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Prioritisation of quarantine pest list for the Caribbean using a multi-criteria decision approach

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Abstract

Quarantine plant pests are socially, economically and environmentally important due to their impact on food security, human health, global trade and crop production costs. The increase in global trade and tourism, frequent occurrence of natural disasters and climate changes have exacerbated the rate of entry, establishment and spread of plant pests regionally and globally. It has, therefore, become exigent to develop a list of pests of quarantine importance at the regional and national levels to prioritise and allocate the limited available resources to manage the associated risks. In the present study, the Technical Committee on the Formulation and Prioritisation of a Regional Priority Pest List for the Caribbean, in collaboration with the National Plant Protection Organisation of the Caribbean countries and the United States Department of Agriculture - Animal and Plant Health Inspection Service (USDA-APHIS), developed and prioritised a quarantine pest list using a multi-criteria decision-making approach. The technical committee successfully evolved the process in 2014 and 2018 and developed a list of the top 10 pests of quarantine importance for the Caribbean Region, employing the Delphi Technique (DT) and Analytical Hierarchy Process (AHP) through the assignment of criteria that are relevant to the region. The Mediterranean fruit fly (*Ceratitis capitata*), frosty pod rot (*Moniliophthora roreri*) and the tomato leaf miner (*Tuta absoluta*), listed as top quarantine pest threats, were subsequently detected in the region. This exercise guided the authorities in advance to allocate resources and to develop response plans including capacity building for surveillance and detection of priority pests. This has demonstrated the significance and appropriateness of the multi-criteria decision approach to determine priority pest lists and prepare the region for development of better management practices.

Keywords
Analytical Hierarchy Process, Delphi Technique, invasiveness, quarantine pest, economic loss

Introduction

The Caribbean Region, characterised by tropical and sub-tropical agriculture, is well known for its diversity. Each country is unique in culture and food habits. Due to its rich diversity, the region has been listed in the world's 36 biodiversity hotspots with more than 1,500 unique plant species that are not present elsewhere in the world (Mittermeier et al. 2004, 2011). The region produces the popularly-known and sought-after fine flavoured cocoa, some of the hottest peppers in the world with more than one million Scoville Heat Units, high pungency ginger, richly flavoured coffee, Spice Islands 'nutmeg', as well as the premium quality starch from the St. Vincent arrowroot. A range of cereals (rice, corn), vegetables (tomato, hot pepper, cucurbits, cabbage, lettuce, legumes), roots and tubers (cassava, sweet potato, yam, taro), sugar-cane, coconut, spices, coffee, citrus, pineapple, plantain, banana, breadfruit and papaya are also produced for local consumption and export.

According to the Food and Agriculture Organisation of the United Nations (FAO), plants provide over 80% of the food consumed by humans and serve as the primary source of nutrition for livestock. It estimates that 40% of global crop production is lost to pests every year. Annually, plant diseases and invasive insects cost the global economy approximately US$220 billion and US$70 billion, respectively (IPPC Secretariat 2021; Ristaino et al. 2021). To date, over 10,000 fungal species associated with plants have been discovered and it is reported that fungal infections cause more harm than the diseases caused by other pathogenic micro-organisms (Hussain and Usman 2019; Nazarov et al. 2020). A viral infection can lead to 98% crop loss in tropical and sub-tropical regions (Czosnek and Laterrot 1997). Phytoplasma infections can significantly decrease both crop yield and quality. Crop losses to an extent of 40%, 60%, 93%, 30–80% and 100% were reported in eggplant, tomato, pepper, potato and cucumber, respectively specific to Phytoplasma diseases (Kumari et al. 2019). Similarly, plant-parasitic nematodes were reported to cause 12.3% crop losses with an estimated value of US$173 billion per year (Kumar et al. 2020).

Many pests of quarantine importance were also reported in the Caribbean (CABI 2012). Lethal yellowing in coconut was first observed in the Caribbean in the late 1800s and continued to be a serious problem in the Caribbean and Central America

(Johnson 1912; Plavsic-Banjac et al. 1972; CARDI 2013). It was proposed that import of cattle fodder from India to the Caribbean would have carried the vector for Phytoplasma disease affecting palms (Ogle and Harries 2005; Gurr et al. 2016). Similarly, the Fusarium wilt fungus (*Fusarium oxysporum* f.sp. *cubense* race1) that devastated the Gros Michel Bananas variety in the region, might have been introduced into the Caribbean with the Silk banana variety that came from south India and, from there, spread to Central and South America (Blomme et al. 2013). The spread of the invasive hibiscus mealybug (*Maconellicoccus hirsutus*) and the red palm mite (*Raoiella indica*) had a serious impact on Caribbean agriculture. Between 1995 and 1998, an estimated total of US$18.3 million was spent on the control of hibiscus mealybug (Edwards 1999). Although total economic losses due to the pink hibiscus mealy bug have not been computed, the cost in Grenada (1995–1998) included annual losses of an estimated US$4.6 million. Amongst these was the cost of $1.1 million for the control of the mealybug and the loss of 38 hectares of blue mahoe (*Talipariti elatum*). The cost in St. Kitts and Nevis, including the employment of management practices, was estimated to be US$0.3 million. The potential loss to agriculture and forestry in Trinidad and Tobago was estimated to be US$125 million. The total reported loss to the Caribbean was approximately US$138 million – excluding control costs and loss of exports. It was estimated that the potential annual loss to the United States of America if the pink hibiscus mealy bug were established there, would have been US$750 million (Moffitt 1999). The introduction of the Giant African Snail (*Achatina fulica*) from East Africa has been a menace in the Caribbean islands of Antigua, Barbados, Dominica, Saint Lucia and Trinidad (Pollard et al. 2008). Additionally, the Mango Seed Weevil (*Sternochetus mangiferae*) and Black Sigatoka Leaf Spot (*Mycosphaerella fijiensis*) are a few more examples of economically significant pests introduced into the Caribbean (Meissner et al. 2009).

Plant pests have also been a major contributing factor to the declining productivity of key plantation crops that contributed significantly to agricultural gross domestic products earning of foreign exchange and employment generation. This in turn contributed to significant decline in these major plantation crops. Some examples of these are Witches broom in Cocoa; Citrus Tristeza Virus and Huanglongbing (HLB) in citrus production; Lethal Yellowing and Red Ring in coconuts and Black Sigatoka in bananas. The increase in agricultural trade due to a huge reliance on food imports (valued at US$5 billion), the high dependency of Small Island Developing States (SIDS) on tourism for their livelihood, the frequent occurrence of natural disasters in the region and the greater vulnerability of SIDS to climate change have intensified the chances of entry, establishment and spread of invasive pests in the region. The Caribbean Region has experienced serious economic, social and environmental challenges due to the intrusion of invasive pests (Pollard et al. 2008). When invasive alien species (IAS) are introduced into the novel habitat with enhanced survivability, they can cause widespread harm to both native and cultivated plant populations. The losses from damage and costs associated with management of established IAS could exceed the cost of measures to prevent introductions from occurring. In this regard, many National Plant Protection Organisations (NPPOs) around the world use a proactive approach through the implementation of trade restrictions as a strategy to minimise the probability of introduction of IAS. NPPOs may also use various strategies to stay informed about pest species that may threaten their respective jurisdictions. In this context, it is important to prioritise the list of pests of quarantine importance and to design strategies for preventing the entry of exotic pests into the country. The strategies include monitoring, assessing and developing capacities to identify and diagnose at all levels, developing an early warning system and risk mitigation measures and developing a national pre-border, border and post-border response plan with continuous intelligence. Furthermore, the prioritisation process guides the national and regional authorities to prioritise and allocate resources towards the implementation of appropriate quarantine and phytosanitary measures (MacLeod and Lloyd 2020).

At the same time, inconsistencies in the randomised prioritisation process may negatively impact sound judgement leading to the oversight of the differences in potential outcomes and the high-risk factors. There is, therefore, a strong need for a standard, precise and rigid valuation process that minimises biases and accommodates multiple factors when prioritising regional pests. In this context, Delphi Techniques and the Analytical Hierarchy Process (AHP) were explored in the present study.

The Delphi method, named after the ancient Greek oracle, was developed by the research organisation RAND in the 1950s to apply research and development-based decisions to predict military actions. Of late, this technique has been popularly used in economics to gain consensus amongst anonymous experts by sharing a specific research question (de Villiers et al. 2005). This technique has been demonstrated to accomplish a convergence of opinion on a specific real-world issue. This has been successfully applied in the field of medicine, social policy, tourism and sustainability where specific information is limited and contrary. However, it is less commonly applied in ecology and conservation despite its suitability in dealing with biodiversity management issues that are equally complex and involve multiple stakeholders and trade-offs (Mukherjee et al. 2015). It has the advantage of developing a full range of alternatives, exploring or exposing underlying assumptions, as well as correlating judgements on a topic spanning a wide range of disciplines. The Delphi Technique was predicated on the rationale that "two heads are better than one, or n heads were better than one". Common surveys often try to identify "what is important", whereas the Delphi Technique attempts to address "what is priority" (Hsu and Sandford 2007).

Similarly, the AHP has been demonstrated as a successful tool that diligently handles the multi-criteria decision-making process. Due to increasing complex nature of multi-criteria decision-making approaches, especially in the fields of agriculture and biodiversity, the process of decision-making has become more critical and challenged nowadays (Kumar and Pant 2023). This technique has allowed the selection of the best alternatives that depends on multiple criteria and sub-criteria and potentially reduces the complications by making several comparisons amongst the elements of the hierarchy. It captures both subjectivity and objectivity of associated problems and provides an ongoing measure of the consistency of the decisions obtained. Based on analysing the merits and applications of these methods in the multi-criteria decision-making approach, the current study employed Delphi Technique and AHP to prioritise the list of pests of quarantine importance for the Caribbean.

Materials and methods

Technical committee on the formulation and prioritisation of a regional priority pest list

The technical committee of the Caribbean region was constituted in 2011. The committee was comprised of the regional subject matter specialists viz. an entomologist, fungal pathologist, virologist, bacteriologist, malacologists, nematologist, weed scientist and an agricultural economist. The committee employed the Delphi Technique and the Analytical Hierarchy Process to formulate and prioritise the regional pest list of quarantine importance in 2014 and 2018. Prior to the committee meetings, a series of virtual meetings and email transactions were held to share the quarantine list of national importance from the National Plant Protection Organisation of the Caribbean countries. These lists were consolidated for consideration and analysis by the committee.

Delphi Technique in prioritisation of regional pest list

The Delphi Technique is used to estimate the likelihood and outcome of future events, based on expert opinion. It places a premium on "Expert Opinion" and uses qualitative information provided by reputable professionals working in a particular subject-matter area.

In this study, the National Technical Authorities were trained in the development of national pest lists, based on the traditional guidelines and International Standards for Phytosanitary Measures (ISPMs). The quarantine pest list of the Caribbean countries (Antigua and Barbuda, Dominica, Dominican Republic, Grenada, Jamaica, Guyana, Guadeloupe and Martinique, Trinidad and Tobago, Saint Lucia and Saint Kitts and Nevis) were reviewed firstly in the process of prioritising a regional pest list by the Regional Technical Committee. The following resources were consulted by the experts in shortlisting the regional pests.

1. The Centre for Agriculture and Bioscience International (CABI) Invasive Alien Species Compendium;
2. Caribbean Pathway Analysis (Meissner et al. 2009);
3. The CARICOM's List of 19 Commodities of Importance;
4. The Agriculture Policy Programme, in which CARICOM identified three (3) commodities that include cassava, condiments, spices and herbs.

Each expert selected their top 10 insect pests, weeds, molluscs, fungi, bacteria, nematodes and viral pathogens, based on the following criteria:

- Invasiveness;
- Potential Spread Entry/ Exit Pathway;
- Impact on social systems;
- Economic domestic impact;

- Economic Trade Impact;
- Economic and Environmental goods Impact;
- Environmental impact;
- Feasibility of Management.

The details of factors considered for each criterion is given in Table 1. After the consultation process facilitated by the technical committee coordinator, the subject matter specialists presented the pest lists. Based on the opinion of the specialists, the top priority pest list was compiled.

Analytical Hierarchy Process in prioritisation of regional pest list

To rank the pests of importance identified from the Delphi Technique (DT), the Analytical Hierarchy Process (AHP) was used in the current study. AHP is a multi-criteria

Table 1. Pest Prioritisation Criteria used by experts in the Delphi Technique.

Criteria	Factors
1. Invasiveness (establishment)	• Pest has demonstrated invasive capability in new distribution outside of its natural range • Pest is distributed in climates similar to that throughout • Hosts of the pest are available and prevalent in the region • Reproductive potential is high (no. progeny/female; no. generations/year; asexual capability) • Dispersal capabilities • How invasive the pest (Ability to establish and thrive)
2. Potential Spread Entry/ Exit Pathway	• Pest is highly mobile (capable of flight; carried easily by wind, other organisms or moving water) • Natural barriers in country absent or not likely to prevent natural spread of the pest • Pest travels with commodities that are moved commonly by man • Documentation and factors to consider: ○ high interception numbers ○ hitchhikes on non-hosts ○ frequently imported commodities are hosts ○ hosts imported for planting ○ Is smuggling likely? ○ What have neighbouring countries recorded for these items?
3. Impact on social systems	• Food security • Loss of employment • Human health • Livestock and pet health • Amenities • Heritage values
4. Economic / domestic impact	• Production cost, domestic market share • GDP considerations • Crop Loss / loss of primary production • Farmers cost of controlling or managing pest
5. Economic / Trade Impact	• Foreign trade / exports of goods
6. Economic / Environmental goods Impact	• Impact on tourism products – export of services and aesthetic value • Reduction in or limitation to indigenous species (flora and fauna) • Negative ecosystem changes
7. Feasibility of Management	• Public costs including surveillance, detection and control

decision-making method that was developed and extensively studied by Thomas L. Saaty in the 1970s. It is grounded in mathematics and human psychology and has specialised application in group decision-making where a diversity of skills, knowledge and experiences are of particular value. The subject matter specialists used the recommendations from the DT to rank pests using the AHP. The AHP model, viewed as better suited to the development of the Caribbean pest list, was tailored by Seepersad and Ram (2011) and used in the current study. The AHP model is given in Suppl. material 1.

The process of ranking the plant pest list comprised of the stepwise processes: (i) identifying the criteria that were relevant to the region, based on the social (food security, human health), environmental (crop health, aesthetic value and ecosystem health) and economic importance (production costs, foreign trade and export earnings, public costs), (ii) developing a scale of importance for pairwise comparison of the criteria identified to prioritise the pest list, (iii) assigning a value to each criterion, based on the importance of the problem, (iv) calculating weightage for each criterion, (v) employing weightage of each criterion to calculate the value for each pest and (vi) ranking of the pest list identified, based on the overall weightage derived. In the current study, a list of seven criteria was developed as a strategy to reduce subjectivity and to keep experts focused on distinct issues. These were selected, based on its relevance to agriculture in the Caribbean region (Table 2):

Table 2. Caption text.

Criteria	Rationale for selection of the criteria
1. Food Security	Food security could be compromised in the Small Island Developing States when the crops are affected by the quarantine pests of importance and could result in civil unrest amongst the population in case of food insecurity. The region has been already toiling with a high food import bill of US$13.76 billion from 2018–2020.
2. Human Health	The zoonotic nature of invasive plant pests of quarantine importance has been taken into consideration as it could potentially harm human health affecting the productive working population and collapsing the public health system. In addition, the nature of toxins produced by the quarantine pests of importance including mycotoxins were taken into consideration for listing this criterion in the list.
3. Crop Health	Healthy crop is critical for feeding the population with safe and nutritious food. When a pest of quarantine importance affects the crop health, it could result in demanding the application of highly hazardous pesticides which in-turn affect the environmental health and animal health.
4. Aesthetic Value / Ecosystem Health	As the Small Island Developing States highly depends on eco-tourism, the quarantine pests affecting the ecosystem health could hamper the economy generated from the tourism. For example, a pest of quarantine importance in coconut and palm trees could potentially destroy the ecosystem in the beaches/seashore. Additionally, when pests of horticultural or ecosystem-associated crops enter the region, management using pesticides would be a determinant to the ecosystem health.
5. Production costs	When quarantine pests of importance affect the crop, the costs incurred in eradication and or prevention of spread of a pest within the island or to the neighbouring island cultivating the same crop and management of a pest, are considered as critical in the Small Island Developing States as all crop production inputs are imported to the region.
6. Foreign Trade / Exports	Since the region has rich diversity and unique environment to produce high value crops that fetch good price at the international market through foreign trade, the entry of quarantine pests of such high-value crops (cocoa, spices, hot pepper) could destroy the industry. Hence, the quarantine pest and its impact on foreign trade was included in the selection criteria to prioritise the pest list.
7. Public Costs	When quarantine pests affecting the high-value crops or tourism industry, the governments would have to put forth the measures at community level supporting the farmers/producers through incentives, supply of chemical inputs etc. In this case, the spending of the public costs would be determined by the nature of quarantine pests. Hence, the reason for inclusion of the criterion in selection of pest list.

Since each country is unique, the criteria in one country could be more important than in another. Each criterion was, therefore, assigned a set of weights. A pair-wise comparison matrix was developed and each criterion was weighted relevant to the other. This process provided the judgements required to develop the matrices. Each criterion was compared with another criterion using a rating scale from 1 to 9 and weightage was developed as presented in Tables 3, 4 and 5 and Fig. 1. The process of identifying a prioritised pest list for the Caribbean using AHP was conducted by the Technical Committee in Tobago in 2014 and in Trinidad in 2018. The process was intensive and systematic with face-to-face sessions.

Table 3. Scale of importance for pairwise comparison of criteria set for prioritising pest list.

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one element over another
5	Strong importance	Experience and judgement moderately favour one element over another
7	Very strong importance	One element is favoured very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation
2, 4, 6, 8 can be used to express intermediate values. 1.1, 1.2 etc. for elements that are very close in importance.		

Table 4. Pairwise comparison and ranking of the criterion identified for prioritising the pest list.

Matrix	Food Security	Human Health	Crop Health	Aesthetic Value / Ecosystem Health	Production Costs	Foreign Trade / Exports	Public Costs
Food Security	1	1/5	5	7	1	5	5
Human Health	5	1	5	7	7	5	5
Crop Health	1/5	1/5	1	5	1/3	1/5	3
Aesthetic Value / Ecosystem Health	1/7	1/7	1/5	1	3	3	3
Production Costs	1	1/7	3	1/3	1	3	3
Foreign Trade / Exports	1/5	1/5	5	1/3	1/3	1	1
Public Costs	1/5	1/5	1/3	1/3	1/3	1	1

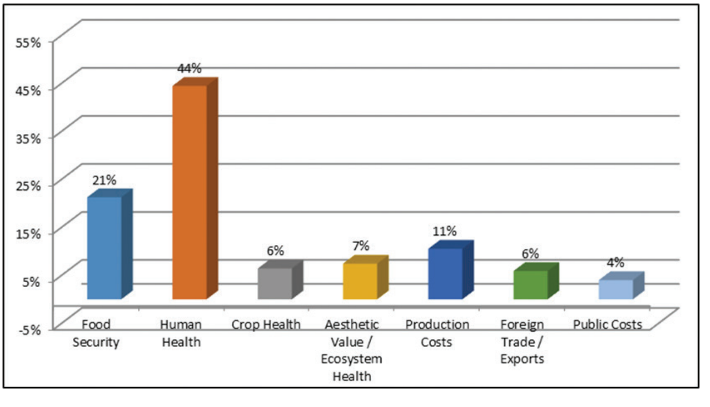

Figure 1. Percentage of weight assigned to criteria, based on the importance of problem.

Table 5. Developing weightage to the criteria, based on the significance in relation to occurrence of pest.

Criterion	Mean value of comparison	Weight
Food Security	2.0914	0.2126
Human Health	4.3739	0.4446
Crop Health	0.6314	0.0642
Aesthetic Value / Ecosystem Health	0.7297	0.0742
Production Costs	1.0366	0.1054
Foreign Trade / Exports	0.5805	0.0590
Public Costs	0.3943	0.0401
TOTAL	**9.8378**	**1**

Results

Priority quarantine pest list identified in 2014 using DT and AHP

The use of the Delphi Technique by the experts has resulted in the determination of 15 regional priority pests for the Caribbean (Table 6). Five pests (Lethal yellowing in coconut; *Cyperus rotundus*, *Parthenium hysterophorus*: Giant African Snail, Black sigatoka leaf spot) that were reported as regulated quarantine pests in some of the islands were removed from the list of 15 before employing the AHP model. The Carambola Fruit Fly, Black Sigatoka leaf-spot and *Fusarium* Tropical Race 4 pathogens were listed as pests of quarantine importance due to their possible impacts on food security. Red Palm Weevil was included in the list, based on their impact on ecotourism as a result of the pest capacity to devastate the palm plants in those islands with large tourism industries. The Mediterranean Fruit Fly,

Table 6. Pests of quarantine importance for the Caribbean in 2014 using the Delphi Technique.

Subject Matter Specialist	Top 15 Pest of importance to the region	Criteria used to determine the pest being in the top 10 for the region
Entomology	Red Palm Weevil (*Rhynchophorus ferrugineus*)	Aesthetic / Food Security / The Plant Propagative Material
	Mediterranean fruit fly (*Ceratitis capitata*)	Production cost and domestic trade implications
	Carambola fruit fly (*Bactrocera carambolae*)	Food security /Economic impact
	Cassava mite (*Mononychellus tanajoa*)	Food security
	Tomato Leaf miner (*Tuta absoluta*)	Food security
Fungi	Fusarium wilt in Banana (*Fusarium oxysporum* f.sp. *cubense* TR4)	Food security/ Economic Impact
	Frosty pod rot in Cacao (*Moniliophthora roreri*)	Trade implications
	Black Sigatoka leaf spot in Banana (*Mycosphaerella fijiensis*)	Food security/ Trade implications / Natural Spread Pathway
Viruses	Citrus leprosis virus	Trade implications
Bacteria / Phytoplasma	Bacterial wilt in banana (*Ralstonia solanacearum*)	Production cost and domestic trade implications
	Citrus canker (*Xanthomonas citri* subsp. *citri*)	Trade implications
	Lethal yellowing in coconut (*Candidatus Phytoplasma*)	Economic and environmental impact (aesthetic value)
Weeds	Nut grass (*Cyperus rotundus*)	Food Security / Economic Impact / Human Movement Pathway
	White top (*Parthenium hysterophorus*)	IAS / Food security/ Public cost
Molluscs	Giant African Snail (*Achatina fulica*)	Human Health / Public cost / Hitch hiking Pest

Frosty Pod Rot, Citrus Leprosis Virus and Moko Wilt pathogens topped the list for domestic and international trade implications. The pests identified using DT, however, did not prioritise one pest over another, but rather only listed the top 10 pests. It was, therefore, difficult for the national authorities to allocate resources to mitigate risk through surveillance and the development of emergency action plan for management. This was overcome using the AHP process, which dexterously used the weightage for each criterion to rank the pest.

In the present study, the AHP model assigned a higher weight to the human health criterion (44%), followed by food security (21%). The lowest weight was assigned to the public costs criterion at 4%. The exercise conducted in 2014 ranked the Mediterranean Fruit Fly (*Ceratitis capitata*) as a pest of high-risk importance, followed by the Carambola Fruit Fly (*Bactrocera carambolae*). The least importance was given to the Cassava Mite and Citrus Leprosis Virus. *Fusarium* Wilt TR4 that received global attention during this assessment period found a place in the top 5 list (Table 7).

Priority quarantine pest list identified in 2018 using DT and AHP

The exercise conducted in 2018 employing DT and AHP methods respectively identified and prioritised the top 10 regional quarantine pests (Table 8). In 2018, the Mediterranean Fruit Fly (insect) was ranked as a pest of high risk to the region followed by *Fusarium* TR4 (fungus) and Tomato Leaf Miner (insect). The Bacterial Wilt, Frosty Pod Rot and Lethal Yellowing were assigned a moderate score by the AHP model. Citrus Canker and Leprosis, Fiji Disease in sugar-cane and Bacterial Panicle Blight in rice were rated low in the model (Table 8).

Discussion

The present study was an attempt to hone the process of developing a regional priority pest list using a multi-criteria decision-making approach. The Delphi Technique was useful in the current study, based on the discussion, peer review, consultation and opinion of

Table 7. Prioritised quarantine pests identified for the Caribbean using the Analytic Hierarchy Process in 2014.

Pest list derived from Delphi Technique	Weighted Score	Final AHP Ranking of Invasive Alien Species
Pest #1: *Bactrocera carambolae* (Carambola Fruit Fly)	0.153	2
Pest #2: *Fusarium oxysporum* f.sp. *cubense* Race 4 (Banana Fusarium Wilt)	0.130	4
Pest #3: *Moniliophthora roreri* (Cocoa Frosty Pod)	0.065	7
Pest #4: *Tuta absoluta* (Tomato Leaf Miner)	0.126	5
Pest #5: *Ceratitis capitata* (Mediterranean Fruit Fly)	0.166	1
Pest #6: Citrus leprosis virus (Leprosis of citrus)	0.048	9
Pest #7: Citrus canker (*Xanthomonas citri* subsp. *citri*)	0.053	8
Pest #8: *Mononychellus tanajoa* (Cassava Mite)	0.045	10
Pest #9: *Ralstonia solanacearum* (Moko Disease Race 2)	0.138	3
Pest #10: *Rhynchophorus ferrugineus* (Red Palm Weevil)	0.076	6

Table 8. Prioritised quarantine pests identified for the Caribbean using the Analytic Hierarchy Process in 2018.

	Pest list derived from Delphi Technique	Weighted Score	Final AHP Ranking of Invasive Alien Species
A	Pest #1: *Burkholderia glumae* (Rice Bacterial Panicle Blight)	0.064	10
B	Pest #2: Fiji disease virus (Fiji Disease in sugarcane)	0.066	9
C	Pest #3: *Fusarium oxysporum* f.sp. *cubense* (Fusarium Tropical Race 4)	0.125	2
D	Pest #4: *Ceratitis capitata* (Mediterranean Fruit Fly)	0.221	1
E	Pest #5: *Ralstonia solanacearum* (Moko wilt in banana)	0.100	4
F	Pest #6: *Candidatus Phytoplasma* (Lethal yellowing in coconut)	0.086	6
G	Pest #7: *Tuta absoluta* (Leaf miner in tomato)	0.113	3
H	Pest #8: Citrus Leprosis Virus (Leprosis of Citrus)	0.068	8
I	Pest #9: *Moniliophthora roreri* (Cocoa Frosty Pod)	0.088	5
J	Pest #10: *Xanthomonas citri* subsp. *citri* (Citrus canker)	0.069	7

the experts. This was evident from the process, during which the regional technical committee initially attempted to employ the Point Score Analysis in prioritising the pest list, based on the survey with less rigour and lack of scientific evidence (data not presented).

While comparing the DT with the AHP model, the latter was seen as a structured technique for organising and analysing complex decisions. It has been used around the world in a wide variety of strategic decision-making situations, in areas such as border disputes, government, business, industry, healthcare and education. Given the complexity of some problems and the number of factors that should be simultaneously considered to derive the best possible outcome, the AHP boasts of going beyond prescribing a "correct" decision; rather, it can help decision-makers find an option that best suits their goal and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals and for evaluating alternative solutions (Wan et al. 2005; Szabo et al. 2021). The AHP Prioritised Pest List criteria set a strategic objective to identify high-risk quarantine pests for early detection.

The prioritisation process gave way to the first Regional Priority Pest List being completed in 2014 identifying the top 10 pests of regional priority and then once again in 2018. The Pest Prioritisation exercises were seen to be both useful and instructive for the region as the lists identified several key pests that were subsequently detected in the region: Mediterranean Fruit Fly (*Ceratitis capitata*) in the Dominican Republic in 2015 (Zavala-López et al. 2021), Frosty Pod Rot in Jamaica in 2016 (Ministry of Agriculture, Fisheries and Mining, Jamaica 2021) and *Tuta absoluta* in Haiti in May 2019 (Verheggen and Fontus 2019).

The outbreak of Mediterranean Fruit Fly was reported in the Dominican Republic in March 2015, causing an export revenue loss of US$ 40 million within 10 months of outbreak, risking 30,000 jobs (Zavala-López et al. 2021). The rapid action taken by the government, in collaboration with the FAO, the International Atomic Energy Agency (IAEA), the United States Department of Agriculture-Animal and Plant Health Inspection Service (USDA-APHIS), Organismo Internacional Regional de Sanidad Agropecuaria (OIRSA) and the Inter-American Institute for Cooperation on Agriculture

(IICA), successfully eradicated the fruit fly in January 2017 through application of the sterile insect technique and integrated pest management practices. This has protected the horticulture industry of neighbouring countries in the Caribbean, Mexico and United States, circumventing significant economic losses (Zavala-López et al. 2021). It is significant to note that this pest was ranked in the top priority quarantine pest list developed in 2014 using the multi-criteria decision approach.

Similarly, various reports had been received in Jamaica that farmers were losing 40–90% of their production due to frosty pod rot disease. It was estimated to destroy anywhere between 80–100% of the entire production in the island. The first case of the frosty pod rot disease was reported to the Ministry of Agriculture in August 2016, at which point it was discovered that the parish of Clarendon was heavily infested. In a matter of approximately 4–5 months, the disease was discovered to be in the neighbouring parishes of St. Catherine, St. Andrew and St. Mary. It was suspected that the pathway of entry of the frosty pod rot disease would have been through human transmission. Based on molecular analysis, it was discovered that the strain of the frosty pod rot disease in Jamaica is similar to that in Columbia. The prioritisation of pests has assisted the region to develop strategies in advance for the management of the pests where they anticipate an entry and spread into the territory. In this case, the strategies employed in Jamaica included: (i) a delimiting survey to identify how far the disease spread, (ii) training and sensitisation of farmers and other stakeholders of the disease, (iii) creation of a buffer zone that eliminated all the conditions that the disease requires to survive and (iv) training of officers in management practices. Similarly, Huanglongbing or citrus greening disease prioritised for the Caribbean region, though identified in Jamaica earlier, was later detected in Trinidad in 2017, leading to the destruction of 200,000 citrus trees as per the Ministry of Agriculture, Trinidad and Tobago. Tomato leaf miner, ranked in the top 10 list from the 2014 and 2018 exercises, was subsequently reported in 2019 and 2021, respectively, in Haiti and Trinidad. This could pose a potential threat for dissemination to the Dominican Republic and North American countries. This has clearly demonstrated the relevance and usefulness of the priority exercise employed in the development of the regional priority pest list.

Most importantly, the use of pest prioritisation techniques has been highly beneficial to the SIDS that are characterised with poor capacity in allocating resources. The prioritisation process can guide SIDS to precisely direct its resources for the prevention and management of the quarantine pests. In addition, the employment of pest prioritisation techniques will be highly useful in determining the pathways and alerting the inspection processes at air and water borders in SIDS which are highly vulnerable to the entry of invasive pests through tourism-related activities. The prioritisation process has furthermore strengthened the local knowledge throughout the region on quarantine pests of importance. The methods used in the study have flexibility to include or exclude the criteria relevant to the changing and demanding needs of region. This model could be employed elsewhere to prioritise the national or regional pest list, based on the criterion relevant to the region. Though the AHP model permitted the ranking of the pest list, based on the relative importance of the criteria proposed, some challenges still remain due to the dependency of the model on the provision of strong scientific evidence and receipt of an unbiased list of pests. Similar to techniques, such as the Horizon Scanning method (Kendig et al. 2022) which employs arrival, establishment and impact of potential pests, the current study systematically combined and gave equal weightage to invasiveness, spread, establishment and impact to generate the pest list and then used the criteria to rank the pest list. In this context, exploring and comparison of risk-based methods, such as Horizon Scanning and the Pest Assessment and Prioritisation Process (OPEP) models with the current technique could provide further validation and reliability of the models in making multi-criteria decisions in fields like agriculture where many factors need to be considered. In addition, continuous monitoring and recording of the impact of these predictions after prioritising the pest list could provide further insights in improving these models.

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Supplementary material 1

AHP model developed for priotization of quarantine plant pests in the Caribbeean

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Data type: xlsx

Explanation note: The Model can be modified and used for prioritizing plant pests.

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