# EFFICACY AND BIASES IN INSPECTIONS FOR BIOSECURITY THREATS IN SOUTH AFRICA

by

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**Submitted in partial fulfilment of the requirements for the degree**

**Master of Science in Environmental Management**

**In the Faculty of Natural and Agricultural Sciences**

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**FEBRUARY 2024**

## DECLARATION

I, Freedom Rudolf Shabangu, declare that the mini dissertation, which I hereby submit for the partial fulfilment for the degree Master of Science in Environmental Management at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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## ABSTRACT

Trade in agricultural commodities is beneficial economically, but it carries risks, as alien agricultural pests can be imported into new regions. To manage this challenge, inspections of agricultural produce are performed at South Africa's ports of entry. This study aims to evaluate the efficacy and identify biases in agricultural inspections on fresh fruit imports to South Africa. Pest interception data for quarantine and non-quarantine insects from fresh fruit imports between 2008 and 2018 from the South African Department of Agriculture, Land reform and Rural Development was analysed. For this analysis, trade pathways were analysed to have three components: the country of origin (*o*); agricultural commodity (*c*); and insect species (*i*). For each trade pathway, the trade volume to be inspected (TV) and the trade volume to be inspected per interception (TVPI) were calculated using import data and host distribution data. TV is an indicator of the risk of importing a particular organism on a given pathway. TVPI can be used to identify pathways where the expected risk is high (high TV), but where the number of interceptions is lower than expected based on risk. During the assessed period there were 399 interceptions on 13 fruit types imported from 22 countries. Only 48% of interceptions were identified to the species level, with quarantine species accounting for far fewer interceptions (45 individuals of 12 species) than non-quarantine species (354 individuals of 75 species). Control bias was observed in quarantine species, indicating the need to improve inspection strategies and sampling efforts to increase the effectiveness of border controls in South Africa. To promote good biosecurity, further studies should be conducted to analyse control bias based on sampling effort data than interceptions relative to TV, to improve phytosanitary controls on agricultural imports, especially fresh fruit.

**Keywords: Biosecurity, phytosanitary measures, quarantine species, non-quarantine species**

## Introduction

Globalisation and international trade are taking place at unprecedented levels, and as people and goods are transported across the world, organisms are transported with them (Meyerson and Mooney 2007, Westphal et al. 2008; Hulme 2009; Perrings et al. 2009). Consequently, the frequency of international trade has been signalled as one of the primary drivers of Invasive Alien Species (IAS) introductions (Faulkner et al. 2017). These organisms range from micro-organisms and pathogens to plants, and from invertebrates to vertebrates (Meyerson and Mooney 2007). More than a million tons of regulated agricultural commodities (e.g., plants or plant products) are traded all over the world annually (Pimentel et al. 2005, Surkov et al. 2008a). This international trade is linked to an escalating incidence of unintentional transmission of innumerable alien species (Kiritani 2001, Follet and Neven 2006, Hulme 2009, Navia et al. 2010). The introduction and establishment of these alien species is a challenge to agricultural systems and biodiversity (Mack et al. 2000, Kiritani and Morimoto 2004, McGeoch et al. 2010; Sujay et al. 2010). Invertebrates (particularly insects, mites, and nematodes) and pathogens are the most frequently intercepted organisms on plants or parts of plants (Liebhold et al. 2006). These species are usually transported with major agricultural and horticultural commodities, in particular fresh fruit, vegetables, or ornamental plants (McCullough et al. 2006; Kenis et al. 2007). Although the trade in agricultural commodities is beneficial economically, it carries risks, as pests can be imported into new regions, which can cause declines in production capacities, expenditures, and export market prospects (DALRRD 2013). Agricultural pests are mostly introduced as contaminants of commodities because they are often transported with their host plants. However, they are not limited to only this pathway or mechanism (Hulme et al. 2008).

The numerous negative impacts posed by agricultural pests continue to exceed previous projections (Baker et al. 2005). Published figures indicate significant irreversible economic losses that are triggered by these pests (Vilà et al. 2010). In a study published in 2016, the estimated cost to global agriculture of about 1300 invasive pests and pathogens was reported to be approximately US$ 540 billion per year (Paini et al. 2016). As a nation primarily dependent on trade, South Africa is exposed to biological invasions (Tatem 2009), and recently there has been a notable sharp increase in the numbers of recorded introduced arthropods (Giliomee 2011). Agriculture has been identified as the cornerstone of community livelihoods in Africa and the rest of the world (Paini et al. 2016), and, due to this, developing countries, particularly those in sub-Saharan Africa, are most vulnerable to the introduction of alien insects associated with trade. The fall armyworm (*Spodoptera frugiperda,* Lepidoptera: Noctuidae) is an example of an alien species that is an agricultural pest in southern Africa, mostly affecting maize production (Venter 2019).

International best practices in managing biological invasions are premised on key adopted agreements, like the World Trade Organisation-Sanitary and Phytosanitary Measures (WTO-SPS); the International Plant Protection Convention (IPPC); and the Convention on Biological Diversity (CBD), with some mechanisms aimed at prevention (Puth and Post 2005; Bogich et al. 2008; Hulme et al. 2009). The adopted defence to prevent pests from entering South Africa is numerous biosecurity measures applied to imported products (Ivess and Frampton 1997, Schrader and Unger 2003, Maynard et al. 2004, Surkov et al. 2008a). Biosecurity encompasses policy and regulatory frameworks that deals with analysing and management of biological risks to agriculture, food, and the environment (FAO 2003). Quarantine pests are those that could have negative economic impacts in South Africa, but are not yet present in the country, or are present, but have restricted distributions and are under official control (IPPC 2017). These pests are prohibited from entering the country and are identified using Pest Risk Analysis (PRA) based on the International Standard for Phytosanitary Measures (ISPM) No.11 (Black and Bartlett 2020). Phytosanitary measures involve legislation, or official procedure that helps to prevent the introduction and/or spread of quarantine pests (FAO 2003). To prevent the accidental introduction of quarantine pests with imported commodities, South Africa requires pre-border inspections of imported consignments in the country of origin, treatment with a pesticide, and a declaration stating that the consignment is free of any organisms (Saccaggi and Pieterse 2013). Imported agricultural commodities are also subjected to border inspections at ports of entry to confirm that they do not contain any listed quarantine pests, as well as other organisms. Based on the guidelines of the ISPMs, approximately 2% of imported consignments are routinely inspected, as informed by the perceived risk and applicable standard at the time (Venette et al. 2002; McCullough et al. 2006). Although many alien organisms have been intercepted during these inspections, incursions do occur (e.g., *Bactrocera dorsalis*), and there has been no formal assessment of the effectiveness of the current inspection strategies (Faulkner et al. 2020a; Zengeya and Wilson 2020).

The implementation of prioritised inspection strategies could lead to better and more effective border control management if the focus is on the underlying risks or possible costs associated with the introduction of pests (Areal et al. 2008; Surkov et al. 2008a; Bacon et al. 2012). To evaluate the effectiveness of South Africa's agricultural inspections and make recommendations on how they could be improved, interception data collected during inspections at the ports of entry (i.e., airports, land borders and seaports) by the Inspection Services Directorate can be analysed. However, the collected data on interceptions are not ideal for an assessment of inspection efficacy. This is because: (1) non-quarantine species are not considered; (2) consignments can be confiscated without further inspection once a quarantine organism has been detected, and consequently, other exotic species in the consignment are not recorded; (3) species are frequently intercepted as larvae, and often cannot be identified to the species level (see Humble 2010); and (4) only a small proportion of the consignments are sampled, which coupled with limited funding and inadequate personnel to conduct thorough inspections (Simberloff 2006), likely results in a considerable number of organisms not being detected (Stanaway et al. 2001; Work et al. 2005).

To overcome these issues, Bacon et al. (2012) developed a method to evaluate the effectiveness of inspections when data are imperfect. This method uses trade data, information on the hosts and distribution of quarantine pests, and imperfect inspection data. The method is based on the expectation that the greater the quantity of a commodity that is imported, the higher the frequency of detection of a quarantine pest should be, if the pest is present in the exporting country and the imported commodity is a host for the pest. The method developed by Bacon et al. (2012) defines the trade volume to be inspected (TV) as the trade volume weighted by the number of quarantine insect species that can be dispersed by that pathway. While the Trade Volume to be inspected Per Interception (TVPI) is interpreted as a measure of the number of insects passing through border controls undetected. This method can be used in instances where there are limitations to the available inspection data, to identify biases in inspections, and pathways that should be better monitored.

This study adapted the methods of Bacon et al. (2012) to evaluate the efficacy and identify biases in agricultural inspections for biosecurity threats in South Africa. This was achieved by using the official interception list from the Department of Agriculture, Land Reform and Rural Development (DALRRD), and analysed the interception data for contaminant organisms recorded on plant products imported to South Africa (Saccaggi et al. 2021). Although a wide variety of organisms can be transported along with the diverse agricultural products imported into South Africa, this research focuses on insects transported with fresh fruit imports. This is because South Africa’s fresh fruit imports have been steadily increasing since 2010 (Trademap 2018; Phaleng 2020), and the transported fruit can harbour organisms that can pose a biosecurity threat (Nnzeru et al. 2021). For example, some quarantine insects that are polyphagous feeders such as *Unaspis citri* and *Aleurocanthus woglumi*, are reported to be major pests for citrus in Europe and elsewhere in the world (Bacon et al. 2012). Although the work of Bacon et al. (2012) focused on quarantine pests, non-quarantine pests could become agricultural pests or have environmental impacts (Brockerhoff et al. 2014) and, therefore, all taxa (i.e., both quarantine and non-quarantine insects) were considered for this study. The following research questions are addressed in this study: (1) how many interceptions of quarantine and non-quarantine insect species are recorded on fresh fruits; (2) to what extent are pest interceptions identified to species level; (3) on which fruits and from which countries are most interceptions of quarantine and non-quarantine insects detected; and (4) are inspections biased in terms of the exporting countries, fruit types, and pests?

## Materials and Methods

### *Datasets*

A desktop analysis was conducted to assess the efficacy of agricultural inspections at South African ports of entry. The approach and methods developed by Bacon et al. (2012) were adapted for this purpose. Pest interception data for the period from 1994 to 2019 from the South African Department of Agriculture, Land reform and Rural Development (DALRRD) was collated and cross-checked by Saccaggi et al. (2021). For the current study, data between 2008 and 2018 were used, as data from 2008 onwards is of a higher quality than that for previous years (Saccaggi et al. 2021). But, for the analysis these data needed to be combined with product import data, and at the time the study was undertaken the most recent product import data available was for 2018. Therefore, we could not include the inspection data for 2019. The dataset on interceptions was separated into a high taxonomic resolution and a low taxonomic resolution dataset. The high taxonomic resolution dataset included all interception records for which the intercepted insect was identified to species level. However, records with indefinite symbols (e.g., ‘‘cf.’’, ‘‘sp.’’, ‘‘larvae’’) within either the genus or species fields were removed prior to the analyses. The low taxonomic resolution dataset included all interception records for which the intercepted insect was not identified to the species level. From the datasets, information for each interception was extracted on the organism (insect) intercepted, the commodity (i.e., fruit type), and the country of origin. A list of quarantine insects for fruits was obtained from DALRRD. *Phenococcus selonopsis* was included on this list as a quarantine species, but a recent publication (Tshikhudu et al. 2021) indicated that the species is a non-quarantine insect. It was identified as a quarantine species on the draft list that was provided by DALRRD. After the analysis the interception list was sent to DALRRD for verification, and as the species was present in the country, its status was then corrected to non-quarantine (meaning the draft list initially provided was not updated), and so it is classified as non-quarantine in this study. A list of non-quarantine insects was compiled by making a list of all the insects that were intercepted, but not listed as quarantine insects of fruits.

For all the intercepted insect species, information on host plants and on the countries where the species is present was obtained from CAB International’s Invasive Species Compendium (https://www.cabi.org/isc/, accessed 01 May 2021), hereafter referred to as the ‘hosts dataset’. The hosts dataset contained the names of the intercepted insects, each of the fruit types that are known hosts, and the countries in which the intercepted species occur. Fresh fruit import data for South Africa was sourced from the Food and Agriculture Organization (FAO) of the

United Nations FAOstat database (https://www.fao.org/faostat/en/, accessed 01 March 2021), hereafter referred to as the 'imports dataset'. The imports dataset contained the name of the country of origin of the import, the fruit type imported, and the quantity of the import (measured in tonnes). The imports dataset included 30 entries of countries that were captured as 'unspecified areas', and such data were excluded from the analysis. The import dataset was joined to the hosts dataset to create a dataset which contained a list of intercepted species, their fruit hosts, the countries where the insect occurs, and the volume of the fruit host imported to South Africa from each of these countries. During the analysis, fruit types categories from the (host-imported and interceptions files) did not match in terms of commodities (trade data), therefore, they were reclassified. As a result, tangerines, mandarins, clementines, satsumas, lemons, limes, and grapefruits from the imports dataset were combined to create a new fruit type which was called "citrus". Note that the fruit type "oranges" was separate from "citrus" as the categories were consistent in both files. Peaches, nectarines, plums, and sloes from the imports dataset were combined to create the fruit type "prunus". Import data could not be obtained for certain country-fruit type combinations, this included Angola-pineapples, Belgium-apples, Democratic Republic of Congo-pineapples, and Mozambique-oranges, and Mozambique-prunus; therefore, these combinations were excluded from the analysis. There were initially 22 fruit types that recorded insect interceptions, and after they were reclassified, the total number was reduced to 13 fruit types.

Originally, there was a total of 891 interceptions on the various fruit types traded; 464 were identified to the species level (high taxonomic resolution), and 427 could not be identified to the species level (low taxonomic resolution). The interceptions from the low taxonomic resolution dataset could not be used for further analysis (calculation of TV and TVPI), because the organisms were not identified to the species level and as the insects intercepted had to be identified to species level to obtain host and distribution information. From the 464 interceptions (high taxonomic resolution), certain species records had to be removed because of missing data or uncertainties. Therefore, the total count of insect interceptions for both quarantine and non-quarantine species was revised from 464 to 399 for the high taxonomic resolution dataset (Table S1 and S2).

***Calculation of indices***

The combined imports dataset was used to calculate, for each trade pathway, two metrics developed by Bacon et al. (2012): the trade volume to be inspected (TV) and the trade volume to be inspected per interception (TVPI). For this analysis, trade pathways were considered to have three components: the country of origin (*o*); agricultural commodity (*c*); and insect species (*i*). The trade volume to be inspected (TV) was quantified as follows: if (*i*) exists in (*o*) and (*c*) is a host, then TV of the [*o-c-i*] pathway will be the trade volume of the commodity imported from the country of origin to South Africa. In contrast, if either (*i*) does not exist in (*o*) and/or (*c*) is not the host, then the TV for that particular [*o-c-i*] pathway will be zero (Figure 1). TV (measured in tonnes) was calculated for all country of origin and fruit type combinations. Separate calculations were performed for quarantine and non-quarantine insect species. TV can thus be interpreted as the sum of each of the individual *o-c-i* pathways weighted by the number of insect species that can be dispersed by that pathway (Bacon et al. 2012). The trade volume to be inspected per interception (TVPI) was calculated for each *o-c-i* pathway by dividing the TV for that pathway by the number of interceptions on that pathway. The TVPI is interpreted as the volume of the trade imported per insect interception recorded. Higher values of TVPI indicate [*o-c-i*] pathways with weak border control measures (i.e. poor biosecurity) because there is a low interception rate relative to the volume of imports to be inspected (TV). In contrast, lower TVPI values indicate [*o-c-i*] pathways with strong border control measures (i.e. good biosecurity), because adequate interceptions are recorded relative to the TV (see Figure 1 for further explanation). For example, in Figure 1, country 1 has weak biosecurity for the fruit-insect combination apples-insect A, as TV is high, but there is a low number of interceptions. In contrast, for the mangoes-insect B combination, country 1 has good biosecurity as TV is low, but there are a relatively high number of interceptions (Figure 1). To relate the volume of imported agricultural goods to insect invasions, phytosanitary control checks could use TV as a measure of border performance. Therefore, the expectation is that trade pathways with higher TV will have a higher output of insect interceptions, otherwise biases exist. For example, countries from which large volumes of fruits that are hosts are imported to South Africa should be prioritized and more insects should be intercepted along these pathways than those with low TV. Therefore, TVPI can be viewed as a tool that indicates the number of insects that can potentially move through border control (Bacon et al. 2012).

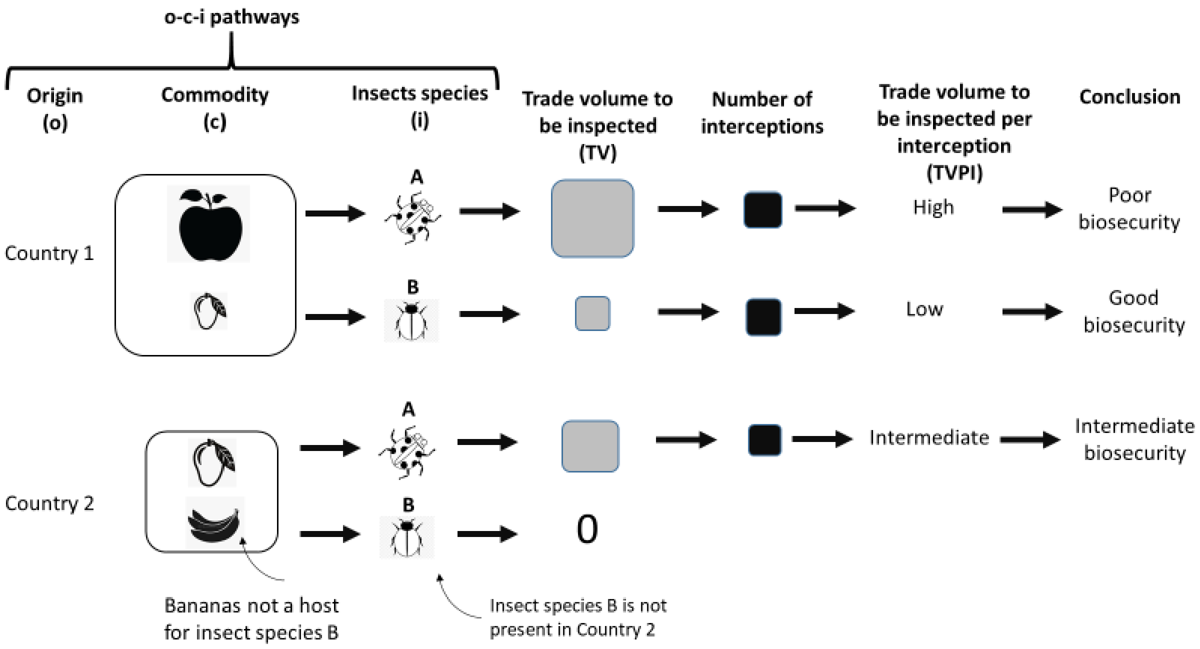


Figure 1. An illustration showing the calculation of the trade volume to be inspected (TV) and the trade volume to be inspected per interception (TVPI) for o-i-c pathways with interceptions of insects on fresh fruit imports. The pathway components are defined as: the country of origin (*o*) of the commodity; agricultural commodity (*c*); and insect species (*i*). A value of zero was assigned for TV for o-i-c pathways if either the insect was not present in the country of origin or if the fruit type was not a host for that insect species.

### *Statistical analysis*

The values of TV for o-i-c pathways were summed to get TV values for specific countries, fruit types and insects using R statistical software (R Core Team 2020). For each pathway, TV was divided by the number of interceptions to calculate the TVPI values and then added to get results at country, species, and fruit type levels. Pearson correlation coefficients were calculated between the number of interceptions, and TV to quantify the strength and nature (i.e. positive or negative) of these relationships. Following Bacon et al. (2012), we interpreted correlation coefficient values below 0.25 as weak, values between 0.25 and 0.3 as good and values of 0.4 and above as very strong. These analyses were performed separately for quarantine and non-quarantine insect species.

**Results**

From the high taxonomic resolution dataset (i.e., 399 insect interceptions), a total of 45 individuals from 12 quarantine insect species were recorded. In contrast, a total of 354 individuals from 75 non-quarantine insect species were recorded (Figure 2). Interceptions were recorded from 13 fruit types (Figure 2a). Fruit types with a relatively high number of interceptions (i.e., 40-85), were kiwifruit, strawberries, citrus, prunus, grapes, and bananas (Figure 2a). Fruit types with moderate interceptions (i.e., 10-39) were pineapples, oranges, avocados, and apples, while those with low interceptions (i.e., 0-9) were cherries, apricots, and pears (Figure 2a). From all insect interceptions, kiwifruit (83 interceptions), followed by strawberries (51 interceptions), prunus (49 interceptions), citrus (46 interceptions), grapes (44 interceptions) and bananas (41 interceptions) had the greatest number of interceptions. In contrast, interceptions for quarantine species were recorded on eight of the 13 fruit types (Figure 2b). Fruit types with the highest number of quarantine insect species interceptions (i.e., 10-25), were kiwifruit, with moderate interceptions (i.e., 4-9) on prunus and apples. Fruit types with the lowest number of quarantine insect species interceptions (i.e., 0-3), were strawberries, citrus, grapes, cherries, and oranges (Figure 2b). The highest number of the quarantine insect interceptions were recorded on kiwifruit (23 interceptions), followed by prunus (nine interceptions), apples (four interceptions), strawberries (three interceptions), grapes and oranges (two interceptions).

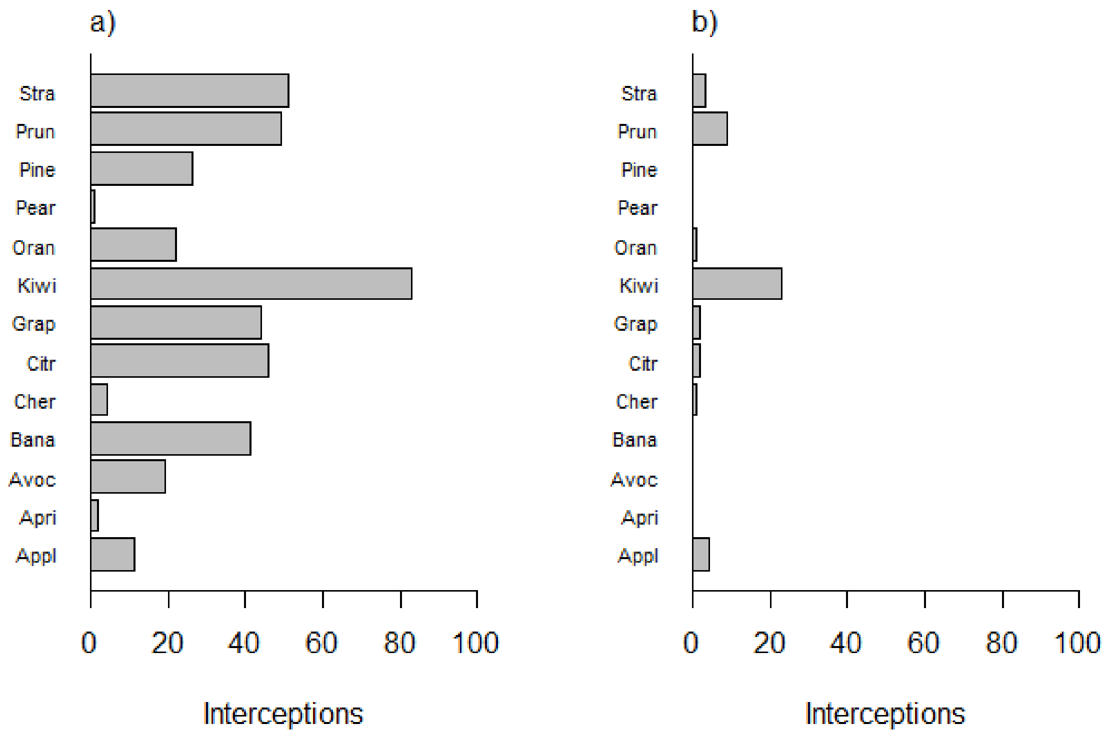

Figure 2. The number of interceptions (high resolution dataset) by fruit type for all insects (a) and quarantine insects (b) from fresh fruit imports to South Africa from 2008 to 2018. Abbreviations: Appl = apples, Apri = apricots, Avoc = avocados, Bana = bananas, Cher = cherries, Citr = citrus, Grap = grapes, Kiwi = kiwifruit, Oran = oranges, Pear = pears, Pine = pineapples, Prun = prunus, Stra = strawberries. The Citr category included all citrus fruit types (tangerines, mandarins, clementines, satsumas, lemons, limes, and grapefruits), but excluded oranges, while the Prun category represented all prunus fruit types (peaches, nectarines, plums and sloes).

Overall, from the 90 FAO partner countries with trade agreements with South Africa for the period 2008-2018, interceptions for all insect species on fresh fruit were only recorded from 21 of these countries (Figure 3). Countries from which a fairly high number of interceptions were recorded (i.e. 20-110) include Spain, Mozambique, Italy, Zimbabwe, Israel, Egypt, and New Zealand. Countries from which a moderate number of interceptions (i.e., 5-19) were recorded were Brazil, United States of America (USA), Eswatini, France, Ghana, Ethiopia, and Greece. Countries from which a low number of interceptions were recorded (i.e., 0-4) were El Salvador, Turkey, United Kingdom, Angola, Belgium, Democratic Republic of Congo, and Thailand (Figure 3a). From all the insect interceptions, the most were recorded from imports from Spain (109 interceptions), followed by Mozambique (61 interceptions), Italy (45 interceptions), Zimbabwe (32 interceptions), Israel (28 interceptions), Egypt (26 interceptions), and New Zealand (24 interceptions). In contrast, quarantine species were intercepted on imports from 11 of the 21 countries (Figure 3b). Countries from which a fairly high number of interceptions (i.e., 10-20) were recorded include Italy, while a moderate number of interceptions (i.e., 4-9) were recorded on imports from Spain, New Zealand, and USA. Imports from countries that had low numbers of interceptions (i.e., 0-3) included those from Egypt, France, Mozambique, Zimbabwe, Brazil, Greece, and Israel (Figure 3b). The highest number of quarantine insect interceptions was recorded on fruits from Italy (16 interceptions), followed by Spain (nine interceptions), New Zealand and USA (four interceptions), Egypt (three interceptions), France, Mozambique, and Zimbabwe (two interceptions).

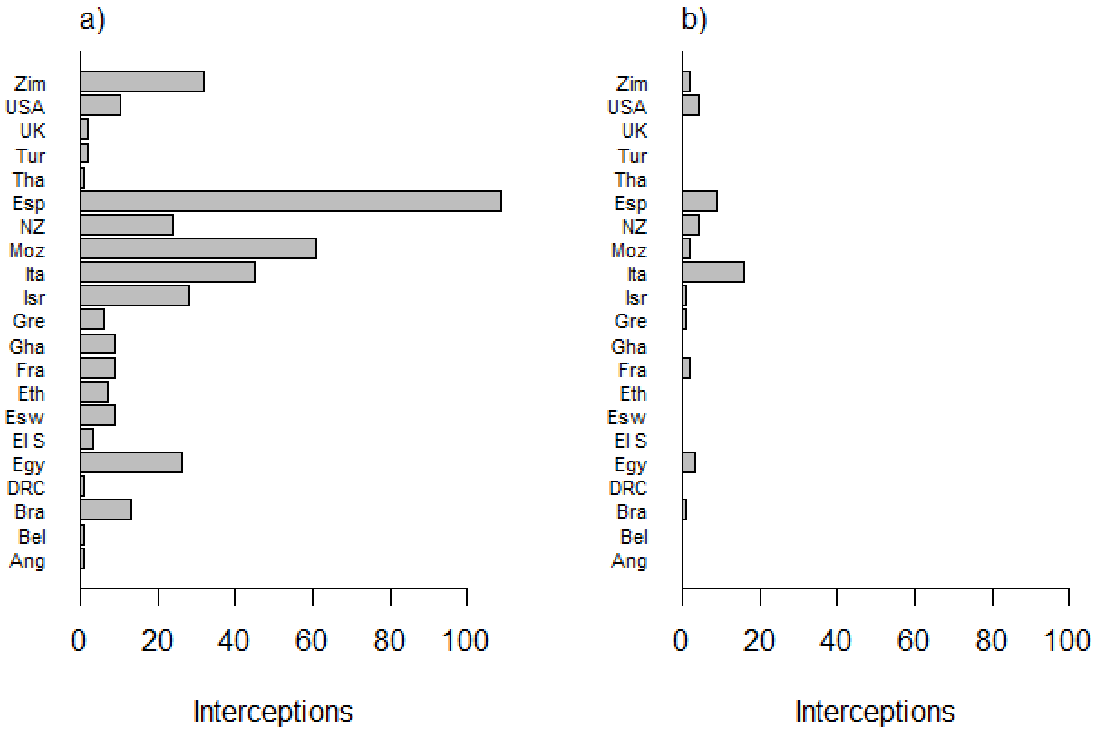


Figure 3. The number of interceptions (high resolution dataset) by the country of origin for all insects (a) and quarantine insects (b) from fresh fruit imports to South Africa from 2008 to 2018. Abbreviations: Ang = Angola, Bel = Belgium, Bra = Brazil, DRC = Democratic Republic of Congo, Egy = Egypt, El S = El Salvador, Esw= Eswatini, Eth = Ethiopia, Fra = France, Gha = Ghana, Gre = Greece, Isr = Israel, Ita = Italy, Moz = Mozambique, NZ = New Zealand, Esp = Spain, Tha = Thailand, Tur = Turkey, UK = United Kingdom, USA = United States of America, Zim = Zimbabwe.

There was a good correlation (r = 0.320) between the number of interceptions and TV across countries for the quarantine species. In contrast, there was a very strong correlation (r = 0.876) between the number of interceptions and TV across countries for the non-quarantine species (Figure 4). The relationship between the number of insects intercepted and TV showed some degree of bias for the quarantine species, as the relationship is moderately positive (i.e., the rate of intercepted insects is low compared to TV). In contrast, the relationship between the number of insects intercepted and TV for non-quarantine species showed no indication of bias, because the relationship is very strong (i.e., more insects are intercepted relative to TV). The five countries that present the greatest threats based on high TVPI for quarantine species are Mozambique (1 082 720 tons per interception), Spain (252 953 tons per interception), Zimbabwe (54 033 tons per interception), Israel (33 586 tons per interception) and Egypt (22 720 tons per interception). For non-quarantine species, high TVPI was recorded for Mozambique (374 784 tons per interception), Eswatini (357 813 tons per interception), Spain (157 842 tons per interception), Israel (98 270 tons per interception) and Egypt (83 965 tons per interception). Furthermore, instances of zero interceptions relative to TV were recorded for Angola (TV = 768 tons) and Belgium (TV = 158 tons) (Figure 4).

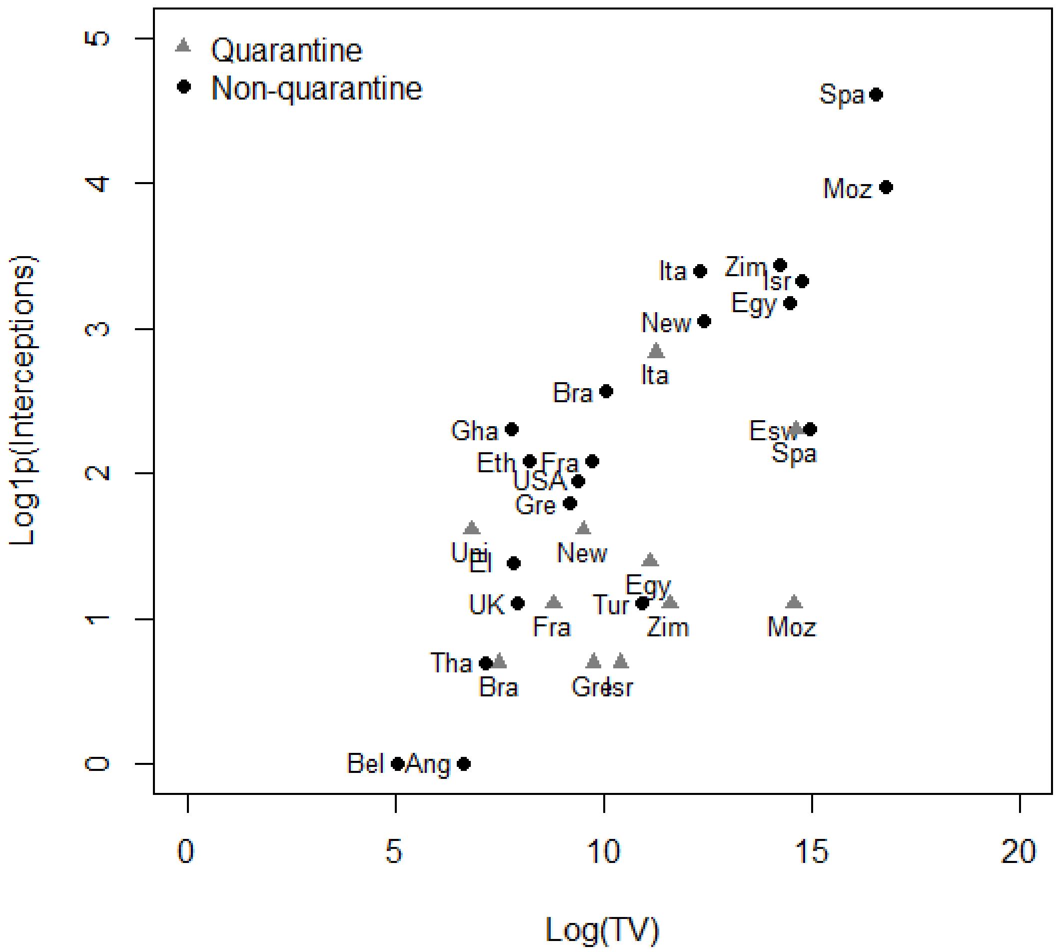


Figure 4. Trade volume to be inspected (TV) and the number of insect (quarantine and non-quarantine) interceptions for each origin country for fresh fruit imports from 2008 to 2018. Abbreviations: Ang = Angola, Bel = Belgium, Bra = Brazil, Egy = Egypt, El = El Salvador, Esw = Eswatini, Eth = Ethiopia, Fra = France, Gha = Ghana, Gre = Greece, Isr = Israel, Ita = Italy, Moz = Mozambique, New = New Zealand, Spa = Spain, Tha = Thailand, Tur = Turkey, UK = United Kingdom, Uni = United States of America, Zim = Zimbabwe).

There was a good correlation (r = 0.271) between the number of insect interceptions and TV across fruit types for quarantine species. In contrast, there was a very strong correlation (r = 0.583) between the number of interceptions and TV across fruit types for the non-quarantine species (Figure 5). The relationship between the number of insects intercepted and TV showed some degree of bias for the quarantine species, as the relationship is moderately positive (i.e., the rate of intercepted insects is lower than expected compared to TV). In contrast, the relationship between the number of insects intercepted and TV for non-quarantine species showed a slight indication of bias, although the relationship is very strong (i.e., the rate of intercepted insects for other fruit types is lower compared to TV). The five fruit types that present the greatest threat of species introduction measured by a high TVPI for quarantine species are bananas (1 071 602 tons per interception), grapes (429 984 tons per interception), citrus (150 404 tons per interception), prunus (69 088 tons per interception) and strawberries (8 741 tons per interception). For non-quarantine species, high TVPI was recorded for bananas (545 025 tons per interception), avocados (217 338 tons per interception), grapes (170 198 tons per interception), oranges (131 721 tons per interception) and prunus (104 325 tons per interception). There were several fruit types where no interceptions were recorded for quarantine insects, while a high value of TV was recorded: avocados (TV = 509 806 tons), oranges (TV = 150 688 tons), papaya (TV = 55 085 tons), tropical fruit (TV = 20 969 tons), coconuts (TV = 11 820 tons).  Similarly, fruit types where no interceptions were recorded for non-quarantine insects, while a high value of TV was recorded included: papaya (TV = 529 569 tons), tropical fruit (TV = 364 178 tons), coconuts (TV = 106 523 tons), dates (TV = 101 956 tons), melons, and other (inc. cantaloupes, TV = 10 440 tons).

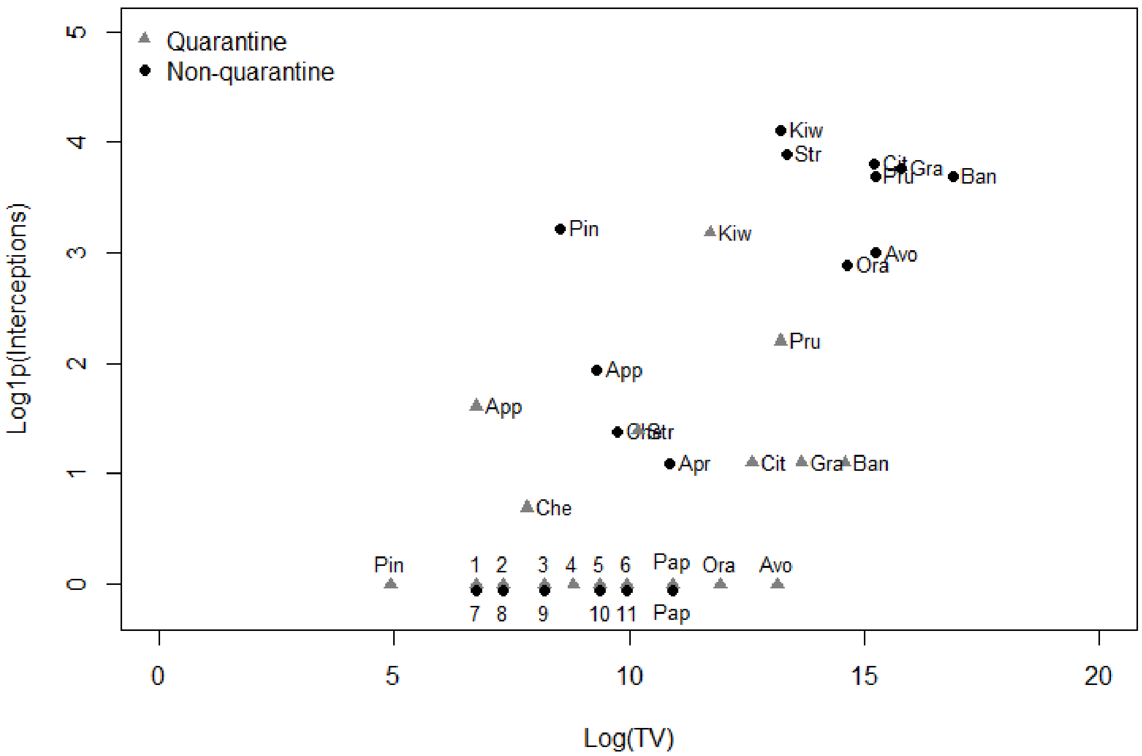

Figure 5. Trade volume to be inspected (TV) and the number of insect (quarantine and non-quarantine) interceptions by fruit types for imports from 2008 to 2018. Abbreviations: App = apples, Apr = apricots, Avo = avocados, Ban = bananas, Che = cherries, Cit = citrus, Gra = grapes, Kiw = kiwifruit, Ora = oranges, Pap = papayas, Pin = pineapples, Pru = prunus, Str = strawberries. The numbers represent 1 = watermelons, 2 = melons, other (inc. cantaloupes), 3 = dates, 4 = apricots, 5 = coconuts, 6 = tropical fruit for quarantine species, and 7 = watermelons, 8 = Melons, other (inc. cantaloupes), 9 = dates, 10 = coconuts, 11 = tropical fruit for non-quarantine species. The positions of the non-quarantine points where interceptions were zero, were jittered (offset) for display purposes.

There was a good correlation (r = 0.375) between the number of interceptions and TV across organisms for the quarantine species. In contrast, there was a weak correlation (r = 0.247) between the number of interceptions and TV across organisms for the non-quarantine species (Figure 6). The relationship between the number of insects intercepted and TV showed a degree of bias for the quarantine species, as the relationship is moderately positive (i.e. the rate of intercepted insects is low compared to TV). In contrast, the relationship between the number of insects intercepted and TV for non-quarantine species is highly biased, because the relationship is weak (i.e., a low number of insects are intercepted relative to TV) (Figure 6). The five-insect species that are most likely to be introduced based on a high TVPI, for quarantine species, are *Thrips major* (207 840 tons per interception), *Maconellicoccus hirsutus* (46 869 tons per interception), *Frankliniella intonsa* (37 110 tons per interception), *Thrips fuscipennis* (30 843 tons per interception), and *Frankliniella schultzei* (27 878 tons per interception). For non-quarantine species, high TVPI was recorded for *Gonocephalum simplex* (18 717 975 tons per interception), *Helicoverpa armigera* (9 596 520 tons per interception), *Callosobruchus maculatus* (5 619 328 tons per interception), *Cacoecimorpha pronubana* (3 808 480 tons per interception) and *Chrysomphalus aonidum* (3 743 595 tons per interception). Furthermore, there were several insect species that had the same high TVPI value and a low number of interceptions, for example, *Matopo typica* (18 717 975 tons per interception), *Porphyronota maculatissima* (18 717 975 tons per interception), *Spodoptera cilium* (18 717 975 tons per interception), *Tribolium castaneum* (18 717 975 tons per interception), *Typhaea stercorea* (18 717 975 tons per interception) and *Ulotrichopus primulinus* (18 717 975 tons per interception).

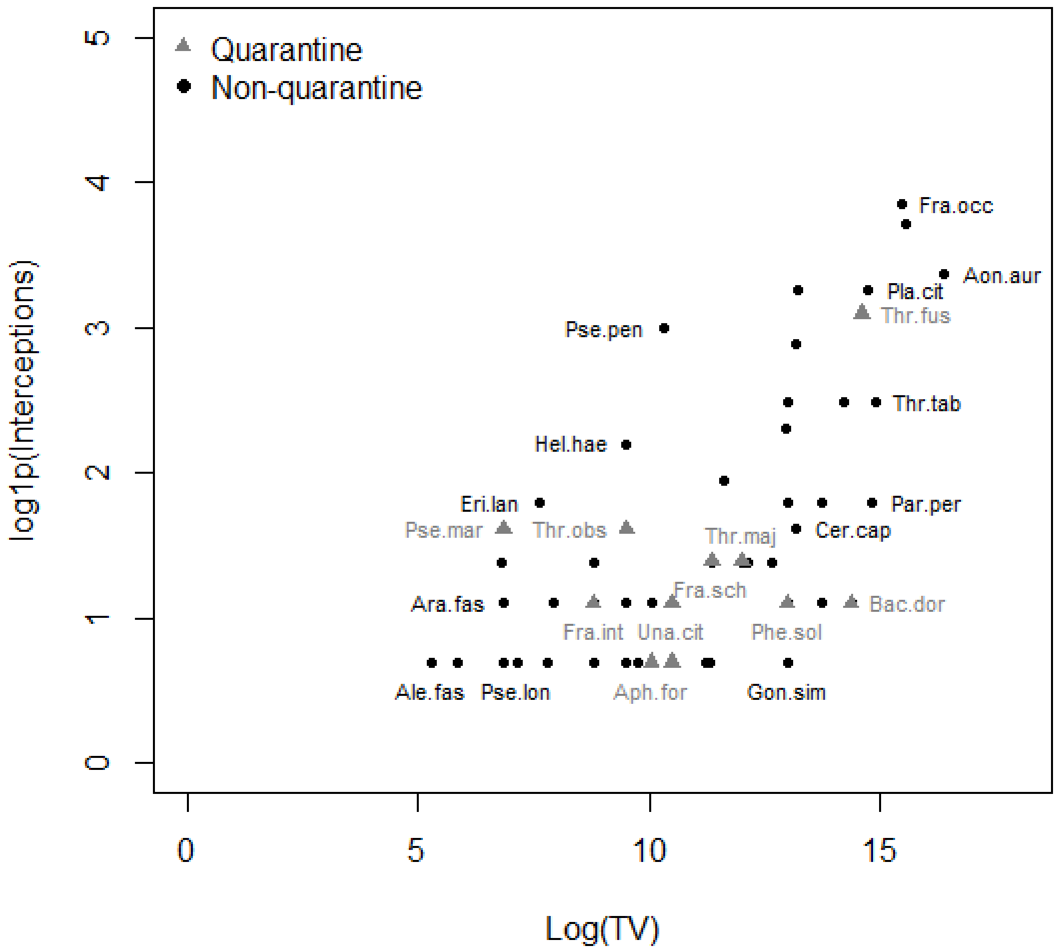


Figure 6. Trade volume to be inspected (TV) and the number of interceptions of different insects intercepted on fresh fruit imports from 2008 to 2018. Selected data points were labelled based on high TVPI as an indicator of poor biosecurity for all recorded interceptions.

## Discussion

This study adapted the approach and methods developed by Bacon et al. (2012) to assess effectiveness and identify potential biases in agricultural inspections for biosecurity threats at South African ports of entry. The objective was to conduct an analysis of the Department of Agriculture, Land Reform and Rural Development's (DALRRD) pest interception data for the period 2008 to 2018 for fresh fruit imports (Saccaggi et al. 2021). Although, this study focusses on the accidental introduction of insects with legally imported products, it is important to note that harmful insects, including quarantine species, can disperse naturally into the country from other countries where they have been introduced (Faulkner et al. 2017). For example, the fall armyworm was transported as a stowaway on a commercial aeroplane from North America to Africa where it spread all over the continent by various other pathways (Cock et al. 2017; Early et al. 2018). In addition, they can be accidentally introduced when products, such as fruit, are brought into the country illegally by travellers (Tshikhudo et al. 2021).

### The taxonomic resolution and quality of the interception database

During the reporting period (2008 to 2018), only 48% of interceptions were identified to the species level. Some studies from other parts of the world have reported that a lower percentage of intercepted insects have been identified to the species level, for example, the United States of America (i.e., 23% in Work et al. 2005; 35% in Haack 2006) and Australia (33.9% in Caley et al. 2015). Furthermore, in central Europe 88.1% of insect interceptions were either identified to genus or family level (Kenis et al. 2007). Different countries have different standards for reporting interceptions (Turner et al. 2021). For example, in South Korea only interceptions that are identified to species level are included in their interception dataset, but in Japan all interceptions identified up to the genus level are included (Turner et al. 2021). It is important to note that in South Africa there is no legal obligation to identify non-quarantine species to species level, as there are time and resource constraints, as they do not pose a threat from a phytosanitary point of view (D. Saccaggi, personal communication, 10 October 2022). Furthermore, DALRRD had an entomology directive to fully analyse pests that are mainly plant feeding to species level, and identification stops when status is known to be that of non-quarantine, precisely due to resource constrains. However, the analysed database also includes all recorded interceptions regardless of the taxonomic level to which they are identified or the quarantine status of the organism (Saccaggi et al. 2021).

Many interception records are identified at higher levels (e.g. family or subfamily) because of the difficulty in classifying specimens of immature life stages (McCullough et al. 2006). This study reported only 52% of interceptions not identified to species level. Madden et al. (2019) suggested that a potential solution to the challenges of morphological identifications for border interceptions is the integration of molecular identification techniques (i.e. DNA barcoding). DNA barcoding is a standardised molecular identification method with numerous applications that has been used extensively to identify immature life stages of animals (Herbert et al. 2003 and Hanner 2009). In the context of this study, there are two main reasons why molecular methods have not improved species identification overall. Firstly, molecular identifications are only as accurate as the DNA databases on which they are based. These DNA databases tend to be quite comprehensive for known quarantine pests (i.e., for certain quarantine pests, molecular methods have actually improved species-level identification). However, for lesser known species, there is a severe lack of DNA data, leading to inaccurate results should molecular identification be attempted. Finally, molecular identifications are expensive and should therefore only be attempted if a quarantine pest is suspected (D. Saccaggi, personal communication, 27 December 2023).

Most interception datasets are seldom collated properly or archived as a single searchable dataset (Masaki 1991; Kiritani 2001; Masaki and Kitamura 2004; McCullough et al. 2006; Roques and Auger-Rozenberg 2006; Surkov et al. 2008b; Robinson et al. 2011; Bacon et al. 2012). I believe that the dataset analysed here can be considered to be one of the most comprehensive datasets of its kind in the world as it contains information on all intercepted organisms, irrespective of quarantine status. The Convention on Biological Diversity in Aichi Target 9 emphasises the importance of identifying, prioritising, and managing invasive alien species and the pathways by which they are introduced (CBD 2010; McGeoch et al. 2016). Identifying the taxa that are typically transported along a particular pathway at the species level can be used to improve the pre-border and at-border management of that pathway to prevent further introductions (Venette et al. 2002; Floerl and Inglis 2005; Hulme et al. 2008; Brockerhoff et al. 2014; Sinclair et al. 2020; Turner et al. 2021). However, this would be challenging and impractical given the limited resources that most countries have.

**Phytosanitary status of insects that are intercepted on fresh fruit**

Quarantine species accounted for far fewer interceptions than non-quarantine species and were intercepted on fewer fruit types coming from fewer countries. There is considerable inspection effort invested in quarantine insects, because of the known impacts that they have on agricultural produce. However, the associated risk to food security, and production for non-quarantine insects cannot be overlooked (Tshikhudo et al. 2021). They could also have negative impacts on biodiversity and ecosystem services. The relatively low number of quarantine insects that were intercepted could be partly due to the effort that exporters have invested in ensuring that consignments are relatively free of quarantine insects. While the responsibility rests with the respective border control agencies and exporters to apply import procedures and biosecurity measures, it is evident that collaboration with our trade partners needs to be improved and strengthened to reduce the volume of insects coming into the country (Giliomee 2011; Nnzeru et al. 2021), especially non-quarantine species.

Exporting countries in line with International Standards for Phytosanitary Measures (ISPMs) are required to declare that goods are free from pests before they can be shipped (FAO 2011a). However, exporters may inconsistently apply or flaunt stipulated phytosanitary measures through illegal imports (Venette et al. 2002; Liebhold et al. 2006; Tshikudo et al. 2021). Furthermore, the legislation in South Africa requires that all imported plant products are subjected to inspections for listed quarantine pests, while no phytosanitary measures are applicable for non-quarantine pests (Saccaggi et al. 2016; Nnzeru et al. 2021).

**Potential bias in inspections**

If inspections are not biased, a strong relationship between the number of interceptions and trade volume to be inspected, which is an indicator of risk (Bacon et al. 2012), would be expected. Based on my results, in South Africa there appear to be biases in inspections and/or possible biases in reporting, particularly for quarantine species. If inspection efforts are not focused on imports with the greatest risk, there will be gaps in management and organisms are likely to pass through border controls. Sampling and inspection protocols in South Africa for imported goods is usually at 2% of the consignment as per International Standards for Phytosanitary Measures (ISPM 20). However, based on the assessed risk posed from different sources, inspection systems can be adjusted to target high-risk goods (Waage and Mumford 2008). Therefore, although the sampling rate for consignments in South Africa is set at 2%, goods from different sources may be inspected to varying degrees. For example, the EU recommends inspecting 5% of citrus from Morocco, 7% from Turkey, 10% from the USA, and 15% from Israel, while due to perceived higher risks, it is recommended that 70% of citrus from Peru is inspected (DEFRA 2006). However, EU recommends inspecting at least 600 of each type of citrus fruit per 30 tonnes from South Africa (Vinti and Makapela 2016). Interception data from other parts of the world are often strongly biased according to sampling priorities determined by the perceived risks posed by the pest or commodity at the time of inspection (Haack 2001; 2006). This may be causing the biases that appear to be evident in the results.

One group of organisms that pose a particular risk of being accidentally introduced are thrips. Thrips species dominated quarantine interceptions in this study, as measured by a high TVPI. Of the five quarantine insects with the highest TVPI, four were thrips, namely *Thrips major*, *Frankliniella intonsa, Thrips fuscipennis*, and *Frankliniella schultzei*. These thrips are potentially invasive species, but have not yet been found in South Africa. In addition, the mealybug, *Maconellicoccus hirsutus*, also has a high risk of being introduced, and is a highly invasive species whose introduction is prohibited under the NEMBA.

**Using TV and TVPI as a measure for setting priorities for biosecurity**

Trade volume to be inspected (TV) is an indicator of the risk of importing a particular organism on a given pathway. It is based on the volume of traded known hosts of organisms that pose a known threat. It is likely to be a more accurate estimate of propagule pressure (a measure of introduction effort) than using the total trade volume with a particular country. TVPI can be used to identify particular pathways where the expected risk is high (high TV), but where the number of interceptions is low. The expectation is that high TV should result in a high number of interceptions. In South Africa, if inspections were prioritized based on TVPI it would be possible to identify high risk pathways. Of the pathways assessed in this study, examples of those with high TVPI included Mozambique-bananas, Greece-kiwifruit, and Egypt-strawberries for quarantine species, and Eswatini-bananas, Zimbabwe-oranges, and Eswatini-oranges for non-quarantine species. One could consider increasing capacity on these pathways, but it would be important to expand calculations of TV and TVPI to include all commodities and pathways to improve biosecurity in South Africa (Roques and Auger-Rozenberg 2006; Kenis et al. 2007; Roques 2010; Bacon et al. 2012).

**Recommendations**

Insects represent most living organisms, are the most frequently intercepted organisms from the fresh fruit trade, and form a large part of the biological invasion problem. A large body of evidence has reported that fresh fruit imports have an inherent risk of introducing quarantine and non-quarantine insect species. Furthermore, there is a need to improve biosecurity to prevent the introduction of non-quarantine species. Based on the results of the study and the reported findings in other studies, the trade volume to be inspected (TV) should be used to guide the inspection and sampling of consignments. However, for such a system to work, priority should be given to the proper collection and recording of inspection effort data (i.e., results of inspections, whether positive or negative), and continuous capacity building and analysis of the records (Saccaggi 2021). Most databases for interceptions record only positive results, whereas a comprehensive analysis of introduction pathways and rates should be based on the outcome of the inspection, not just the number of interceptions (Kenis et al. 2007). An exception is the USA Agricultural Quarantine Inspection Monitoring (AQIM) dataset which consists of recorded imports that are collected and analysed with the aim of identifying infestation levels, high-risk imports, and potential pest threats (Venette et al. 2002; Work et al. 2005). However, implementing these measures may be beyond the reach of the many and already overburdened and underfunded biosecurity agencies. There is a great need for more studies to properly analyse inspection biases based on sampling effort data versus the rate of interceptions relative to the TV. To the best of my knowledge, no published study in South Africa has been conducted to deal with inspection biases as informed by TV and TVPI outputs. There is a need to fully integrate the various components of South Africa's biosecurity so that agricultural and environmental threats are equally considered, as is envisioned under the new Border Management Authority (BMA) (Border Management Act, Act No. 2 of 2020; also see Tshikhudo et al. 2021). Furthermore, in South Africa there is an urgent need to have a comprehensive species watch list to assist with monitoring biosecurity threats, specifically within the fresh fruit trade. It is further recommended that consignment sampling should be improved beyond the standardised 2% ratio and should be based on TV, to directly target those high-risk import pathways.

## Conclusion

Despite certain limitations and biases, the study showed that the trade in fresh fruit has an inherent risk of introducing pests of economic importance into South Africa. Although non-quarantine pests were most often intercepted, the continued interception of quarantine pests should not be taken lightly (e.g., *Thrips fuscipennis* recorded the highest interceptions at 21). Furthermore, the threat posed by non-quarantine insects to the agricultural sector and biodiversity is often unknown. The lack of coordinated biosecurity for those species not on the quarantine list creates the potential for biological invasions, and possible wide-ranging impacts on agriculture and biodiversity. Using pest interception records on traded agricultural commodities allows for a proper analysis of the effectiveness of border control and is useful in identifying important patterns in international trade. The evidence indicates that TV and TVPI could be used to improve inspection efforts for phytosanitary threats and to monitor important pathways of introduction. Therefore, appropriate measures, which include improved inspection strategies and sampling effort, could improve efficacy and limit biases within border control in South Africa and would help to overhaul phytosanitary control on agricultural imports, especially the management of fresh fruit to promote good biosecurity.

## Acknowledgements

First and foremost, I would like to thank GOD for the gift of life and protection. I would like to extend my sincere appreciation to my supervisor Professor Mark Robertson and my co-supervisor Dr Katelyn Faulkner for all the guidance and support throughout the study. The research process was challenging and at times it felt overwhelming, but your commitment and dedication kept pushing me until the very end. I would further like to extend my gratitude to Davina Saccaggi for the assistance in various biosecurity issues that challenged me. I would also like to acknowledge the Department of Agriculture, Land Reform & Rural Development for financial support and supplying of the quarantine species list. Furthermore, the Department of Forestry, Fisheries and Environment is acknowledged for the financial support (running costs for the research). My appreciation also goes to Aphelele Nqameni for words of encouragement when I wanted to quit. Lastly, I would like to send special words of appreciation to my family for the unmatched support over the past 4 years, my wife (Nikiwe Ntimane), my boys (Quinton and Ntokozo) thank you for putting up with me during my brief absence.

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**Supplementary data**

Table S1: Total number of recorded interceptions for quarantine insects from fresh fruit imports to South Africa from 2008 to 2018. Country refers to country from which the commodity was imported. Citrus refers to tangerines, mandarins, clementines, satsumas, lemons, limes, and grapefruits (oranges is separate from citrus). Prunus refers to peaches, nectarines, plums, and sloes.

| Organism | Country | Commodity | Interceptions |
|---|---|---|---:|
| *Aphis forbesi* | Egypt | Strawberries | 1 |
| *Bactrocera dorsalis* | Mozambique | Oranges | 1 |
| *Bactrocera dorsalis* | Mozambique | Prunus | 1 |
| *Frankliniella intonsa* | Italy | Kiwi fruit | 2 |
| *Frankliniella schultzei* | Italy | Kiwi fruit | 2 |
| *Frankliniella schultzei* | Zimbabwe | Strawberries | 1 |
| *Maconellicoccus hirsutus* | Egypt | Grapes | 1 |
| *Pseudococcus maritimus* | United States of America | Apples | 4 |
| *Scirtothrips dorsalis* | Egypt | Grapes | 1 |
| *Thrips fuscipennis* | Spain | Cherries | 1 |
| *Thrips fuscipennis* | France | Kiwi fruit | 2 |
| *Thrips fuscipennis* | Greece | Kiwi fruit | 1 |
| *Thrips fuscipennis* | Italy | Kiwi fruit | 11 |
| *Thrips fuscipennis* | Spain | Prunus | 6 |
| *Thrips gowdeyi* | Zimbabwe | Strawberries | 1 |
| *Thrips major* | Italy | Kiwi fruit | 1 |
| *Thrips major* | Spain | Prunus | 2 |
| *Thrips obscuratus* | New Zealand | Kiwi fruit | 4 |
| *Unaspis citri* | Brazil | Citrus | 1 |
| *Unaspis citri* | Israel | Citrus | 1 |

Table S2: Total number of recorded interceptions for non-quarantine insects from fresh fruit imports to South Africa from 2008 to 2018. Country refers to country from which the commodity was imported. Citrus refers to tangerines, mandarins, clementines, satsumas, lemons, limes, and grapefruits (oranges is separate from citrus). Prunus refers to peaches, nectarines, plums, and sloes.

| Organism | Country | Commodity | Interceptions |
|---|---|---|---|
| *Ahasverus advena* | France | Kiwi fruit | 1 |
| *Aleurodothrips fasciapennis* | El Salvador | Citrus | 1 |
| *Aonidiella aurantii* | Israel | Avocados | 4 |
| *Aonidiella aurantii* | Brazil | Citrus | 2 |
| *Aonidiella aurantii* | Egypt | Citrus | 1 |
| *Aonidiella aurantii* | Eswatini | Citrus | 1 |
| *Aonidiella aurantii* | Israel | Citrus | 3 |
| *Aonidiella aurantii* | Spain | Citrus | 7 |
| *Aonidiella aurantii* | Eswatini | Oranges | 2 |
| *Aonidiella aurantii* | Mozambique | Oranges | 2 |
| *Aonidiella aurantii* | Spain | Oranges | 5 |
| *Aonidiella aurantii* | Zimbabwe | Oranges | 1 |
| *Aphis gossypii* | Egypt | Strawberries | 8 |
| *Aphis gossypii* | Zimbabwe | Strawberries | 1 |
| *Araecerus fasciculatus* | France | Kiwi fruit | 2 |
| *Aspidiotus destructor* | Mozambique | Bananas | 11 |
| *Aspidiotus nerii* | Spain | Citrus | 1 |
| *Baenothrips moundi* | New Zealand | Kiwi fruit | 1 |
| *Cacoecimorpha pronubana* | Spain | Prunus | 1 |
| *Caliothrips fasciatus* | United States of America | Apples | 1 |
| *Callosobruchus maculatus* | Spain | Grapes | 1 |
| *Carientothrips capricornis* | New Zealand | Kiwi fruit | 2 |
| *Carpophilus dimidiatus* | Spain | Grapes | 2 |
| *Carpophilus dimidiatus* | Israel | Prunus | 1 |
| *Ceratitis capitata* | Egypt | Grapes | 1 |
| *Ceratitis capitata* | Spain | Grapes | 2 |
| *Ceratitis capitata* | Spain | Prunus | 1 |
| *Ceratitis cosyra* | Mozambique | Oranges | 1 |
| *Ceratitis cosyra* | Mozambique | Prunus | 1 |
| *Ceratitis rosa* | Eswatini | Prunus | 1 |
| *Ceratothrips ericae* | Spain | Prunus | 1 |
| *Chaetocnema tibialis* | Italy | Kiwi fruit | 1 |
| *Chaetosiphon fragaefolii* | Egypt | Strawberries | 1 |
| *Chrysomphalus aonidum* | Mozambique | Bananas | 5 |
| *Dendrothrips degeeri* | Italy | Kiwi fruit | 1 |
| *Diaspidiotus perniciosa* | Spain | Cherries | 1 |
| *Diaspidiotus perniciosa* | Italy | Kiwi fruit | 1 |
| *Diaspidiotus perniciosa* | Spain | Prunus | 3 |
| *Drosophila melanogaster* | Spain | Grapes | 1 |
| *Dysmicoccus brevipes* | Eswatini | Bananas | 2 |
| *Dysmicoccus brevipes* | Mozambique | Bananas | 13 |
| *Dysmicoccus brevipes* | Angola | Pineapples | 1 |

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|---|---|---|---|
| *Dysmicoccus brevipes* | Democratic Republic of Congo | Pineapples | 1 |
| *Dysmicoccus brevipes* | Ghana | Pineapples | 8 |
| *Dysmicoccus brevipes* | Mozambique | Pineapples | 15 |
| *Epichoristodes acerbella* | Zimbabwe | Strawberries | 1 |
| *Eriosoma lanigerum* | Belgium | Apples | 1 |
| *Eriosoma lanigerum* | United States of America | Apples | 4 |
| *Frankliniella occidentalis* | United States of America | Apples | 1 |
| *Frankliniella occidentalis* | Spain | Apricots | 1 |
| *Frankliniella occidentalis* | Spain | Grapes | 1 |
| *Frankliniella occidentalis* | Israel | Prunus | 1 |
| *Frankliniella occidentalis* | Spain | Prunus | 17 |
| *Frankliniella occidentalis* | Ethiopia | Strawberries | 6 |
| *Frankliniella occidentalis* | Zimbabwe | Strawberries | 19 |
| *Geocoris megacephalus* | Zimbabwe | Strawberries | 1 |
| *Gonocephalum simplex* | Mozambique | Bananas | 1 |
| *Haplothrips gowdeyi* | Zimbabwe | Strawberries | 1 |
| *Haplothrips statices* | Spain | Prunus | 1 |
| *Haplothrips subtilissimus* | Greece | Kiwi fruit | 1 |
| *Helicoverpa armigera* | Mozambique | Bananas | 1 |
| *Helicoverpa armigera* | Egypt | Strawberries | 1 |
| *Heliothrips haemorrhoidalis* | New Zealand | Kiwi fruit | 8 |
| *Hemiberlesia lataniae* | Israel | Avocados | 1 |
| *Hemiberlesia lataniae* | Spain | Avocados | 13 |
| *Hemiberlesia lataniae* | Egypt | Grapes | 1 |
| *Hemiberlesia lataniae* | New Zealand | Kiwi fruit | 2 |
| *Hemiberlesia rapax* | Israel | Avocados | 1 |
| *Hemiberlesia rapax* | Italy | Kiwi fruit | 1 |
| *Hemiberlesia rapax* | New Zealand | Kiwi fruit | 4 |
| *Holoparamecus caularum* | Spain | Citrus | 1 |
| *Hoplandrothrips armiger* | Italy | Kiwi fruit | 1 |
| *Horridipamera ferruginosa* | Egypt | Strawberries | 1 |
| *Lema erythrodera* | Italy | Kiwi fruit | 1 |
| *Lepidosaphes beckii* | Israel | Citrus | 1 |
| *Limothrips angulicornis* | Spain | Oranges | 1 |
| *Matopo typica* | Mozambique | Bananas | 1 |
| *Musca domestica* | Egypt | Grapes | 2 |
| *Myzocallis castanicola* | Spain | Grapes | 1 |
| *Myzus persicae* | Zimbabwe | Strawberries | 1 |
| *Neohydatothrips lepidus* | Zimbabwe | Strawberries | 1 |
| *Nesothrips propinquus* | New Zealand | Kiwi fruit | 2 |
| *Nysius pusillus* | Zimbabwe | Strawberries | 2 |
| *Odontothrips meliltoti* | Spain | Prunus | 1 |
| *Oulema melanopus* | Italy | Kiwi fruit | 1 |
| *Oxycarenus hyalinipennis* | Italy | Kiwi fruit | 1 |
| *Parlatoria cinerea* | Brazil | Citrus | 3 |
| *Parlatoria pergandii* | Eswatini | Citrus | 1 |
| *Parlatoria pergandii* | France | Citrus | 1 |
| *Parlatoria pergandii* | Israel | Citrus | 1 |

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|---|---|---|---|
| *Parlatoria pergandii* | Israel | Oranges | 1 |
| *Parlatoria pergandii* | Mozambique | Oranges | 1 |
| *Phenacoccus solenopsis* | Mozambique | Bananas | 2 |
| *Phyllotreta striolata* | Italy | Kiwi fruit | 1 |
| *Phyllotreta vittula* | Italy | Kiwi fruit | 3 |
| *Planococcus citri* | Brazil | Citrus | 7 |
| *Planococcus citri* | Egypt | Citrus | 2 |
| *Planococcus citri* | El Salvador | Citrus | 2 |
| *Planococcus citri* | Israel | Citrus | 6 |
| *Planococcus citri* | Turkey | Citrus | 1 |
| *Planococcus citri* | Israel | Oranges | 2 |
| *Planococcus citri* | Spain | Oranges | 4 |
| *Planococcus citri* | Turkey | Oranges | 1 |
| *Planococcus ficus* | Egypt | Grapes | 3 |
| *Planococcus ficus* | Israel | Grapes | 1 |
| *Planococcus ficus* | Spain | Grapes | 21 |
| *Porphyronota maculatissima* | Mozambique | Bananas | 1 |
| *Pseudaulacaspis pentagona* | France | Kiwi fruit | 1 |
| *Pseudaulacaspis pentagona* | Greece | Kiwi fruit | 4 |
| *Pseudaulacaspis pentagona* | Italy | Kiwi fruit | 14 |
| *Pseudococcus longispinus* | Thailand | Pears | 1 |
| *Pseudococcus viburni* | Ghana | Pineapples | 1 |
| *Sitona discoideus* | Spain | Prunus | 1 |
| *Sitophilus oryzae* | Egypt | Grapes | 1 |
| *Sitophilus oryzae* | Spain | Grapes | 3 |
| *Sitophilus oryzae* | France | Kiwi fruit | 2 |
| *Sitophilus oryzae* | Italy | Kiwi fruit | 2 |
| *Sitophilus oryzae* | New Zealand | Kiwi fruit | 1 |
| *Sitophilus oryzae* | Israel | Prunus | 1 |
| *Sitophilus oryzae* | Spain | Prunus | 1 |
| *Sitophilus zeamais* | Spain | Grapes | 1 |
| *Spodoptera cilium* | Mozambique | Bananas | 1 |
| *Taeniothrips picipes* | Spain | Prunus | 1 |
| *Thaumastocoris peregrinus* | Zimbabwe | Strawberries | 1 |
| *Thaumatotibia leucotreta* | Eswatini | Citrus | 2 |
| *Thaumatotibia leucotreta* | Spain | Prunus | 1 |
| *Thrips flavus* | United Kingdom | Cherries | 2 |
| *Thrips tabaci* | Spain | Apricots | 1 |
| *Thrips tabaci* | Italy | Kiwi fruit | 1 |
| *Thrips tabaci* | Israel | Prunus | 3 |
| *Thrips tabaci* | Spain | Prunus | 3 |
| *Thrips tabaci* | Egypt | Strawberries | 1 |
| *Thrips tabaci* | Ethiopia | Strawberries | 1 |
| *Thrips tabaci* | Zimbabwe | Strawberries | 1 |
| *Tribolium castaneum* | Mozambique | Bananas | 1 |
| *Typhaea stercorea* | Mozambique | Bananas | 1 |
| *Ulotrichopus primulinus* | Mozambique | Bananas | 1 |