci*, *Globodera pallida*, *Heterodera glycines*, *Meloidogyne chitwoodi*, *Meloidogyne fallax*, *Nacobbus aberrans*, and *Rotylenchulus reniformis* (Supplementary Material S9; Sheet: Assessment of Nematodes).

More than half (59%, n=80; N = 136) of these nematodes affected a prioritised crop. The majority (58%; n=79; N = 136) were reported in Africa, with 19 (24%; N = 79) in neighbouring countries. A proportion of 67% (n=91) were likely introduced solely as contaminants, whereas 13% (n=18) were probably introduced as stowaways. The remaining 20% (n=27) could have been introduced either as contaminants or stowaways (Table 4). The highest score was 175, reported for *Pratylenchus zeae* and *Rotylenchulus reniformis*, whereas the lowest score was two, recorded for *Meloidogyne mali* (Supplementary Material S9; Sheet: Assessment of Nematodes). Four of the nematodes could be transmitted by arthropods and included *Orthotomicus erosus* for *Bursaphelenchus fungivorus*; *Rhynchophorus palmarum* for *Rhadinaphelenchus cocophilus*; *Monochamus scutellatus* and *Monochamus sutor* for *Bursaphelenchus mucronatus*; and *Bursaphelenchus xylophilus* (Supplementary Material S9; Sheet: Assessment of Nematodes). *Bursaphelenchus xylophilus* is vectored by nine species in the *Monochamus* genus, with *M. alternatus* as the primary vector in China, Japan, and South Korea; *M. carolinensis* in the United States, and *M. galloprovincialis* in Portugal (Aikawa, 2008).

Seventeen of the nematodes assessed are reported vectors of pathogenic organisms, with two of these transmitting bacterial pathogens (Supplementary Material S9; Sheet: Assessment of Nematodes). They included *A. agrostis*, which transmitted *R. rathayi* and *R. toxicus*, and *A. tritici*, which transmitted *R. rathayi* and *R. tritici*. The *Arabis mosaic virus*, *cherry rasp leaf virus*, *pea early-browning virus*, *potato black ringspot virus*, *raspberry ringspot virus*, *strawberry latent ringspot virus*, *tobacco rattle virus*, *tobacco ringspot virus*, *tobravirus capsici*, *TBRV*, *tomato necrotic ring virus*, *TNRSV*, and *tomato ringspot virus*. All data have been consolidated in Supplementary Material S9; Sheet: Assessment of Nematodes.

Assessment of parasitic plants

The four assessed *Cuscuta* species (*C. campestris*, *C. ceanothi*, *C. europaea*, and *C. reflexa*) were not included in the horizon-scanning output but were evaluated because of their role as vectors for the assessed species (Table 2). Aside from *C. ceanothi*, the other three species were reported in Africa, with only *C. campestris* found in a neighbouring country, Tanzania (Table 3). All were likely introduced as contaminants, except for *C. campestris*, which could have been introduced either as a contaminant or a stowaway (Table 4). The highest risk score recorded was 72 for *C. campestris*, while the lowest was 24, attributed to *Cuscuta europaea* (Supplementary Material S10; Sheet: Assessment of Plants).

Assessment of protists

The selected 10 protists included nine species identified by the HST (Table 2) and one species, *Spongospora subterranea*, which was included because it was listed on the regulated list (Table 2). *Spongospora subterranea* was not assessed because it was already reported in Rwanda. The remaining nine species included one, *Plasmodiophora brassicae*, listed as a regulated pest (Table 3). Three of the nine species, *P. brassicae*, *Polymyxa betae*, and *Polymyxa graminis*, were reported in Africa, with none observed in a neighbouring country (Table 3). All nine species could be introduced exclusively as contaminants (Table 4). The highest overall risk score was 105, recorded for *P. graminis*, while the lowest was 12, recorded for *Physarum cinereum* (Supplementary Material S11; Sheet: Assessment of Protists). Two protists, *P. betae* and *P. graminis*, are known to serve as vectors for viruses. *Polymyxa betae* is known to vector *beet necrotic yellow vein virus* (*BNYVV*), *beet soil-borne mosaic virus*, *beet soil-borne virus*. *Polymyxa graminis* vectors *barley mild mosaic virus*, *barley yellow mosaic virus*, *Chinese wheat mosaic virus*, *Indian peanut clump virus*, *oat mosaic virus*, *peanut clump virus*, *rice stripe necrosis virus*, *soil-borne cereal mosaic virus*, *soil-borne wheat mosaic virus*, *wheat spindle streak mosaic virus*, *wheat streak mosaic virus*, *wheat yellow mosaic bymovirus*, *wheat yellow mosaic virus*. Additionally, three protists, *Gregarina sitophili*, *P. leptovasorum*, and *P. staheli*, can be transmitted by arthropod vectors. All data have been consolidated in Supplementary Material S11; Sheet: Assessment of Protists.

Assessment of viroids

The viroid assessment included 18 species (Table 2), none of which were reported as invasive. Of these, 61% (n=11; N = 18) were found in Africa, with only one, *potato spindle tuber viroid* (*PSTVd*), reported in a neighbouring country (Table 3). The main prioritised crop affected by the assessed viroids is *S. tuberosum*, which is impacted by *PSTVd* (Supplementary Material S12; Sheet: Assessment of Viroids). This viroid also affects avocado (*Persea americana*), a value chain that is increasingly important in Rwanda due to its export potential. *Avocado* is also impacted by *avocado sunblotch viroid* (*ASBVd*), which had an overall risk score of 84. Most (94%, n=17) of the viroids were likely introduced solely as contaminants in planting materials, with only one (*citrus exocortis viroid*) possibly introduced as either a contaminant or a stowaway, since it was vectored by *Cuscuta ceanothi*, the canyon dodder (Table 4). However, this pathway was unlikely because *C. ceanothi* has only been reported from Mexico and the United States, neither of which is a typical source of planting material for avocado or potato. The highest overall risk score was 175, recorded for *PSTVd*. The lowest was eight, recorded for three species (*apple scar skin viroid*, *coconut cadang-cadang viroid*, and *coconut tinangaja viroid*). All data have been consolidated in Supplementary Material S12; Sheet: Assessment of Viroids.

Assessment of viruses

The total number of selected viral species was 418, including 46 regulated species, of which 40 were categorised as quarantine and six as RNQPs (Table 2). Only 402 were included in the risk assessment (Table 2). The remaining 16 species were selected because they were listed as regulated (seven) or had been identified by the HST (nine) in Burundi, Kenya, and Rwanda; however, they were considered for assessment as they had been reported in Rwanda (Table 2, Supplementary Material S12; Sheet: Assessment of Viroids). The seven regulated pests included one quarantine virus (*potato virus Y* (*PVY*)) and six RNQPs: *BCMV*, *cassava brown streak virus* (*CBSV*), *ACMV*, *CMV*, *maize chlorotic mottle virus* (*MCMV*), and *SCMV* (Supplementary Material S13; Sheet: Assessment of Viruses). The remaining nine species were included because other assessed pests, mainly arthropods, vectored them. They are *BBTV*, *BSV*, *PeVYV*, *PVMV*, *PVM*, *PVX*, *SPCSV*, *sweet potato feathery mottle virus*, and *sweet potato latent virus* (Supplementary Material S13; Sheet: Assessment of Viruses).

The 402 species comprised 388 generated by the HST (Table 2) and 14 added because they were listed as regulated (3) or considered for risk assessments (11) in Burundi and Uganda. The regulated viruses were all categorised as quarantine and included *apple green crinkle disease*, *garlic latent virus*, and *TBRV*. The 11 species comprised *African cotton mosaic disease*, *dichorhavirus coffeae*, *maize mal de Rio Cuarto virus*, *maize mottle/chlorotic stunt virus*, *okra leaf curl disease*, *papaya bunchy top agent*, *peanut green mosaic virus*, *raspberry leaf blotch virus*, *rose yellow leaf virus*, *TNRS*, and *wheat yellow mosaic virus* (Supplementary Material S13; Sheet: Assessment of Viruses). The 388 species identified by the HST included 22 (6%) that were reported as invasive (Table 2). In total, the 402 species comprised 125 (31%) that affected a prioritised crop in Rwanda (Table 2) and 39 (10%) regulated species, all categorised as quarantine (Supplementary Material S13; Sheet: Assessment of Viruses).

The 402 species included 167 (42%) reported from Africa, of which 26% (n=43; N = 167) occurred in neighbouring countries (Table 3). The majority (54%; n=219; N = 402) of viruses were likely introduced solely through a single pathway; 13% (n=53) as contaminants, and 41% (n=166) as stowaways (Table 4). The remaining 46% (n=183; N = 402) could have been introduced as either contaminants, stowaways, or both (Table 4). The highest overall risk score recorded was 175, observed in 19 species, while the lowest was 3, recorded across four species, including *raspberry latent virus*, *raspberry leaf blotch virus*, *raspberry leaf curl virus*, and *raspberry leaf mottle virus* (Supplementary Material S13; Sheet: Assessment of Viruses). Nearly nine out of ten of the assessed viruses (n=360; N = 402; 89%) were transmitted by a recognised vector (Supplementary Material S13; Sheet: Assessment of Viruses). These vectors included arthropods (most species), fungi (four species), nematodes (15 species), and plants (four species). The fungal species included *O. bornovanus, O. brassicae, O. radicale*, and *S. endobioticum*, while the plant species included *C. campestris*, *C. ceanothi*, *C. europaea*, and *C. reflexa*. All data have been consolidated in Supplementary Material S13; Sheet: Assessment of Viruses.

Assessment of vector species

The total number of species considered for rapid risk assessment was 326, of which 219 were also generated by the HST. The 219 vectored species comprised 32 bacteria, six fungi, four nematodes, three protists, and 174 viruses. The six fungi were *Albonectria rigidiuscula*, *A. areolatum*, *F. euwallaceae*, *H. haematococca*, *Leptographium procerum*, and *Raffaelea lauricola*; the four nematodes, *B. fungivorus*, *B. mucronatus*, *B. xylophilus*, and *R. cocophilus*; and the three *G. sitophili*, *P. leptovasorum*, and *P. staheli*. The 326 vector species comprised 296 arthropods, three fungi, two molluscs, 17 nematodes, and two protozoa.

The three fungi included *O. brassicae*, which vectors *lettuce big-vein virus*, *tobacco necrosis satellite virus*, and *tobacco necrosis virus*; *O. radicale*, which vectors *cucumber necrosis virus and melon necrotic spot virus*; and *S. endobioticum*, which vectors *PVX*. The two molluscs, *P. canaliculata* and *Sarasinula plebeia*, both serve as vectors of *A. cantonensis*. The 17 nematode species were from the genera *Anguina*, *Longidorus*, *Paratrichodorus*, *Trichodorus*, *Xiphinema*, and *Zygotylenchus*. They all vector viruses except *Anguina agrostis*, which vectors *R. rathayi* and *R. toxicus*, and *A. tritici*, which vectors *R. rathayi* and *R. tritici*. The two protists were *P. betae*, which vector *BNYVV*, *beet soil-borne mosaic virus*, and *beet soil-borne virus*, and *P. graminis*, which vector viruses in cereal such as barley, oats, rice, and wheat, except for two viruses, the *Indian peanut clump virus* and the *peanut clump virus*, which affect peanuts.

The 326 species comprised 302 identified by the HST and 26 added because they vectored an assessed species. About 38% (n=123) affected a prioritised value. Three species, *A. tritici*, *Frankliniella occidentalis*, *S. subterranea*, and *S. endobioticum* are listed as regulated. A total of 134 species, representing 41% of the total, were reported in Africa; 45% (n=60, N = 134) were reported in a neighbouring country, and 18% (n=24, N = 134) were reported in

Rwanda. None of the species reported in Rwanda was assessed. The majority of the 302 assessed vectors could be introduced solely as contaminants (86%; n=259), while the least (1%; n=4) as stowaways. The remaining 39 (13%) could be introduced via multiple pathways: seven as contaminants, 32 as contaminants or stowaways, and 32 as contaminants, stowaways, or unaided. The highest overall score was 175 for 28 species, and the lowest was two for two species. All the data are presented in Supplementary Material S15, Sheet: Vector species assessment.

Assessment of vectored organisms

A total of 433 species could be vectored by other assessed species. They comprised 403 generated by the HST and 30 species added either because they were listed as regulated (8) or because assessed species vectored them (22). The regulated virus included two categorised as quarantine (*PVY* and *TBRV*) and six categorised as RNQPs (*BCMV*, *CBSV*, *ACMV*, *CMV*, *MCMV*, and *SCMV*). Only 50% (n=15; N = 30) of the added species were assessed, with the other 50% excluded either because they were reported in Rwanda or did not affect a crop (*A. cantonensis*). The other 14 not assessed included *BBTV*, *BSV*, *BCMV*, *CBSV*, *ACMV*, *CMV*, *MCMV*, *PeVYV*, *PVMV*, *PVM*, *PVX*, *PVY*, *SCMV*, and *SPCSV*.

The 403 species comprised 33 bacteria, 12 fungi, four nematodes, three protists, three viroids, and 348 viruses. The 12 fungi were *A. rigidiuscula*, *A. areolatum*, *Ceratocystis cacaofunesta*, *Ceratocystis paradoxa*, *Fo*CTR4, *Gibberella circinata*, *Haematonectria haematococca*, *L. procerum*, *Leptographium wingfieldii*, *Lidophia graminis*, *R. lauricola*, and *Verticillium albo-atrum*. Arthropods vectored all except for the nematode *A. agrostis*, which vectored *L. graminis*. The four nematodes were *B. fungivorus*, *B. mucronatus*, *B. xylophilus*, and *R. cocophilus*. *B. mucronatus* and *B. xylophilus* are vectored by species in the *Monochamus* genus. The other two nematodes, *B. fungivorus* and *R. cocophilus*, are vectored by *O. erosus* and *R. palmarum*, respectively.

The three protists, *G. sitophili*, *P. leptovasorum*, and *P. staheli* are all vectored by arthropods, including *Sitophilus oryzae*, which vectors *G. sitophili*, and *Dieuches humilis*, *N. viridula*, *Nysius euphorbiae*, and *Phthia picta*, which vector *P. leptovasorum* and *P. staheli*. The three viroids are *citrus exocortis viroid*, *potato spindle tuber viroid*, and *tomato apical stunt viroid*. *Citrus exocortis viroid* is transmitted by the plant-parasitic species *C. ceanothi*. *Potato spindle tuber viroid* and *tomato apical stunt viroid* are transmitted by *Myzus persicae* (green peach aphid) and *Bombus terrestris* (bumblebee), respectively. All the 33 bacterial species except for *R. rathayi* and *R. toxicus* are vectored by *A. agrostis*, and *R. tritici* is vectored by *A. agrostis*. The 348 viral species are vectored by arthropods (the majority), fungi (*O. bornovanus*, *O. brassicae*, *O. radicale*), nematodes (*P. anemones*, *P. minor*, *P. pachydermus*, *P. porosus*, *P. teres*, *T. obtusus*, *T. primitivus*, *T. similis*, *T. viruliferus*, *X. americanum*, *X. diversicaudatum*, and *X. rivesi*), and protists (*P. betae* and *P. graminis*).

The 403 species comprised 176 reported in Africa, of which 24% (n=43; N = 176) were reported in a neighbouring country. Some species could be introduced solely as contaminants (15%; n=61; N = 403) or stowaways (40%; n=163; N = 403), while others could be introduced through multiple pathways. They include 176 (44%; N = 403) that could be introduced as contaminants and stowaways, and three (less than 1%) as contaminants and unaided. The highest overall risk score is 175, recorded for 23 species, while the lowest score is two, recorded for one species, *L. wingfieldii*. All the data are presented in Supplementary Material S15, Sheet: Vectored species assessment.

Actions for management

A no-action was recommended for 1,266 species, representing approximately 58% (N = 2,166) (Table 5). This group included 25 species, of which 24 have already been reported in Rwanda, and one (*A. cantonensis*), which does not infect plants but humans, was not assessed. All these 24 species were vectors, except for *Mycosphaerella cruenta* and *pepper veinal mottle virus*. The remaining 1,244 species included 1,239 with overall risk scores below 54; therefore, their risk was considered very low at the time of assessment but could still be monitored. Five species had overall risk scores above 54. They included *Belonolaimus longicaudatus* (60), *Candidatus Liberibacter solanacearum* (90), *Penicillium ulaiense* (72), *Squash leaf curl virus* (140), and *Trirachys holosericeus* (175) and were recommended for this action because the pathways for introduction were not plausible. The 44 regulated species were recommended for a no-action because their risk was very low. The 1,266 species included 295 arthropods, 62 bacteria, 36 chromists, 522 fungi, 13 molluscs, 53 nematodes, three plants, seven protists, nine viroids, and 266 viruses. All data have been consolidated in Supplementary Material S14 (Sheet: No-action).

Detection-surveillance was considered for 358 species, representing approximately 17% (N = 2,166). The species considered for this action were mainly those found in a neighbouring country, for which a phytosanitary regulation would be inappropriate unless the pest's status in the country is established. This category comprised about 91% (n=328; N = 358) of the species considered for this action. The second category comprised 18 species reported in Africa but not in a neighbouring country, for which it is highly suspected that they may be present in Rwanda (11) or for which status needs to be established to confirm freedom from the pest (11). The 11 species are mainly soft-rot pathogens caused by species in the *genera Dickeya* and *Pectobacterium*, while the seven species include *ASBVd*, *Bactrocera zonata*, *cowpea severe mosaic virus*, *Foc*TR4, *G. pallida*, *Oligonychus perseae*, *P. canaliculata*, and the three *X. fastidiosa* subspecies. The last category comprised species not reported in Africa but of great phytosanitary concern, for which surveillance is required to establish freedom from the pest. In addition to soft rot pathogens, this category included one emerging bacterial organism in the genus *Xylella*. The three subspecies were suggested for this category. A total of 85 species listed as regulated were recommended for surveillance to establish pest status before their reinstatement on the regulated list. The 358 pests comprised 103 arthropods, 47 bacteria, 17 chromists, 134 fungi, two molluscs, 19 nematodes, two viroids, and 34 viruses. All data have been consolidated in Supplementary Material S14 (Sheet: Surveillance).

The previous list of regulated pests for Rwanda was last updated in 2022; however, analysis indicates that it requires revision, as some quarantine pests have been reported in Rwanda since then. The proposed list includes 563 species classified as quarantine (522) and RNQPs (41). Of the 112 regulated pests on the previous list, 112 were considered; however, some species were elevated to quarantine status or downgraded to RNQP status. For instance, one species, *Magnaporthe grisea*, previously indicated as RNQP, was elevated to quarantine status. Of the 17 species initially classified as quarantine were downgraded to RNQP status because they have since been reported in Rwanda. The 85 regulated species for which a surveillance was recommended could be reinstated on the regulated list after establishing pest status. The 521 quarantine pests comprise 94 arthropods, 58 bacteria, 26 chromists, 156 fungi, seven molluscs, 66 nematodes, one plant, two protists, eight viroids, and 103 viruses (Table 6). The 42 RNQPs comprise five arthropods, five bacteria, two chromists, 12 fungi, two nematodes, one protist, and 15 viruses (Table 6). All data have been consolidated in Supplementary Material S14 (Sheet: Surveillance).

Additional management actions included developing contingency and response plans; communicating the risk by raising public awareness; collaborating with industry to limit the introduction and spread of high-risk species; and conducting research to support evidence-based phytosanitary decision-making. A contingency plan has been proposed for 19 pest species, including six arthropods, seven bacteria, two fungi, one mollusc, two nematodes, and one viroid (Supplementary Material S14; Sheet: Contingency Plan). Awareness-raising has been proposed for 22 species, including five arthropods, 13 bacteria, one fungus, one mollusc, one nematode, and one viroid (Supplementary Material S14; Sheet: Publicity). Five species, including *ASBVd*, *Clavibacter nebraskensis*, *O. perseae*, *P. canaliculata*, and *Trogoderma granarium*, were identified as posing a risk to the industry and were recommended to be managed by industry (Supplementary Material S14; Sheet: Management by Industry). Lastly, the development of new knowledge for evidence-based management and phytosanitary guidance was identified for 22 species. They include two arthropods, 17 bacteria, two fungi, and one nematode (Supplementary Material S14; Sheet: Research). Species considered for additional categories were also for either surveillance or regulation.

Discussion

The World Trade Organisation's (WTO) Agreement on the Application of Sanitary and Phytosanitary (SPS) Measures, also known as the SPS Agreement, establishes guidelines on the measures a country may take to protect human, animal, and plant life and health from risks related to food safety and pests or diseases (WTO, 2025). The SPS Agreement allows WTO members to set their own standards on food safety and animal and plant health. However, these standards must be based on science, applied only to the extent necessary to protect human, animal or plant life or health, and not arbitrarily or unjustifiably discriminate between countries where identical or similar conditions prevail. Under the SPS Agreement, the standard-setting body for plant health, the International Plant Protection Convention (IPPC), has the primary role of protecting the world's plant resources from the introduction and spread of pests while facilitating safe international trade (IPPC, 2025). This mission is achieved by implementing various International Standards for Phytosanitary Measures (ISPMs), established and regularly reviewed by the Commission on Phytosanitary Measures. The Law on Plant Health Protection in Rwanda (Law 16 of 2016[6]), under ARTICLE THREE, provides that the import of any plant, plant product, or other article that may contribute to the introduction and spread of pests is subject to a licence and a phytosanitary certificate.

Using the CABI HST, a list of pest species not reported in Rwanda but present in other countries where Rwanda may source commodities (including plants and plant products) was compiled, and key species were identified. These species underwent a rapid risk assessment to determine which might require measures to prevent their introduction and spread. This step helps address the lack of information about high-risk species, a common challenge faced by many countries in SSA (Mulema et al., 2022). When such information is available, it allows for the development and enforcement of measures, particularly phytosanitary measures, to prevent the introduction and spread of high-risk species.

Prevention remains the most cost-effective method for managing IAS and can be achieved by restricting pathways of introduction. Most IAS are primarily introduced via two pathways: contaminants and stowaways, with the contaminant pathway being the more significant. The majority of contaminants arrive through regulated articles[7] such as flowers, fruits, grains, growing media, planting materials (including bits, budwood, corms, crowns, micropropagated plants, minisetts, rhizomes, runners, seed, seedlings, stem cuttings, suckers, sugarcane setts and stalks, sweet potato slips, tubers, and vine cuttings), wood (including bark, dunnage, logs, and lumber), and wood packaging materials (such as bins, boxes, cases, chips, containers, crates, reels, drums, pallets, pallet collars, and skids). High-risk species that could be introduced through these commodities can be prioritised and included on regulated lists as quarantine species. Through a pest risk analysis, a comprehensive risk assessment is conducted to inform phytosanitary import requirements. This study has prioritised 522 species which should be regulated within the territory of the Republic of Rwanda.

Creating a list of pests for regulation supports the objectives of the Kunming-Montreal Global Biodiversity Framework (KMGBF). The KMGBF is an international agreement adopted in December 2022 to halt and reverse biodiversity loss. It acts as a roadmap for global action through 2030, setting four goals and 23 targets for a world living in harmony with nature. The framework addresses threats to biodiversity, promotes the sustainable use of biodiversity, and provides tools and solutions for implementation. Actions to

6 https://bwcimplementation.org/sites/default/files/resource/Law%20on%20Plant%20Health%20Protectionin%20Rwanda.pdf. Accessed on 28 July 2026 at 03:43

7 Regulated article is regarded as any plant, plant product, storage place, packaging, conveyance, container, soil and any other organism, object or material capable of harbouring or spreading pests, deemed to require phytosanitary measures, particularly where international transportation is involved

achieve the set targets shall be implemented consistently and in harmony with the Convention on Biological Diversity (CBD) (CBD, 2002) and its Protocols. Invasive alien species can cause significant harm to the environment, the economy, or human health when introduced into new ecosystems. The CBD emphasises the need for effective management and mitigation of IAS to protect biodiversity. Target six of the KMGBF, is specifically aimed at eliminating, minimising, reducing and or mitigating the impacts of IAS on biodiversity and ecosystem services by identifying and managing pathways of the introduction of alien species, preventing the introduction and establishment of priority IAS, reducing the rates of introduction and establishment of other known or potential IAS by at least 50% by 2030, and eradicating or controlling IAS, especially in priority sites (CBD, B, 2024). The set targets will also be implemented in line with other relevant international obligations, taking into account national circumstances, priorities, and socioeconomic conditions.

ARTICLE TWO and SECTION TWO of the World Trade Organization (WTO) SPS Agreement state that SPS measures must be applied only to the extent necessary to protect human, animal, or plant health, be based on scientific principles, and not be maintained without sufficient scientific evidence. Therefore, developing and maintaining an up-to-date, evidence-based list of regulated pests is essential to prevent their introduction and spread in Rwanda and to align with the SPS Agreement. The current list of regulated pests for Rwanda was last revised in 2022. From this list, 85 species found in neighbouring countries were recommended for detection surveillance to establish pest status before they are reinstated on the list, to avoid regulating pests that may already be present in Rwanda. In addition, all other species present in a neighbouring country can only be regulated if there is sufficient evidence that they are not present in Rwanda. Other pests removed from the current regulated list included those that do not affect a host grown in Rwanda or for which there is no plausible pathway of introduction, which is also consistent with the SPS Agreement.

Once an IAS has been introduced, the next goal is eradication, followed by containment. This is achievable with an effective early-detection and rapid-response system and the availability of information about high-risk species. For some species that are not present in a neighbouring country, routine detection surveillance in likely hotspots has been recommended for *ASBVd*, *Bactrocera zonata*, *cowpea severe mosaic virus*, *Dickeya* species, *Foc*TR4, *G. pallida*, *Pectobacterium* species, *Oligonychus perseae*, *P. canaliculata*, and the three *X. fastidiosa* subspecies. A contingency and response plan has also been proposed to guide actions by key actors once the pest is detected in the country. This strategic framework aims to address various challenges posed by IAS through comprehensive planning and implementation, ensuring effective management processes are in place to mitigate their impact on ecosystems and biodiversity. Capacity, in terms of equipment, knowledge, and up-to-date protocols, is required to support early detection initiatives and enhance border interceptions. Interceptions are key to detecting and stopping pests and other contaminants at borders and are part of an effective border biosecurity strategy.

Stopping the introduction and spread of high-risk species is not only the responsibility of RICA and the Rwanda NPPO, but also of

TABLE 6 Summary of the new suggested list of regulated pests for Rwanda.

Pest group	Quarantine						Regulated Non-quarantine pest						
	Abscent in Africa (A)	Present in Africa (B)	Present in a country neighbouring Rwanda	Present in Rwanda	Affects a priority crop	Total (C = A+B)	Abscent in Africa (D)	Present in Africa (E)	Present in a country neighbouring Rwanda	Present in Rwanda	Affects a priority crop	Total (F = D + E)	Total (G = C + F)
Arthropods	04	90	03		42	**94**		05	05	05	05	**05**	**99**
Bacteria	08	50	07		37	**58**		05	05	05	05	**05**	**63**
Chromista	01	25	01		10	**26**		02	02	02	01	**02**	**28**
Fungi		156	01		79	**156**		12	12	12	10	**12**	**168**
Mollusca		07			04	**07**							**07**
Nematodes	16	50	02		45	**66**		02	02	02	02	**02**	**68**
Plants		01	01			**01**							**01**
Protista		02			01	**02**		01	01	01	01	**01**	**03**
Viroids		08				**08**							**08**
Viruses	01	102	07		39	**103**		15	15	15	09	**15**	**118**
Total	**30**	**491**	**22**		**257**	**521**		**42**	**42**	**42**	**33**	**42**	**563**

The bold values indicate tolals for each section.

many other actors, including academia, agricultural extension service providers, farmers, researchers, travellers, and the private sector, particularly importers. Therefore, it is essential to develop an effective risk communication strategy to raise awareness amongst all key actors about high-risk species. Agricultural extension providers can be included in surveillance initiatives, especially for general surveillance, because they interface with farmers and the general public more frequently than NPPOs and are more likely to detect or receive reports of alien species. Secondly, in areas where plant clinics are conducted, there is a high likelihood that farmers will introduce an alien species or report a plant health problem likely caused by one (Rambauli et al., 2021). Reporting of unusual plant health problems by farmers can be strengthened by raising awareness of these issues through plant health rallies (PHRs). The PHRs are community meetings held by experts, such as agricultural extension officers (often called plant doctors), to inform farmers about plant health problems and educate them on management (Ochilo et al., 2022). In addition to raising awareness among farmers, specialised training can be provided to other actors, especially importers.

There is a need to ensure that phytosanitary measures are regularly updated and science-based or technically justified. However, research is not the core mandate of most NPPOs, though many are increasingly involved in phytosanitary research. It is essential that collaborative initiatives be established between the NPPO (RICA), Authorised Entities/Assignees, Producers and Farmers, Traders and Exporters, Researchers and Academia, and the general public. For instance, while a farmer may raise an alarm about the possibility of a new pest, diagnosis to confirm the identity is mostly conducted by research through the National Agricultural Research Systems (NARS), which also includes Academia; however, reporting should be done to the NPPO of Rwanda, which issues the official pest status in the country. In addition, authorised entities may also assist in inspection and surveillance. The NARS in Rwanda can also support routine surveillance; the development or adaptation of detection protocols and management strategies; the development of model pathways of introduction; vector studies; and other phytosanitary research areas. A couple of pests have been suggested for which research may be undertaken.

Collaborative initiatives can be established between RICA and other regional NPPOs, such as Direction de la Protection des Végétaux (DPV) of Burundi, Kenya Plant Health Inspectorate Service (KEPHIS), Tanzania Plant Health and Pesticides Authority (TPHPA), Department of Crop Inspection and Certification (DCIC) of Uganda, and Plant Quarantine and Phytosanitary Service (PQPS) of Zambia. This is essential because most of the high-risk species in Rwanda are also prioritised in Burundi, Kenya, Uganda, and Zambia, where rapid risk assessments have been conducted; however, some of the high-risk species that are not reported in Rwanda have been reported in these countries (Mulema et al., 2022, 2024, 2025a, 2025b).

Once IAS are widely distributed and there is no economic reason for eradication or containment, the focus shifts to protecting assets by deploying climate- and nature-smart management options. These include using low-risk products, developing tolerant varieties, and applying classical biological control. While some pests may be widespread, as confirmed by a delimiting survey and therefore do not qualify as quarantine pests, if their presence in plants for planting could affect the intended use of those plants with an economically unacceptable impact, they may be regulated as RNQPs. Most of these pests are caused by bacteria, nematodes, viroids, viruses, and some arthropod pests. Although the list may be updated regularly, up to 41 pests have been proposed for regulation as RNQPs. Updating the risk status of the assessed species can be achieved by establishing a register of priority pests. The NPPO may establish a risk monitoring group that should meet regularly to assess changes in the likelihood of introduction and establishment, and the associated impacts of each pest. In some NPPOs, risk monitoring groups may be referred to by alternative names, such as the PRA group. Risk monitoring is a key component of the pest risk analysis process. Such risk registers have also been established in other countries, including Burundi, Ghana, Kenya, Uganda, and Zambia.

Conclusion

Invasive alien species are recognised as a major cause of biodiversity loss, and their impacts on the economy and livelihoods should not be underestimated. Risk assessment is the first step in addressing information gaps about high-risk species and establishing management mechanisms. Since risk is dynamic, it is essential that Rwanda consistently updates risk levels for the assessed species through ongoing risk monitoring. This monitoring will also help expand the current list of priority pests with new risks. Rwanda should also utilise existing information to strengthen phytosanitary research; however, it is crucial to establish or reinforce collaborations with academia and research institutions. The NPPO (RICA) should further strengthen existing partnerships with regional NPPOs, as regional preparedness against IAS is more effective. While information from this work is vital for protecting Rwanda against the threat of IAS, it also underscores Rwanda's commitment to global initiatives such as the SPS Agreement, the IPPC, the CBD, the KMGBF, and regional initiatives such as the EAC. This information will also be used by other countries in the region and globally to address risks associated with IAS.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

Author contributions

JM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. BU: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. LH: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. BW: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. PM: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. EB: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. MM: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. PI: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. CB: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. PN: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. TM: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. SM: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. JH: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. TH: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. EG: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. LR: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. AN: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. BM: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. DM: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. VB: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. VO: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. OT: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. AH: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. AU: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. SH: Formal analysis, Validation, Visualization, Writing – review & editing. MO: Funding acquisition, Project administration, Writing – review & editing. DK: Funding acquisition, Project administration, Writing – review & editing. MA: Funding acquisition, Project administration, Writing – review & editing. EO: Formal analysis, Funding acquisition, Methodology, Writing – review & editing. WO: Funding acquisition, Project administration, Writing – review & editing. FU: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. AM: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. IR: Methodology, Writing – review & editing. IN: Formal analysis, Methodology, Project administration, Validation, Visualization, Writing – review & editing. PH: Formal analysis, Methodology, Project administration, Validation, Visualization, Writing – review & editing.

Funding

The author(s) declared that financial support was received for this work and/or its publication. The study was carried out as part of CABI's PlantwisePlus Programme, funded by the UK Foreign, Commonwealth & Development Office (FCDO), the Netherlands Directorate-General for International Cooperation (DGIS), the Swiss Agency for Development and Cooperation (SDC), and the European Commission (DG INTPA). CABI is an international intergovernmental organisation and gratefully recognises the core financial support from its member countries (and lead organisations), including the United Kingdom (Foreign, Commonwealth and Development Office), China (Chinese Ministry of Agriculture and Rural Affairs), Australia (Australian Centre for International Agricultural Research), Canada (Agriculture and Agri-Food Canada), the Netherlands (Directorate-General for International Cooperation), Switzerland (Swiss Agency for Development and Cooperation), and Ireland (Irish Aid, International Fund for Agricultural Development-IFAD). For further details, see https://www.cabi.org/what-we-do/how-we-work/cabi-donors-and-partners/.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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