International Journal of Tropical Insect Science (2021) 41:3075–3086
https://doi.org/10.1007/s42690-021-00501-y

ORIGINAL RESEARCH ARTICLE

Pest interceptions on imported fresh fruits into South Africa

Livhuwani R. Nnzeru[1] · Phumudzo P. Tshikhudo[2] · Bester T. Mudereri[3,4] · Moleseng C. Moshobane[5,6]

Received: 9 September 2020 / Accepted: 11 March 2021 / Published online: 1 April 2021

Abstract

Global trade through imports and exports of commodities brings an excessive risk of accidental introduction of invasive alien species in many countries. South Africa imports a range of fresh fruits and other commodities to complement its local production. Despite the substantial impacts of these invasive alien species, relatively little is known about the pathways and origins by which these organisms arrive in South Africa. In this study, we analyzed the susceptibility of South Africa to introduced plant-feeding pests detected from imported consignments of fresh fruits into the country over 10 years between 2009 and 2018. The analysis was conducted from pest samples drawn from 19 ports of entry through archived records, audits, and physical identification. A total of 378 species of pests, were taxonomically identified, quantified, and categorized into four groups, viz. quarantine, non-quarantine, potential quarantine, and uncategorized pest. Of the total examined pests, species identified as potential quarantine or quarantine was relatively low, however, their risk on introduction is deemed unacceptable. Although the quarantine pest proportion was relatively low, our investigation also demonstrated that most intercepted pests were among the non-quarantine pests (74%), while 11% were uncategorized pests whose ecological impacts are relatively unknown. Thus, there is an urgent need for the revision of the current phytosanitary policies and border controls to intensify reduction in the future introduced alien invasive species. Also, there is a need for the intensification of surveys, monitoring, and tracing of the potential hazards that are likely to be caused by these identified pests on the South African agriculture industry, the environment, and biodiversity. Our study can be used as a base for the improvement of the already available phytosanitary policies and provides baseline information for future research of the observed species and their relative control mechanisms.

Keywords Invasive species · Global trade · Horticultural pests · Phytosanitary · Quarantine pests

Introduction

There is a great risk of inadvertent introduction of invasive species (IS) through global trade of commodities, goods, and services (Bradely et al. 2012; Schindler et al. 2018; Chapman et al. 2017). The rate of introduction and spread of IS are on the rise globally, in particular, through human activities such as horticultural trade and international travel (Barrett et al. 1999; Dehnen-Schmutz et al. 2007; Bradie et al. 2013; Early et al. 2018), this happens despite the regulations to curb the spread (Moshobane et al. 2020, 2019). IS dramatically weaken the biodiversity, productivity function, and resilience of natural and agricultural ecosystems within their introduced environment (Singh 2005; Didham et al. 2005; Grice 2006; Saccaggi and Pieterse 2013; Dueñas et al. 2021). This has far-reaching effects that distress the socioeconomic and ecological wellbeing of any country such as costs invested in research, reduction in crop yields,

✉ Moleseng C. Moshobane
moshobanemc@gmail.com

[1] Department of Environment, Forestry and Fisheries, Directorate Biosecurity, 14 Loop Street, 8000 Cape Town, South Africa

[2] Department of Agriculture, Land Reform and Rural Development, Directorate Plant Health, 30 Hamilton Street, Arcadia 0002, Pretoria, South Africa

[3] International Centre of Insect Physiology and Ecology (Icipe), P. O. Box, Nairobi 30772-00100, Kenya

[4] Department of Animal and Wildlife Science, Midlands State University, P. Bag 9055, Gweru, Zimbabwe

[5] Biological Invasions Directorate, South African National Biodiversity Institute, Pretoria National Botanical Garden, 2 Cussonia Avenue, Brummeria, Pretoria, South Africa

[6] Department of Biology, Sefako Makgatho Health Sciences University, Ga-Rankuwa, South Africa

predation, parasitism, genetic change, habitat transformations, and pollution from chemicals used in pest control (Azrag et al. 2018; Ikegawa et al. 2019; Marsh et al. 2021; Warziniack et al. 2021).

Management options to control these IS are often limited to eradication or regulatory regimes aimed at containing, or slowing the spread of the pest (Hidalgo et al. 2013; Holder et al. 2015; Gherardi and Angiolini 2007; Ikegawa et al. 2019). However, these efforts are usually costly, time-consuming, require intensive pesticide applications, and are often unsuccessful (Allendorf and Lundquist 2003; McCullough et al. 2006; Marten and Moore 2011). Therefore, phytosanitary inspections and control at ports of entry inevitably becomes the most desirable option for the prevention and control of biological invasion. This option becomes extremely successful if it is coupled with international cooperation and taxonomic networking for the identification and understanding of the intercepted pests (Liebhold et al. 2012; Steffen et al. 2015; Holder et al. 2015; Saccaggi and Pieterse 2013). Also, early detection and rapid response to emerging IS are recognized as critical steps to reduce the high ecological and economic costs brought by such biological invasions (Lodge et al. 2006; Ricciardi et al. 2017; Mudereri et al. 2020a, b, c).

Global trade movements of fresh fruit in 2017 was around 80 million tons (Trademap 2018). The major fruits consumed in the South Africa are apples, pears, litchis, mangoes, plums, peaches, apricots, grapefruit, pineapples, avocados, and lemons (Mordor Intelligence 2020). South Africans spend approximately 16% of their incomes on fresh produce. Over the past decade, fresh fruit imports into South Africa have shown exponential growth (Trademap 2018). South Africa imports most of the fruits from countries such as Spain, Egypt, Italy, Israel, France, Greece, USA, Ethiopia, El Salvador, and Turkey (Trademap 2018). In the Southern hemisphere, the imports originate mainly from New Zealand, Brazil, Eswatini, Mozambique, and Zimbabwe (Trademap 2018). The importance of importing the fruit from various countries is to supplement the off-season. The South Africa government has been supporting the import of fresh fruit with a number of plant health policies, to manage the pest risk associated with movement fresh fruit. The fresh fruit itself may not pose a pest risk but may harbor organisms that are pests. The South African Department of Agriculture, Land Reform, and Rural Development (DALRRD) plant health interception records at ports of entry create a critical inventory of plant pests introduced from different parts of the world including those intercepted in South Africa. This information provides compelling scientific evidence useful to assess the potential biosecurity threat to the Republic of South Africa.

Therefore, our motivation for this study emanates from the various recent studies that report convincing evidence pointing to the potential increase in the severity and occurrences of IS and their impacts in the coming decade, particularly in Africa (Bebber 2015; Hulme et al. 2018; Seebens et al. 2018, 2017). Yet, there is less frequent research on the intensity and severity of the pests arriving in South Africa from its trading partners (National Research Council 2002; Saccaggi and Pieterse 2013). Therefore, this study aims to provide an overview and general description of the relative rates and status associated with interceptions of fresh fruits plant-feeding pests at South African borders and ports of entry. We summarized fresh fruits pest interception records data from 2009 to 2018 to examine the origins, the commodities associated with such interceptions, interception sites, and mode of transport associated with the pest taxa.

Methods

Sample collection and preparation

A total of 4213 recorded samples that were collected from import consignments at the 19 ports of entry and 6 container depots were screened for relevance and used in this study. Specifically, the samples (both audit and identification) were collected and collated from different ports of entry depending on the mode of transportation into the country i.e. the 4 seaport harbors and the 6 container depots located in Durban, Cape Town, East London, Port Elizabeth, City Deep and Terminals (Pretcon and Eastcon). Additionally, data was also obtained from the 6 South African International airports i.e. Durban, O.R. Tambo, Cape Town, Kruger Mpumalanga, Lanseria, and Port Elizabeth and 9 road border posts located at Vioolsdrift, Nakop, Grobler's Bridge, Skilpad's Gate, Ramatlabama, Beitbridge, Lebombo, Oshoek and Golela.

During the year, the pest interception samples from these ports are collected from randomly tested consignments and are sent to the DALRRD diagnostic laboratories in Pretoria (Gauteng Province) or Stellenbosch (Western Cape Province) for pest identification. The insects are preserved in 70% ethanol, AGA solution, or Sorbitol solution before being sent for identification to the respective diagnostic laboratories. All identifications are then conducted by qualified and experienced acarologists, entomologists, and mycologists in sealed contained facilities. The data is then systematically and centrally stored and archived at the DALRRD.

The intercepted taxa are either identified to the species, genus, or family levels using published international species keys and reference resources to identify the intercepted taxa (Saccaggi and Pieterse 2013). These operations are conducted in close cooperation with the South African Agricultural Research Council (ARC)'s biosystematics division to enhance the identification process. Based on the intercepted pest status in South Africa, we then collated the records and grouped them into 4 groups viz quarantine, non-quarantine, potential quarantine, and uncategorized pest in preparation for data analysis. Uncategorized pests are pests which could not be identified to a species level but only identified to either genus or family level, for determination of its quarantine status in South Africa.

Data analysis

The arranged pest interception data from the identification and audit samples collected between 2009 and 2018 were analyzed using STATISTICA Software package (Statsoft Inc., Tulsa, OK, USA, Version 2010) to calculate percentage of interceptions and frequencies. The records were grouped according to the fruit taxa, country of origin, and the date of importation.

These data excluded some organisms such as predatory mites, fungi-feeders, and storage product pests as they are as pests of economic importance on fruits in South Africa.

Results

Pest interceptions and fruit hosts by country of origin

A total of 378 species of pests were intercepted between 2009 and 2018 from all the samples examined from the 19 South African ports of entry and 6 container deports. These pests were intercepted from the host fruits such as *Vitis vinifera*, *Actinidia* spp., *Prunus* spp., *Fragaria ananassa, Citrus* spp., *Musa* spp., *Persea americana, Ananas comosus, Ficus carica, Punica granatum, Malus* spp. and *Mangifera indica* imported from Spain, Egypt, Italy, Mozambique, New Zealand, Zimbabwe, Israel, Brazil, Greece, Swaziland, France, USA, El Salvador, Ethiopia, Turkey and Mozambique. The type of pests detected were mites, fungi, and insects. The results also show that continentally, most of the important quarantine pests originated from Europe. It was also established that most of the quarantine pests were detected at the seaports, airports and border posts. Table 2 shows the percentage of pest interceptions collated from the various ports of entry and their associated countries of origin. Spain had the highest number of intercepted pests (40.21%), followed by Egypt (16%) and Italy (11.64%). Countries that had the least number of pest interceptions (< 1%) are El Salvador, Ethiopia, and Turkey. Of the South African trading partners in Africa, Mozambique had the highest percentage of intercepted pests i.e. ~ 7% of the total intercepted pests. Details of the individual countries' contribution in import tonnage, the imported fruit species, and the intercepted pests are provided in Table 1. Majority of fresh fruit consignments were imported through OR Tambo International Airport and Cape Town Harbour.

According to Table 1 the intercepted pests were insects and mites belonging to Hemiptera, Prostigmata, Thysanoptera, and Lepidoptera; and while pathogens dominated by Leotiomycetes. The identities of intercepted quarantine species were *Aculus* cf. *wagnoni* (Keifer, 1959) (Acari: Eriophyidae), *Brevipalpus lewisi* (McGregor) (Acari: Tenuipalpidae), *Frankliniella intonsa* (Trybom) (Thysanoptera: Thripidae), *Thrips fuscipennis* (Haliday) (Thysanoptera: Thripidae), *Aphis forbesi* Weed, 1889 (Hemiptera: Aphididae), *Ostrinia nubilalis* (Hübner) (Lepidoptera: Crambidae), *Unapsis citri* Comstock (Hemiptera: Diaspididae), *Phyllosticta citricarpa* (McAlpine) Aa (Botryosphaeriales: Botryosphaeriaceae), *Cenopalpus pulcher* Canestrini and Fanzago (Acari: Tenuipalpidae), *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), *Cenopalpus lanceolatisetae* Pritchard & Baker 1958 (Acari: Tenuipalpidae), *Monilinia fructigena* Honey ex Whetzel 1945 (Helotiales: Sclerotiniaceae), *Diptacus gigantorhynchus* (Nalepa) (Acari: Eriophyidae), *Amphitetranychus viennensis* (Zacher) (Acari: Tetranychidae), *Tetranychus kanzawai* Kishida (Acari: Tetranychidae) and *Tenuipalpus punicae* Pritchard and Baker (Acari: Tenuipalpidae). The potential quarantine pest was *Brevipalpus* sp. nov (Acari: Tenuipalpidae) that was intercepted on kiwifruit imported from Italy and France (Table 1).

Table 1. The percentage of pest interceptions and their associated countries of origin.

The threat status of the intercepted pests

Pests belonging to the group of quarantine pests were 7%, the potential quarantine pests were 8% compared with the non-quarantine pests (74%) which were the majority of the intercepted pests. Of the total intercepted pests 11% have not yet been given a threat level category in South Africa (Table 2). The highest number of pest interceptions occurred during 2016 (Fig. 1). The total number of quarantine pests intercepted was low over 10 years a period compared to other pests.

Table 2. Percentage of the pests intercepted under different threat categories.

The largest number of species were intercepted from the common grapes (*Vitis vinifera* L), while the lowest number of species was collected from the Mango (*Mangifera indica* L.). On the other hand, the highest percentage of quarantine pests were intercepted from fruits in the genus *Prunus* on consignment from Spain (Table 2 and 3). Details of the individual countries contribution in import tonnage, the imported fruit species are summarized in Table 1.

Table 3. Fruit species and number of interceptions.

Table 1 Records of pest interceptions occurred from 2009 to 2018 at South African ports of entry ($N = 379$)

Name of fruit	Fruit volume imported from 2009 to 2018 (tons) (Trademap 2018)	Export country	Port of entry	Intercepted organism
Actinidia sp.	624	Egypt	OR Tambo International Airport	*Colomerus* sp. (Eriophyid mite)
	25	France	OR Tambo International Airport; Cape Town Harbour	*Brevipalpus* sp. Nov. (Flat mite), *Ahasverus advena* (Foreign grain beetle), *Araecerus fasciculatus* (Coffee Bean Weevil), and *Thrips fuscipennis*[QP] (Rose thrips)
	544	Greece	OR Tambo International Airport; Cape Town Harbour	*Brevipalpus* sp. (Flat mite), *Brevipalpus lewisi* (Citrus flat mite), *Haplothrips subtilissimus* (Thrips) and *Thrips fuscipennis*[QP] (Rose thrips)
	612	Italy	OR Tambo International Airport; Cape Town Harbour	*Pseudaulacaspis pentagona* (Mulberry scale), *Hoplandrothrips* sp. (Thrips), *Corticaria* sp. (Scavenger beetle), *Phlaeothrips* sp. (Thrips), *Thrips fuscipennis*[QP] (Rose Thrips), *Frankliniella intonsa*[QP] (Flower tthrips),*Corythucha* sp. (Lace bug), *Tuckerella japonica* (Peacock mite), *Brevipalpus obovatus* (Ornamental flat mite), *Phyllotreta vittula* (Barley flea beetle) and *Brevipalpus* sp. Nov (Flat mite)
	1580	New Zealand	OR Tambo International Airport; Cape Town Harbour	*Tuckerella japonica* (Peacock mite), *Nesothrips propinquus* (Thrips), *Tuckerella flabellifera* (Peacock mite), and *Hemiberlesia rapax* (Greedy scale)
	22	Spain	OR Tambo International Airport; Cape Town Harbour	*Brevipalpus* sp. (Flat mite) and *Colomerus* sp. (Eriophyid mite)
Ananas sp.	955	Mozambique	Lebombo and Beit Bridge Border Posts	*Dysmicoccus brevipes* (Pineapple mealybug)
	365	Swaziland	Golela Border Post	*Dysmicoccus brevipes* (Pineapple mealybug)
Citrus sp.	142	Brazil	Cape Town Harbor	*Brevipalpus* sp. (Flat mite), *Planococcus citri* (Citrus mealybug), *Aonidiella aurantii* (Red scale), *Unapsis citri*[QP] (Citrus snow scale), *Parlatoria* cinerea (Tropical grey chaff scale) and *Pseudococcus* sp. (Mealybug)
	13	El Salvador	OR Tambo International Airport	*Planococcus citri* (Citrus mealybug)
	480	Israel	Cape Town Harbor	*Planococcus citri* (Citrus mealybug), *Aonidiella aurantii* (Red scale), *Unapsis citri*[QP](Citrus snow scale) and *Hemiberlesia rapax* (Greedy scale)
		Mozambique	Lebombo and Beit Bridge Border Posts	*Phyllosticta citricarpa*[QP] (Citrus black spot)
	1827	Spain	Cape Town Harbor	*Tetranychus* sp. (Spider mite), *Neophyllobius* sp. (Camerobiid mite), *Aonidiella aurantii* (Red scale), *Parlatoria pergandii* (Black parlatoria scale), *Brevipalpus californicus* (False spider mite), *Planococcus citri* (Citrus mealybug), *Colomerus* sp. (Eriophyid mite), and *Aspidiotus nerii* (Oleander scale)

Table 1 (continued)

Name of fruit	Fruit volume imported from 2009 to 2018 (tons) (Trademap 2018)	Export country	Port of entry	Intercepted organism
	4734	Swaziland	Golela Border Post	*Phyllosticta citricarpa*^{QP} (Citrus black spot), *Parlatoria pergandii*(Black parlatoria scale), *Tuckerella* cf. *murreensis* (Peacock mite) and *Aonidiella aurantii* (Red scale)
Cydonia sp.	*	Azerbaijan	OR Tambo International Airport	*Cenopalpus pulcher*^{QP} (Flat scarlet mite)
Ficus sp.	123	Israel	OR Tambo International Airport	*Carpophilus* sp. (Sap beetle), *Aceria ficus* (Fig mite), *Rhyncaphytoptus* cf. *ficifoliae* (Fig leaf mite) and *Planococcus ficus* (Vine mealybug)
Fragaria sp.	624	Egypt	OR Tambo International Airport	*Aphis gosssypii* (Cotton aphid), *Chaetosiphon fragaefolli* (Strawberry aphid), *Tetranychus* sp. (Spider mite), *Frankliniella schultzei* (Common blossom thrips), *Tetranychus urticae* (Two-spotted spider mite), *Botrytis* sp.(Grey mould), *Tetranychus* cf. *urticae* (Two-spotted spider mite), *Frankliniella occidentalis* (Western flower thrips) and *Aphis forbesi* ^{QP} (Strawberry aphid)
	99	Ethiopia	OR Tambo International Airport	*Frankliniella occidentalis occidentals* (Western flower thrips)
	228	Zimbabwe	Beit Bridge Border Post	*Dendroptus* sp. (Tarsonemid mite), *Frankliniella occidentalis* (Western flower thrips), *Theridion* sp. (Tangle-web spider), *Haplothrips gowdeyi* (Gold-tipped tubular thrips), *Neohydatothrips lepidus* (Thrips), *Thrips gowdeyi* (gold-tipped tubular thrips), *Frankliniella schultzei* (Common blossom thrips), *Tetranychus* sp. (Spider mite), *Phenacoccus* sp. (Mealybug), *Nysius pusillus* (Heteropteran bug) and *Geocoris megaceohalus* (Big-eyed bug)
Malus sp.	108	USA	Cape Town Harbour	*Eriosoma lanigerum* (Woolly aphid) and *Pseudococcus* sp. (Mealybug)
Mangifera sp.	945	Mozambique	Lebombo and Beit Bridge Border Posts	*Bactrocera dorsalis*^{QP} (Oriental fruit fly)
Musa sp.	13,000	Mozambique	Lebombo and Beit Bridge Border Posts	*Phenacoccus solenopsis* (Cotton mealybug), *Ulotrichopus primulinus* (Primrose Underwing), *Chrysomphalus aonidum* (Circular scale), *Dysmicoccus brevipes* (Pineapple mealybug) and *Aspidiotus destructor* (Coconut scale)
Persea sp.	571	Israel	Cape Town Harbour	*Aonidiella aurantii* (Red scale)
	1825	Spain	OR Tambo International Airport; Cape Town Harbour	*Hemiberlesia lataniae* (Latania scale)
	118	Turkey	OR Tambo International Airport; Cape Town International Airport	*Planococcus citri* (Citrus mealybug)
	37	USA	Cape Town Harbour	*Pseudococcus* sp. (Mealybug)

Table 1 (continued)

Name of fruit	Fruit volume imported from 2009 to 2018 (tons) (Trademap 2018)	Export country	Port of entry	Intercepted organism
Prunus sp.	205	Israel	Cape Town Harbour	*Carpophilus dimidiatus* (Cornsap beetle) and *Cenopalpus lanceolatisetae*[QP] (Flat mite)
	2706	Spain	OR Tambo International Airport; Cape Town Harbour	*Aculus cf. wagnoni*[QP] (Eriophyoid mite), *Bryobia* sp. (Spider mite), *Tetranychus* sp. (Spider mite), *Frankliniella occidentals* (Western flower thrips), *Tetranychus* cf. *urticae* (Two-spotted spider mite), *Aculus* sp. (Clover mite), *Drosophila* sp., *Monilinia laxa, Aculus fockeui* (Plum rust mite), *Pheidole* sp. (Big-headed ant), *Bryobia rubrioculus* (Brown apple mite), *Colomerus* sp. (Eriophyid mite), *Tetranychus turkestani* (Strawberry spider mite), *Sitophilus oryzae* (Lesser grain weevil), *Tychius* sp.(Weevil), *Dictyla* sp.(Lace bug), *Planococcus ficus* (Vine mealybug), *Taeniothrips picipes* (Thrips), *Monilinia fructicola*[QP] (Brown rot), *Diptacus* cf. *gigantorhynchus*[QP](Rust-mite species) *Ostrinia nubilalis* (European corn borer), *Amphitetranychus viennensis*[QP] (Hawthorn spider mite) and *Tetranychus* cf. *kanzawai*[QP] (Kanzawa spider mite)
Punica sp.	*	Israel	Cape Town Harbour	*Planococcus citri* (Citrus mealybug) and *Tuneipalpus punicae*[QP] (Pomegranate false spider mite)
	*	Spain	OR Tambo International Airport; Cape Town Harbour	*Colomerus* sp. (Eriophyid mite)
	*	Zimbabwe	Beit Bridge Border Post	*Planoccocus citri* (Citrus mealybug)
Vitis sp.	2740	Egypt	OR Tambo International Airport; Cape Town Harbour	*Colomerus* sp. (Eriophyid mite), *Empoasca* sp. (Leafhopper), *Planococcus ficus* (Vine mealybug), *Tuckerella* cf. *flabellifera* (Peacock mite), *Tetranychus* sp. (Spider mite), *Drosophila* sp. (Vinegar fly) and *Brevipalpus* cf. *californicus* (False spider mite)
	18	Israel	OR Tambo International Airport; Cape Town Harbour	*Aonidiella aurantii* (Red scale) and *Colomerus* sp. (Eriophyid mite)
	3539	Spain	OR Tambo International Airport; Cape Town Harbour	*Colomerus* sp. (Eriophyid mite), *Drosophila* sp. (Vinegar fly), *Tetranychus* sp. (Spider mite), *Tydeus* sp. (Predaceous mite), *Planococcus ficus* (Vine mealybug),, *Frankliniella occidentalis* (Western flower thrips), *Colomerus* sp. (Eriophyid mite), *Monilinia* laxa (Brown rot), *Tetranychus* cf. *turkestani* (Strawberry spider mite) *Carpophilus dimidiatus* (Cornsap beetle) and *Tetranychus* cf. *urticae* (Two-spotted spider mite)

NB: * not determined as no data was available on TradeMap (Trademap 2018); **QP** indicates the quarantine pests detected

Table 2 The percentage of pest interceptions and their associated countries of origin

Country	Total Interceptions	Quarantine pests	Potential quarantine pests	Non-quarantine pests	Un-categorized	Total Percentage (%)
Spain	152	13	5	117	17	40
Egypt	62	1	1	52	8	16
Italy	43	4	23	12	4	12
Mozambique	26	1	0	25	0	7
New Zealand	22	0	0	21	1	6
Zimbabwe	20	0	0	16	4	5
Israel	20	2	1	16	1	5
Brazil	7	0	1	5	1	1
Greece	6	2	0	1	3	1
Swaziland	6	0	0	6	0	1
France	6	2	1	3	0	1
USA	4	0	0	3	1	1.05
El Salvador	1	0	0	1	0	0.26
Ethiopia	1	0	0	1	0	0.26
Turkey	1	0	0	1	0	0.26
Total	378	25	32	280	40	100

Discussion

The trends in the interception of pests as contained in the plant health database can indicate numerous factors, such as increased tourism or most importantly the increase in trade volumes (Hidalgo et al. 2013). Many imports such as timber, animal products, and fresh agricultural produce have the potential to introduce species to new locations (Saccaggi and Pieterse 2013). Despite the importance of these trade agreements, nutritional, and economic benefits, there is a great need to continuously consider the biosafety threats that are posed if phytosanitary measures are not fully and effectively observed (McCullough et al. 2006). The focus of this study was to examine and quantify pests intercepted on fresh fruits products imported into South Africa.

This study established that the majority of the intercepted pests were from imports of fruit species particularly *Vitis* spp. Differences in the number of pest interceptions originating from the European, Asian, USA, and African markets were observed, with a large margin of intercepted pests of concern originating from Spain. This could be attributable to the huge volumes of product exchange between South Africa and these regions (Trademap 2018). There is a relationship between high trade volumes and pest detection.

On the other hand, most of the intercepted pests were non-quarantine pests and are known to occur in the South African environment. While it is true that these pests are not listed on the South African phytosanitary import requirements (Republic of South Africa 2017), our study showed a surge in these non-quarantine pests coming into South Africa. Since such consignments intercepted with these pests are not confiscated or denied access at the port of entry, this may be of concern as it indicates less concern about managing these pests and more focus exerted on only the quarantine pests listed by the DALRRD on the authorized commodities. However, when such unlisted organisms are detected and allowed entry, or when specific identification is not possible it introduces a lot of grey areas as the potential threat caused by these species is usually unknown (Saccaggi and Pieterse 2013). Hence, it is equally essential to pay attention to the uncategorized or newly identified pests to champion prevention rather than remediation.

In terms of the South African phytosanitary import requirements, trading partners are required to ensure control measures for the listed quarantine pests and non-quarantine pests to guarantee the eradication of the pests during shipment of the consignment to South Africa (Republic of South Africa 2017). Based on the established results in this study, there is a need to collaborate with the trading partners and ensure strict measures are put in place to reduce the volume of pests reaching the South African ports.

In most cases, the potential quarantine pests are also on the unlisted organisms and their potential threat to the South African environment is usually unknown. To determine the threat associated with these pests, a pest risk assessment needs to be conducted before an informed decision to permit entry into South Africa can be taken (Maynard et al. 2004; Lichtenberg and Olson 2018) or the precautionary principle must be implemented while waiting for the outcomes of the risk assessment.

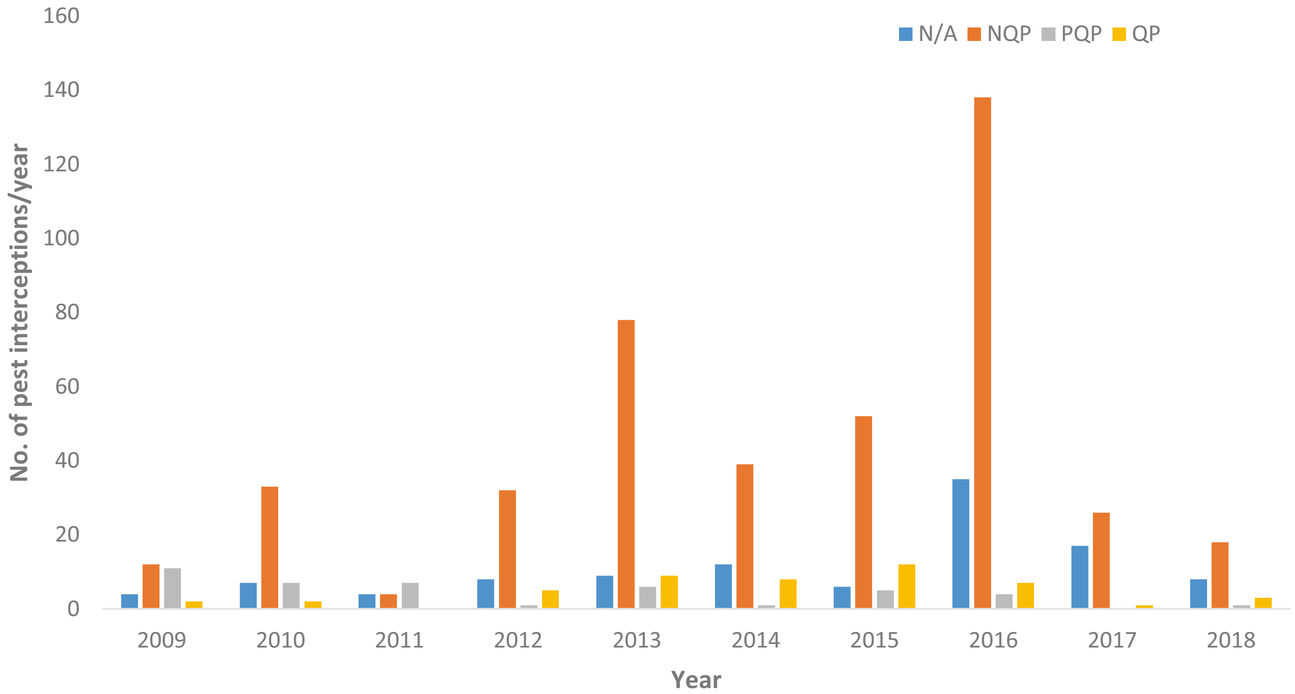

Fig. 1 Number of pest interceptions over a period of 10 years (N/A = pest not categorized due to uncertain status in South Africa; NQP = non-quarantine pest; PQP = potential quarantine pest; QP = quarantine pest)

Our study established that arthropods were the most recorded interceptions compared to pathogens. Similar findings were reported by Work et al. (2005) and McCullough et al. (2006) in United States. The dominant taxa and order in the intercepted insects were the Hemiptera, Prostigmata, Thysanoptera, and Lepidoptera while Leotiomycetes were dominant among pathogens. This concurs with other similar previous studies that confirmed that insects dominated pest interceptions of most imports (McCullough et al. 2006; Areala et al. 2008; Saccaggi et al. 2013; Lee et al. 2016). Therefore a comprehensive list of the most frequent intercepted pests must constantly be updated to cater for the newly identified pests.

At a first glance, the effect of these quarantine pests may appear insignificant, however, a closer inspection shows that the establishment and spread of quarantine pests in South Africa can have major effects on current export programs on many commodities such as apples, citrus, peaches, litchi, strawberries, and table grapes or impede requests for new market access (Saccaggi and Pieterse 2013). This study

Table 3 Fruit species and number of interceptions

Fruit name	Country of origin	Port of entry	Total interceptions	Percentage (%)
Vitis vinifera	Italy	Airport and harbor	121	32.01
Actinidia spp.	Zimbabwe	Land border	82	21.69
Prunus spp.	Spain	Airport and harbor	64	16.93
Fragaria ananassa	Spain	Airport and harbor	32	8.46
Citrus spp.	Spain	Airport and harbor	29	7.67
Musa spp.	Mozambique	Land border	15	3.96
Persea americana	Spain	Airport and harbor	11	2.91
Ananas comosus	Mozambique	Land border	10	2.64
Ficus carica	Israel	Airport and harbor	5	1.32
Punica granatum	Israel	Airport and harbor	5	1.32
Malus spp.	USA	Airport and harbor	3	0.79
Mangifera indica	Mozambique	Land border	1	0.26

forms the basis for the revision of the current phytosanitary import requirements and monitoring of the potential quarantine and uncategorized pests through pest risk analysis. The introduction and establishment of invasive species can be detrimental to agriculture, requiring regular and costly crop protection measures which mostly include the spraying of broad-spectrum pesticides, therefore, cascading the impacts (Giliomee 2011; Ikegawa et al. 2019).

A case in point in this study is the fact that the plant-feeding mites contributed the highest number of the intercepted quarantine pest. In particular, there are three families of mites that are particularly threatening to fruit production worldwide including in South Africa i.e. Eriophyidae, Tetranychidae, and Tenuipalpidae. Some of the species belonging to these families were observed in our analysis. For instance, *Aculus* cf. *wagnoni* (Keifer 1959) (Acari: Eriophyidae) that infests leaves and fruits causing damage to epidermal cells of leaves and fruit while plant tissues become blackened or rusted which lead to reduced fruit size and increase fruit drop which may negatively impact market quality (Vacante 2010).

Additionally, Eriophyid mites pose a high risk if they establish in South Africa (Hulme 2009). This is mainly because they spread rapidly in the environment. This often leads to a reduction of production and export fruit commodities as they are known to be hubs of vector plant diseases that quickly develop resistance to pesticides, are difficulties to detect, and can survive adverse conditions (Navia et al. 2010). Although the DALRRD regularly intercepts mites of *Brevipalpus* species from kiwifruit consignments imported from Greece and Italy since 2008, there are still high chances that these species may pass inspection points without being detected. Therefore, mitigatory measures, continued research, and surveillance within the South African agricultural industry is necessary.

These mites colonize a great number of *Vitis vinifera* fruits, ornamental, and forest plants (Miranda et al. 2007). Feeding injury symptoms caused by *Brevipalpus* spp. can be observed on plant parts such as leaves, fruits, stems, twigs, and bud tissues of host plants in the form of chlorosis, blistering, bronzing, or necrotic areas (Childers et al. 2003). Such feeding damage is only serious at high mite densities (Dean and Maxwell 1967). Although this is the case, the damage caused by feeding, *Brevipalpus* spp. can cause far more serious damage by transmitting plant viruses (Rodrigues and Childers 2012), while Tetranychid mites' introduction will lead to observations of either curled-up leaves and/or defoliation on the host plants, which may reduce the photosynthetic capability of plants (Li et al. 2006). Thus the interception of these mites on South African ports shows that the control measures implemented by the trading partners may not be adequate to eliminate mites' introduction putting South African at high risk of spread. One illustration of this is the *Brevipalpus lewisi* (McGregor) (Trombidiformes: Tenuipalpidae) which was reported in South Africa after it was found on grapevine in the Western Cape and Northern Cape provinces (Saccaggi et al. 2017).

Also, among the observed pests was the Strawberry root Aphid (*Aphis forbesi* Weed, 1889 (Hemiptera: Aphididae)). This pest affects strawberry crops and serves as a vector of the Strawberry crinkle virus (Araujo et al. 2016). *Aphis gossypii* attacks most parts of the plant if population density is high, although exceptions include direct feeding on mature reproductive structures (fruits, berries, nuts) and feeding on roots, thereby causing a great threat to the fruit industry in the entire southern African region and other South African trading partners (CABI 2019).

Additionally, the Eurasian flower hrips (*Frankliniella intonsa* (Trybom) ((Thysanoptera: Thripidae) and the rose thrips (*Thrips fuscipennis* (Haliday)) (Thysanoptera: Thripidae) that are not present in any part of South Africa are pests of quarantine concern. Thrips are small size and this minute size and cryptic behavior of thrips make them difficult to detect in the field and on plants or plant products transported for international trade but with severe consequences. There is a large body of scientific evidence indicating that many members of the Thripidae are plant pests of economic consequence (CABI 2018). This is also supported by the fact that Australia has intercepted Thrips in large numbers on the plant import pathway (Morse and Hoddle 2006). Therefore there is a need to intensify the control and interception of thrips South African ports.

The European maize borer *(Ostrinia nubilalis* (Hübner) (Lepidoptera: Crambidae) was also detected in the consignment of *Prunus* spp. (stone fruits) from Spain. According to CABI (2018), *Prunus persica* is known as a host for this pest and is also known to cause damage to Maize (*Zea mays*) and other crops of economic value including Sorghum (*Sorghum bicolor*), Cotton (*Gossypium hirsutum*), Pepper (*Capsicum*) spp., and Potatoes (*Solanum tuberosum*) (CABI 2018). These crops are the staple crops providing food and nutrition to ~ 90% of the African population including South Africa (Mudereri et al. 2020c). Therefore from these few examples, the overall findings of this study challenge the measures taken by South African trading partners to reduce the spread of such pests through the exchange of agricultural products and other goods. Thus there is a great need for the South African government to increase the interception capacity to reduce the undetected entry of these pests into South Africa. Several studies have already lamented the lack of comprehensive biosecurity strategies to curb the influx of pests (Bacon et al. 2012). Notable recommendation are provided by Essl et al. (2015), more specifically they propose the classification of pathways of entry.

Pests such as Citrus mealybug (*Planococcus citri*), Pineapple mealybug (*Dysmicoccus brevipes*), Two-spotted spider mite (*Tetranychus urticae*), Blossom blight (*Monilinia laxa*), Vine mealybug (*Planococcus ficus*), Red scale (*Aonidiella aurantii*), Strawberry spider mite (*Tetranychus turkestani*), Plum rust mite (*Aculus fockeui*), Western flower thrips (*Frankliniella occidentalis*), Gold-tipped tubular thrips (*Thrips gowdeyi*), *Neohydatothrips lepidus* (Thrips), Common blossom thrips (*Frankliniella schultzei*), Strawberry aphid (*Chaetosiphon fragaefolli*), Fig mite (*Aceria ficus*), Black parlatoria scale (*Parlatoria pergandii*), Greedy scale (*Hemiberlesia rapax*), Tropical grey chaff scale (*Parlatoria cinerea*), etc. are non-quarantine pests for South Africa and are known to occur in the country. Among the quarantine pests detected, Citrus black spot (*Phyllosticta citricarpa*) and Oriental fruit fly (*Bactrocera dorsalis*) that are occurring in South Africa but official control, which is regarded as an active enforcement of mandatory phytosanitary regulations and the application of mandatory phytosanitary procedures with the objective of eradication or containment.

Conclusion

The study showed that import fruits may pose higher risk of introducing quarantine pests and potential quarantine pests which may have a significant impact on the South African fruit industry and biodiversity. The DALRRD interception data provide valuable historical records on pests' origin and the fruits associated with frequent interceptions. This information forms the basis for the revision of the current phytosanitary import requirements and monitoring of the potential quarantine and uncategorized pests through pest risk analysis. There is a need to properly assess the economic impact of pests and take the appropriate measures to prevent the introduction of quarantine or potential quarantine pests in South Africa.

Acknowledgments The South African Department of Environment, Forestry, and Fisheries (DEFF) are thanked for funding, noting that this publication does not necessarily represent the views or opinions of DEFF or its employees. We greatly appreciate the DALRRD for permission to publish the historical data of pest interception. The authors are greatly indebted to the anonymous reviewers for their insightful comments that improved our manuscript. We thank JRU Wilson and other staff members of the Biological invasions directorate for their inputs.

Author contributions M.C.M. conceived the idea, designed the methods, analyzed the data and wrote the first draft. P.P.T provided data. All authors contributed critically to the manuscript and contributed to the written sections. All authors read and approved the final manuscript.

References

Allendorf FW, Lundquist LL (2003) Introduction: population biology, evolution, and control of invasive species. Conserv Biol 17(1):24–30

Araujo ES, Benatto A, Mógor AF, Penteado SC, Zawadneak MAC (2016) Biological parameters and fertility life table of *Aphis forbesi* Weed, 1889 (Hemiptera: Aphididae) on strawberry. Braz J Biol Sci 76(4):937–941

Areal FJJT, MacLeod A, Dehnen-Schmutz K, Perrings C, Palmieri MG, Spence NJ (2008) Integrating drivers influencing the detection of plant pests carried in the international cut flower trade. J Environ Manage 89(4):300–307

Azrag AGA, Pirk CWW, Yusuf AA, Pinard F, NISsy S, Mosomtai G, Babi, R, (2018) Prediction of insect pest distribution as influenced by elevation: Combining field observations and temperature-dependent development models for the coffee stink bug, *antestiopsis thunbergii* (gmelin). PLoS One 13:1–18. https://doi.org/10.1371/journal.pone.0199569

Bacon SJ, Bacher S, Aebi A (2012) Gaps in Border Controls Are Related to Quarantine Alien Insect Invasions in Europe. PLoS One 7:1–9. https://doi.org/10.1371/journal.pone.0047689

Barrett HR, Ilbery BW, Brown AW, Binns T (1999) Globalization and the changing networks of food supply: the importation of fresh horticultural produce from Kenya into the UK. Trans Inst Br Geogr 24(2):159–174

Bebber DP (2015) Range-Expanding Pests and Pathogens in a Warming World. Annu Rev Phytopathol 53:335–356. https://doi.org/10.1146/annurev-phyto-080614-120207

Bradie J, Chivers C, Leung B (2013) Importing risk: Quantifying the propagule pressure-establishment relationship at the pathway level. Divers Distrib 19:1020–1030. https://doi.org/10.1111/ddi.12081

Bradley BA, Blumenthal DM, Early R, Grosholz ED, Lawler JJ, Miller LP, Sorte CJ, D'Antonio CM, Diez JM, Dukes JS, Ibanez I (2012) Global change, global trade, and the next wave of plant invasions. Front Ecol Environ 10(1):20–28

CABI (2018) Invasive Species Compendium. Global Module. Commonwealth Agricultural Bureau International, Wallingford, UK. https://www.cabi.org/isc/datasheet/55685. Accessed on 17 January 2019.

CABI (2019) Invasive Species Compendium. Global Module. Commonwealth Agricultural Bureau International, Wallingford, UK. https://www.cabi.org/isc/datasheet/ 109283. Accessed on 22 May 2019.

Chapman D, Purse BV, Roy HE, Bullock JM (2017) Global trade networks determine the distribution of invasive non-native species. Glob Ecol Biogeogr 26(8):907–917

Childers CC, French JV, Rodrigues JCV (2003) *Brevipalpus californicus*, *B. obovatus*, *B. phoenicis*, and *B. lewisi* (Acari: Tenuipalpidae): a review of their biology, feeding injury and economic importance. Exp Appl Acarol 30(1–3):5.

Dean HA, Maxwell NP (1967) Spotting of grapefruit as associated with false spider mites. Proceedings of the Rio Grande Valley Horticultural Society 21:35–45

Dehnen-Schmutz KA, Touza J, Perrings C, Williamson M (2007) The horticultural trade and ornamental plant invasions in Britain. Conserv Biol 21(1):224–231

Didham RK, Tylianakis JM, Hutchison MA, Ewers RM, Gemmell NJ (2005) Are invasive species the drivers of ecological change? Trends Ecol Evol 20(9):470–474

Dueñas MA, Hemming DJ, Roberts A, Diaz-Soltero H (2021) The threat of invasive species to IUCN-listed critically endangered species: a systematic review. Glob Ecol Conserv p e01476

Early R, González-Moreno P, Murphy ST, Day, (2018) Forecasting the global extent of invasion of the cereal pest *Spodoptera frugiperda*, the fall armyworm. NeoBiota 40:25–50. https://doi.org/10.3897/neobiota.40.28165

Essl F, Bacher S, Blackburn TIMM et al (2015) Crossing Frontiers in Tackling Pathways of Biological Invasions. Biosci Adv 65:769–782. https://doi.org/10.1093/biosci/biv082

Gherardi F, Angiolini C (2007) Eradication and control of invasive species. Biodiversity Conservation and Habitat Management, Encyclopedia of Life Support Systems (EOLSS); Gherardi, F., Gualtieri, M., Corti, C., Eds. 2007:271–299.

Giliomee JH (2011) Recent establishment of many alien insects in South Africa: a cause for concern. –Afr. Entomol 19:151–155

Grice AC (2006) The impacts of invasive plant species on the biodiversity of Australian rangelands. Rangel J 28(1):27–35

Hidalgo E, Benjamin T, Casanoves F, Sadof C (2013) Factors influencing the abundance of pests in production fields and rates of interception of *Dracaena marginata* imported from Costa Rica. J Econ Entomol 106:2027–2034. https://doi.org/10.1603/ec12446

Holder PW, Frew R, Van Hale R (2015) The geographic origin of an intercepted biosecurity pest beetle assigned using hydrogen stable isotopes. J Econ Entomol 108:834–837. https://doi.org/10.1093/jee/tou097

Hulme PE, Brundu G, Carboni M, Dehnen-Schmutz K, Dullinger S, Early R, Essl F, González-Moreno P, Groom QJ, Kueffer C, Kühn I, Maurel N, Novoa A, Pergl J, Pyšek P, Seebens H, Tanner R, Touza JM, van Kleunen M, Verbrugge LNH (2018) Integrating invasive species policies across ornamental horticulture supply chains to prevent plant invasions. J Appl Ecol 55:92–98. https://doi.org/10.1111/1365-2664.12953

Hulme PE (2009) Trade, transport and trouble : managing invasive species pathways in an era of globalization. J Appl Ecol 46:10–18

Ikegawa Y, Honma A, Himuro C, Matsuyama T (2019) A new system for detecting initial colonization by invasive pests and their locations. J Econ Entomol 112:2976–2983. https://doi.org/10.1093/jee/toz228

Lee W, Lee Y, Kim S, Lee JH, Lee H, Lee S, Hong KJ (2016) Current status of exotic insect pests in Korea: comparing border interception and incursion during 1996–2014. J Asia Pac Entomol 19:1095–1101

Li D, Hou Y, Shen Z (2006) Influence of host plant species on the development and reproduction of hawthorn spider mites. Front Forest China 1:182. https://doi.org/10.1007/s11461-006-0010-z

Lichtenberg E, aL.J. Olson LJ, (2018) The fruit and vegetable import pathway for potential invasive pest arrivals. PLoS ONE 13(2):e0192280. https://doi.org/10.1371/journal.pone.0192280

Liebhold AM, Brockerhoff EG, Garrett LJ, Parke JL, Britton KO (2012) Live plant imports: the major pathway for forest insect and pathogen invasions of the US. Front Ecol Environ 10(3):135–143

Lodge DM, Williams S, MacIsaac HJ, Hayes KR, Leung B, Reichard S, Mack RN, Moyle PB, Smith M, Andow DA, Carlton JT (2006) Biological invasions: recommendations for US policy and management. Ecol Appl 16(6):2035–2054

Marsh AS, Hayes DC, Klein PN, Zimmerman N, Dalsimer A, Burkett DA, Huebner CD, Rabaglia R, Meyerson LA, Harper-Lore BL, Davidson JL (2021) Sectoral Impacts of Invasive Species in the United States and Approaches to Management. InInvasive Species in Forests and Rangelands of the United States (pp. 203–229). Springer, Cham.

Marten AL, Moore CC (2011) An options based bioeconomic model for biological and chemical control of invasive species. Ecol Econ 70(11):2050–2061

Maynard GV, Hamilton JG, Grimshaw JF (2004) Quarantine: phytosanitary, sanitary and incursion management: an Australian entomological perspective. Aust J Entomol 43:318–328

Miranda LC, Navia D, J.C.V. Rodrigues JCV, (2007) *Brevipalpus* Mites Donnadieu (Prostigmata: Tenuipalpidae) Associated with Ornamental Plants in Distrito Federal. Brazil Neotrop Entomol 36(4):587–592

McCullough DG, Work TT, Cavey JF, Liebhold AM, Marshall D (2006) Interceptions of nonindigenous plant pests at US ports of entry and border crossings over a 17-year period. Biol Invasions 8:611–630. https://doi.org/10.1007/s10530-005-1798-4

Mordor Intelligence (2020) Agriculture in South Africa - Growth, Trends, Covid-19 Impact, And Forecasts (2021 - 2026). Mordor Intelligence.

Morse JG, Hoddle MS (2006) Invasion biology of thrips. Annu Rev Entomol 51:67-89. https://doi.org/10.1146/annurev.ento.51.110104.151044 PMID:16332204.

Moshobane MC, Mukundamago M, Adu-Acheampong S, Shackleton R (2019) Development of alien and invasive taxa lists for regulation of biological invasions in South Africa. Bothalia 49:1–12. https://doi.org/10.4102/abc.v49i1.2361

Moshobane MC, Nnzeru LR, Nelukalo K, Mothapo NP (2020) Patterns of permit requests and issuance regulated alien and invasive species in South Africa for the period 2015–2018. Afr J Ecol 58:514–528. https://doi.org/10.1111/aje.12720

Mudereri BT, Abdel-Rahman EM, Dube T, Landmann T, Khan Z, Kimathi E, Owino R, Niassy S (2020a) Multi-source spatial data-based invasion risk modeling of Striga (*Striga asiatica*) in Zimbabwe. GIScience and Remote Sensing 57:553–571. https://doi.org/10.1080/15481603.2020.1744250

Mudereri BT, Kimathi E, Chitata T, Moshobane MC (2020b) Abdel-Rahman EM (2020b) Landscape-scale biogeographic distribution analysis of the whitefly, *Bemisia tabaci* (Gennadius, 1889) in Kenya. Int J Trop Insect Sci. https://doi.org/10.1007/s42690-020-00360-z

Mudereri BT, Dube T, Niassy S, Kimathi E, Landmann T, Khan Z, Abdel-Rahman EM (2020c) Is it possible to discern Striga weed (*Striga hermonthica*) infestation levels in maize agro-ecological systems using in-situ spectroscopy? "Int J Appl Earth Obs Geoinf 85, 102008. https://doi.org/10.1016/j.jag.2019.102008

Navia D, Ochoa R, Welbourn C, Ferragut F (2010) Adventive eriophyoid mites: a global review of their impact, pathways, prevention and challenges. Exp Appl Acarol 51:225–255

National Research Council (2002). Predicting invasions of nonindigenous plants and plant pests.

Ricciardi A, Blackburn TM, Carlton JT, Dick JT, Hulme PE, Iacarella JC, Jeschke JM, Liebhold AM, Lockwood JL, MacIsaac HJ, Pyšek P (2017) Invasion science: a horizon scan of emerging challenges and opportunities. Trends Ecol Evol 32(6):464–474

Republic of South Africa (RSA). (2017) Agricultural Pests Act No.36 of 1983 (Act No.36 of 1983) as amended. Control Measures Amendment. R.1271 of 17 January 2017. Republic of South Africa. Pretoria.

Rodrigues JCV, Childers CC (2012) *Brevipalpus* mites (Acari: Tenuipalpidae): vectors of invasive, non-systemic cytoplasmic and nuclear viruses in plants. Exp Appl Acarol 59(1–2):165–175

Saccaggi D, L, Ueckermann EA, du Toit I, Ngubane-Ndhlovu NP, (2017) First Records of *Brevipalpus lewisi* McGregor (Acari: Trombidiformes: Tenuipalpidae) in South Africa, with Notes on Distribution and Field Ecology. Afr Entomol 25(2):523–528

Saccaggi DL, Pieterse W (2013) Intercepting Aliens: Insects and Mites on Budwood Imported to South Africa. J Econ Entomol 106:1179–1189. https://doi.org/10.1603/ec12465

Schindler S, Rabitsch W, Essl F, Wallner P, Lemmerer K, Follak S, Hutter HP (2018) Alien species and human health: Austrian stakeholder perspective on challenges and solutions Int J Environ Res Public Health 15 https://doi.org/10.3390/ijerph15112527

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pyšek P, Winter M, Arianoutsou M, Bacher S, Blasius B, Brundu G, Capinha C, Celesti-Grapow L, Dawson W, Dullinger S, Fuentes N, Jäger H, Kartesz J, Kenis M, Kreft H, Kühn I, Lenzner B, Liebhold A, Mosena A, Moser D, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, Van Kleunen M, Walker K, Weigelt P, Yamanaka T, Essl F (2017) No saturation in the accumulation of alien species worldwide. Nat Commun 8:1–9. https://doi.org/10.1038/ncomms14435

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pyšek P, van Kleunen M, Winter M, Ansong M, Arianoutsou M, Bacher S, Blasius B, Brockerhoff EG, Brundu G, Capinha C, Causton CE, Celesti-Grapow L, Dawson W, Dullinger S, Economo EP, Fuentes N, Guénard B, Jäger H, Kartesz J, Kenis M, Kühn I, Lenzner B, Liebhold AM, Mosena A, Moser D, Nentwig W, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, Walker K, Ward DF, Yamanaka T, Essl F (2018) Global rise in emerging alien species results from increased accessibility of new source pools. Proc Natl Acad Sci USA 115:E2264–E2273. https://doi.org/10.1073/pnas.1719429115

Steffen K, Grousset F, Schrader G, Petter F, Suffert M (2015) Identification of pests and pathogens recorded in Europe with relation to fruit imports. Bull OEPP 45(2):223–239

Singh KP (2005) Invasive alien species and biodiversity in India. Curr Sci 25;88(4):539.

TradeMap. (2018) Market analysis and research, International Trade Centre (ITC); Geneva 10, Switzerland.

Vacante V (2010) Citrus mites: identification, bionomy and control. Walingford: CABI Publishing. pp. 371.

Warziniack T, Haight RG, Yemshanov D, Apriesnig JL, Holmes TP, Countryman AM, Rothlisberger JD, Haberland C (2021) Economics of invasive species. InInvasive Species in Forests and Rangelands of the United States (pp. 305–320). Springer, Cham.

Work TT, Cavey MDG, JF, Komsa R, (2005) Arrival rate of nonindigenous insect species into the United States through foreign trade. Biol Invasions 7:323–332