PEST AND DISEASES IN MANGO (*MANGIFERA INDICA* L.)

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EXECUTIVE SUMMARY

In this work, we review the most important pests and diseases that affect mango production worldwide as well as the main measures implemented to control them. Pests and diseases are the main factors that can impact sustainable mango fruit production in the tropics and subtropics worldwide. Commercial cultivation of mango, characterized by expansion to new areas, changing crop management, replacement of varieties and increased chemical interventions, has altered significantly the pest and disease community structure in this crop in the different mango producing regions. In addition, climate change is inducing the emergence of new pests and, whereas globalization and trade liberalization have created wide opportunities for mango commercialization growth, at the same time, this can result in faster dispersion of pests and diseases among different mango growing areas if proper sanitary measures are not implemented.

This review covers different topics related to pests and diseases in mango. First, a thorough description of the main pests and diseases that affect mango is provided. Second, the different approaches used in different mango producing countries for chemical and biological control are described. Third, recommendations for appropriate mango management techiques that include integrated pest and disease management, reduction in the use of chemicals and the implementation of a good monitoring and surveillance system to help control the main pests and diseases, are also discussed. Finally, the current knowledge on agrohomeopathy and Korean Natural Farming is analyzed and recommendations on future lines of research to optimize mango pest and disease control are discussed. The fight against mango pests and diseases will require internationally coordinated research, development and innovation efforts to find effective responses and proper management approaches to the extant pests and diseases and be prepared for new threats. This should include the selection of disease and pest tolerant/resistant varieties; the development of those varieties has so far been made through conventional breeding and selection programs and empirical selection made by growers, but new biotechnological approaches will surely speed up this process in the future. Ideally, effective mango pest and disease management will involve a holistic combination of management approaches combined with strict quarantine and regulatory measures that should be enforced for fruit and plant materials at entry points of countries in which mango is produced to prevent introduction of new pests and diseases.

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INTRODUCTION

As in other horticultural crops, pests and diseases are among the main factors that impact sustainable mango fruit production worldwide. Commercial cultivation of mango, characterized by expansion to new areas, changing crop management, replacement of varieties and increased chemical interventions, has altered significantly the pest and disease community structure in this crop. In addition, climate change is resulting in the emergence of new pests and diseases and, whereas globalization and trade liberalization have created wide opportunities for mango commercialization, at the same time, this can result in faster dispersion of pests and diseases among different mango growing areas. As a result, some pests and diseases earlier considered to be minor or secondary have become serious problems recently.

Pests and diseases are serious constraints to mango production throughout the tropics and subtropics. They can affect tree vigor and survival, canopy and root growth, fruit set, yield and pre and post-harvest quality of fruits and have a big impact on the market potential mango fruits. In total, about 400 species of pests are known to infest mango in different parts of the world. Regarding diseases, most plant diseases are caused by fungi. Although anthacnose, malformation and sudden decline are considered as the main mango diseases worldwide, many additional fruit, foliar, floral and soil-borne diseases have been described in different countries and, therefore, could become potential risks in the international mango commercial trade.

Harmonizing efforts at every mango management level as well as combining different approaches are necessary to control and mitigate the destructive effects of pests and diseases on mango production worlwide. Strict quarantine and regulatory measures should be enforced at entry points of countries in which mango is produced to prevent introduction of new pests and diseases. At the farm level, mango growers should be trained to adopt good agricultural practices that include integrated pest and disease management, reduction in the use of chemicals and the implementation of a good monitoring and surveillance system. In addition, coordinated research, development and innovation efforts should be implemented internationally to find effective responses and proper management approaches to the extant pests and diseases and be prepared for new threats.

Although chemical management of mango pests and diseases is widespread, non-chemical measures such as the selection of disease and pest tolerant/resistant varieties are most desirable. The development of those varieties can be made through conventional breeding and selection programs and empirical selection made by growers but also, in recent years, by biotechnological approaches. Ideally, effective mango pest and disease management will involve a holistic combination of management approaches.

In this work we review the most important pests and diseases that affect mango production worldwide as well as the main measures that can be implemented to control them, including biological control. In this sense, a specific section is devoted to evaluating the scarce information available on agrohomeopathy and Korean Natural Farming for mango pest and disease control.

OBJECTIVES

1. To produce an overall picture of the current status worldwide of the main pests and diseases affecting mango (leaves, fruits, inflorescences and branches) with special focus on the countries exporting mango fruits to the US market.
2. To critically review the advances made in biological control of the main pests and diseases affecting mango including agro-homeopathy approaches in order to provide recommendations for biological control management. Special importance will be given to Korean Natural Farming (KNF) approaches that are based on the use of microorganisms to improve the fertility of the soils
3. To define potential future areas or/and lines of research based on the information collected

1. MAIN INSECT PESTS AFFECTING MANGO

1.1. DESCRIPTION OF THE MAIN PESTS

About 400 species of pests are known to infest mango in different parts of the world (Tandon and Verghese 1985; Peña *et al*. 1998). Worldwide lists of pests of mango have been compiled by de Laroussilhe (1980), Tandon and Verghese (1985), Veeresh (1989) and Peña and Mohyuddin (1997). In turn, the pests of mango in India (Srivastava, 1998; Anonymous, 2006), Australia (Anonymous, 1989), Pakistan (Mohyuddin, 1981), Israel (Wysoki *et al*., 1993; Swirski *et al.*, 2002), the USA (Peña, 1993), Western Africa (Vannière *et al*., 2004), Brazil (Assis and Rabelo, 2005), Central America (Coto *et al*., 1995) and Puerto Rico (Martorell, 1975) have also been described.

According to Reddy *et al*. (2018), commercial cultivation of mango, characterized by expansion to new areas, changing crop management, replacement of varieties and increased chemical interventions, has altered the pest community structure significantly. In addition, climate change has induced the emergence of new pests and mango international trade has promoted the movement of pests between regions. As a result, some pests earlier considered to be minor or secondary pests have become serious problems recently (Jayanthi *et al*. 2014a, b).

According to de Faveri (2018), the major pests of mango are mango scale (*Aulacaspis tubercularis*), mango tipborer (*Chlumetia euthysticha*), mango shoot caterpillar (*Penicillaria jocosatrix*), mango cecid flies, MSW (*Sternochetus mangiferae*), mango pulp weevil (*Sternochetus frigidus*), mango red-banded caterpillar (*Deanolis sublimbalis*), mango citripestis (*Citripestis euthraphera*), pink wax scale (*Ceratoplastes rubens*), mango mealybug (*Rastrococcus*), mango planthopper (*Colgaroides acuminata*), mango leafhoppers, tea red spider mite (*Oligonychus coffeae*), tea mosquito bug (*Helopeltis* spp.), mango bud mite (*Aceria mangiferae*), red-banded thrips (*Selenothrips rubricinctus*), flower caterpillars, fruit-spotting bug (*Amblypelta lutescens* and *A. nítida*), coconut bug (*Pseudotheraptus wayi*) and different species of fruit flies (*Bactrocera* spp., *Ceratitis* spp. and *Anastrepha* spp.). Nevertheless, four species on this list, *Chlumetia euthysticha*, *Colgaroides acuminata*, *Amblypelta lutescens* and *A. nitida*, have been so far only reported in Australia.

Below is a summary of arthropod pests of mango, included in Peña and Mohyuddin (1997)

ORDER	FAMILY	SPECIES	GEOGRAPHICAL AREA	PLANT PART AFFECTED
Acari	Eryophidae	*Aceria mangiferae*	South Pacific, India and Pakistan	Buds
		Cisaberoptus kenyae	Israel	Leaves
		Metaculus mangiferae	Australia and North America	Blossom
	Tarsonemidae	*Polyphagotarsonemus latus*	North America	Blossom
	Tenuipalpidae	*Brevipalpus phoenicis*	North America	Leaves
	Tetranychidae	*Oligonychus coffeae*	Australia	Leaves
		O. mangiferae	India, Pakistan, Israel	Leaves
		O. punicae	Central America and islands of the Caribbean region	Leaves
		O. yothersi	North America	Leaves
		Tetranychus bimaculatus	Islands of the Caribbean region	Leaves
		T. cinnabarinus	Israel	Leaves
		T. telarius	Southeast Asia	Leaves
		T. tumidus	North America	Leaves
	Tydeidae	*Lorrya Formosa*	North America	Leaves
Coleoptera	Bostrichidae	*Apate monachus*	Islands of the Caribbean region	Trunk and Branches
	Cerambycidae	*Batocera rubus*	India and Pakistan	Trunk and Branches
		B. rufomaculata	Israel	Trunk and Branches
		Indarbela quadrinonata	India and Pakistan	Trunk and Branches
		Stenodontes downesi	South America	Leaves
		Macrotoma spp.	South America	Trunk and Branches
		M. scutellaris	Israel	Trunk and Branches
	Chrysomelidae	*Bassereus brunipes*	North America	Leaves
		Crimissa cruralis	South America	Leaves
		Diabrotica balteata	North America	Leaves
		Monolepta lepida	Israel	Leaves
	Curculionidae	*Anthonomus spp.*	Islands of the Caribbean region	Buds
		Artipus floridanus	North America	Leaves
		Deporaus marginatus	India and Pakistan	Leaves
		Diaprepes abbreviatus	India and Pakistan	Leaves
		Pachneus spp.	North America	Leaves
		Rhynchaenus mangiferae	India and Pakistan	Leaves
		Sternochetus mangiferae	South America, Islands of the Caribbean region	Fruit
	Scarabaeidae	*Cotinis nitida*	North America	Fruit, Leaves
		Euphoria sepulcralis	North America	Fruit, Leaves
		E. limbata	North America	Fruit, Leaves
		Macraspis spp.		Leaves
		Phyllophaga spp.		Leaves and Root
	Scolytidae	*Hypocryphalus mangiferae*	North and South America	Root, Trunk and Branches
		Stephanoderes spp.	North America	Trunk and Branches

		Xyleborus saxesini	North America	Fruit
Diptera	Cecidomyiidae	*Procontarina amaramanjae*	India and Pakistan	Buds
		P. mangiferae	East Africa and Southeast Asia	Leaves
		P. schreineri	South Pacific	Leaves
		Erosomyia indica	India and Pakistan	Buds and Leaves
		E. mangiferae	Islands of the Caribbean region	Buds
	Loncheidae	*Lonchaea spp.*	South America	Fruit
	Tephritidae	*Anastrepha spp.*	South America	Fruit
		A. distincta	South America	Fruit
		A. fraterculus	South America	Fruit
		A. ludens	Central and South America	Fruit
		A. obliqua	Islands of the Caribbean region	Fruit
		A. pseudoparalella	South America	Fruit
		A. serpentina	Central, South and North America	Fruit
		A. striata	Central, South and North America	Fruit
		A. suspensa	Central and North America	Fruit
		Bactrocera jarvisi	Australia	Fruit
		B. aquilonis	Australia	Fruit
		B. carveae	Southeast Asia	Fruit
		B. correcta	Southeast Asia	Fruit
		B. dorsalis	Southeast Asia	Fruit
		B. spp. near B. dorsalis (A)	South Pacific, India and Pakistan	Fruit
		B. spp. near B. dorsalis (B)	Southeast Asia, India and Pakistan	
		B. spp. near B. dorsalis (C)	Southeast Asia, India and Pakistan	
		B. spp. near B. dorsalis (D)	Southeast Asia, India and Pakistan	
		B. facialis	South Pacific	Fruit
		B. frauenfeldi	Australia, Southeast Asia, South Pacific	Fruit
		B. frogatti	South Pacific	Fruit
		B. incisa	Southeast Asia, South Pacific	Fruit
		B. kirki	South Pacific	Fruit
		B. latifrons	Southeast Asia	Fruit
		B. melanota	South Pacific	Fruit
		B. neohumeralis	Australia	Fruit
		B. occipitalis	Southeast Asia	Fruit
		B. opilae	Australia	Fruit
		B. passiflorae	South Pacific	Fruit
		B. psidii	South Pacific	Fruit
		B. trilineola	South Pacific	Fruit
		B. tryoni	South Pacific	Fruit
		B. tuberculata	Southeast Asia	Fruit
		B. versicolor	Southeast Asia	Fruit
		B. zonata	South Pacific, Southeast Asia, India and Pakistan	Fruit
		B. (Hemigymnodacus) diversa	Southeast Asia	Fruit
		B. (Zeudacus) cucurbitae	Southeast Asia, India and Pakistan	Fruit
		B. (Zeudacus) tau	Southeast Asia	Fruit

		B. (Notodacus) xanthodes	South Pacific	Fruit
		Ceratitis capitata	Cosmopolitan	Fruit
		C. catoirii	East Africa	Fruit
		C. cosyra	West Africa	Fruit
		C. punctata	East Africa	Fruit
		C. anonae	East Africa	Fruit
		C. flexuosa	East Africa	Fruit
		C. rosa	East Africa	Fruit
		Dirioxa confuse	Australia	Fruit
		D. pornia	Australia	Fruit
		Cochliomya macellaria	North America	Fruit
		Toxotrypana curvicauda	North, Central and South America, Islands of the Caribbean region	Fruit
Hemiptera	Coreidae	*Amblypelta lutescens*	Australia	Fruit
		A. nitida	Australia	Fruit
		Pseudotherapterus wayi	East Africa	Fruit
		Veneza stigma	South America	Fruit
	Miridae	*Daghbertus fasciatus*	North America, Islands of the Caribbean region	Buds
		Rhinacloa spp.	North America. Islands of the Caribbean region	Buds
	Pentatomidae	*Brochymena spp.*	North America	Leaves
		Plautia affinis	Australia	Leaves
		Stenozygum coloratum	Israel	Fruit?
	Scutelleridae	*Symphillus caribbeanus*	North America. Islands of the Caribbean region	Fruit
Homoptera	Acanalonidae	*Acanalonia latifrons*	North America	Buds, Leaves and Fruit
	Aleyrodidae	*Aleurocanthus woglumi*	North, Central and South America, West Africa	Leaves
		Aleurodicus dispersus	North America	Leaves
	Aphididae	*A. craccivora*	Israel	Leaves
		A. fabae	Israel	Leaves
		A. gossypii	Israel	Leaves
		A. spiraecola	Israel	Leaves
		Toxoptera aurantii	North America, Islands of the Caribbean region	Buds and Leaves
	Asterolecanidae	*Asterolecanium pustulans*	North America, Israel	Leaves
	Ciccadellidae	*Amrasca splendens*	Australia, East Africa, Southeast Asia, India and Pakistan	Leaves
		Amritodus atkinsoni	India and Pakistan	Leaves
		A. brevistylus	India and Pakistan	Leaves
		Busoniomimus manjunathi	India and Pakistan	Leaves
		Chunrocerus niveosparsus	South Pacific	Leaves, Blossom
		Empoasca spp.	Israel	Leaves
		Idioscopus anasuyae	India and Pakistan	Leaves, Fruits
		I. clavosignatus	India and Pakistan	Blossom, Leaves
		I. clypealis	Southeast Asia, India and Pakistan	Leaves, Fruits
		I. decoratus	India and Pakistan	Blossom, Leaves
		I. jayashirae	India and Pakistan	Blossom, Leaves
		I. nagpurensis	India and Pakistan	Leaves, Fruits
		I. niveosparsus	Southeast Asia, India and Pakistan	Trunk and Branches,

				Leaves, Blossom
		I. nigroclypeatus	India and Pakistan	Blossom, Leaves
		I. spectabilis	India and Pakistan	Blossom, Leaves
		Rabela tabebuia	North America	Leaves
		Scaphytopius spp.	North America	Leaves
	Cixiidae	*Myndus crudus*	North America	Leaves
	Coccidae	*Ceroplastes cirripediformis*	North America	Leaves
		C. floridensis	North America, Israel	Leaves
		C. martinae	South America	Trunk and Branches
		C. rubens	Australia, East Africa, North America, Southeast Asia, Islands of the Caribbean region, India and Pakistan	Leaves
		C. rusci	Israel	Leaves
		C. trochezi	South America	Trunk and Branches
		Coccus acutissimus	North America	Leaves
		C. elatensis	Australia	Leaves
		C. hesperidum	Australia	Leaves
		C. mangiferae	East and West Africa, South and North America, Southeast Asia	Leaves
		C. moestus	Islands of the Caribbean region	Leaves
		C. viridis	North America	Leaves
		Eucalymnatus tessellatus	North America	Leaves
		Kilifa acuminata	North America	Leaves
		Milviscutulus mangiferae	Israel	Trunk and Branches, Leaves, Fruits
		Philephedra tuberculosa	North America	Leaves, Fruits
		Protopulvinaria pyriformis	Israel	Leaves
		P. mangiferae	West Africa	Leaves
		Pulvinaria psidii		Leaves
		Saissetia oleae	Israel	Leaves
		S. neglecta	Islands of the Caribbean Region	Leaves
		Vinsonia stellifera	South America	Leaves
	Diaspididae	*Aonidiella aurantii*	Israel	Leaves
		A. orientalis	Israel	Leaves
		Aspidiotus destructor	North and South America, Southeast Asia	Leaves
		Aulacaspis tubercularis	Australia, East and West Africa, North and South America, Islands of the Caribbean region	Leaves, Fruits
		Chrysomphalum aonidum	North America, Israel	Leaves
		C. dyctiospermi	North and South America, West Africa, Islands of the Caribbean region	Leaves
		Fiorinia florinae	North America	Leaves
		Hemiberlesia latanidae	North America, Israel	Leaves
		Howardia biclavis	North America	Trunk and Branches
		Ischnaspis longirostris	North and South America	Leaves

		Lindingaspis floridana	North America	Leaves
		L. ferrisi	India and Pakistan	Leaves
		Morganella longispina	North America	Trunk and Branches
		Parlatoria spp.	North America	Leaves
		Phenacaspis cockerelli	South America	Leaves
		P. dilatata	Australia	Leaves
		P. sandwichensis	South Pacific	Leaves
		Pinnaspis strachani	East Africa, North America	Leaves
		Pseudaulacaspis cockerelli	North America	Leaves
		Pseudaonidia trilibitiformia	South and North America	Leaves
		Radionaspis indica	North America	Leaves
		Selanaspidus articulatus	South America	Leaves
		Unaspis citri	South America	Trunk and Branches
	Flatidae	*Colgaroides acuminata*	Australia	Blossom, Fruits
	Margarodidae	*Drosicha stebbingii*	India and Pakistan	Leaves
		D. magiferae	India and Pakistan	Leaves
		Icerya seychellarum	East Africa, Southeast Asia, India and Pakistan	Leaves
	Ortheziidae	*Orthezia spp.*	South America	Leaves
		O. olivicola	South America	Leaves
	Pseudococcidae	*Drosicha mangiferae*	India and Pakistan	Leaves
		D. stebbingi	India and Pakistan	Leaves
		Pseudococcus adonidum	East and West Africa, South America, India and Pakistan	Leaves, Fruits
		P. elisae	South Pacific	Leaves
		P. longispinus	Islands of the Caribbean region	Buds
		Rastrococcus invadens	East and West Africa	Buds, Leaves, Fruits
		R, spinosus	India and Pakistan	Buds, Leaves, Fruits
	Psyllidae	*Apsylla cistellata*	India and Pakistan	Leaves
		Pauropsylla nigra	Southeast Asia	Leaves
Hymenoptera	Apididae	*Trigon spp.*	Central America	Blossom
	Formicidae	*Atta spp.*	Central America	Leaves
Isoptera	Termiticidae	*Coptotermes acinaciformis*	Australia	Root, Trunk and Branches
		C. formosanus	South Pacific	Trunk and Branches
		Microcerotermes biroi	Australia	Trunk and Branches
		M. edenatus		Trunk and Branches
		Microtermes obesis	India and Pakistan	Trunk and Branches
		Neotermes insularis	Australia	Trunk and Branches
		Nisutitermis graveolus	Australia	Root, Trunk and Branches
		Odontotermes lokanandi	India and Pakistan	Trunk and Branches
		O. gurdaspurensis	India and Pakistan	Trunk and Branches

		O. wallonensis	India and Pakistan	Trunk and Branches
		O. obesus	India and Pakistan	Trunk and Branches
		O. horai	India and Pakistan	Trunk and Branches
		Termes cheeii	Australia	Trunk and Branches
Lepidoptera	Arctiidae	*Diacrisa obliqua*	India and Pakistan	Leaves
		Lymira edwardisii	North America	Leaves
	Coreuthidae	*Eccopsis praecedens*	East Africa	Fruit
		Lobesia vanillana	East Africa	Fruits
	Ctneuchidae	*Syntomeidaepilais jucundisima*	North America	Buds
	Gracillariidae	*Marmara spp.*	North America	Fruits
		Acrocercops spp.	Australia	Leaves
	Gelechiidae	*Thiotrina godmani*	Islands of the Caribbean region	Buds
	Geometridae	*Oxydia spp.*	North America	Fruits
		O. vesulia	Islands of the Caribbean region	Fruits
		Pleuroprucha insulsaria	Islands of the Caribbean region	Buds
		Chloropteryx glauciptera	Islands of the Caribbean region	Buds
		Thalassodes dissita	India and Pakistan	Leaves
	Limacodidae	*Latoia lepida*	Southeast Asia, India and Pakistan	Leaves
	Lymanthriidae	*Lymanthria marginata*	India and Pakistan	Leaves
	Megatopygidae	*Megatopyge defoliate trujillo*	North America	Leaves
		M. lanata	South America	Leaves
	Noctuidae	*Alabama argillacea*	Islands of the Caribbean region	Fruits
		Chlumetia transversa	Southeast Asia, India and Pakistan	Buds
		Gonodonta spp.	Islands of the Caribbean region	Fruits
		G, pyrgo	Islands of the Caribbean region	Fruits
		Othreis fullonia	Australia	Fruits
		O. materna	Islands of the Caribbean region	Fruits
		O. tyrannus	Australia	Fruits
		Penicillaria jocosatrix	South Pacific	Leaves
	Pyralidae	*Davara caricae*	Islands of the Caribbean region	Buds
		Noorda albizonalis	Southeast Asia, India and Pakistan	Fruits
		Orthaga exvinacea	India and Pakistan	
		Pococera atramentalis	North America, Islands of the Caribbean region	Buds, Fruits
		Tallula spp.	North America	Fruits
	Saturnidae	*Nataurelia zambesiana*	East Africa	Leaves
	Tortricidae	*Aethes spp.*	Australia, Islands of the Caribbean region	Buds
		Amorbia aequiflexia	Islands of the Caribbean region	Buds
		Cosmetra anthophaga	East Africa	Fruits
		Episimus transferrata	Islands of the Caribbean region	Buds
		Playnota rostrata	North America	Buds, Fruits

Orthoptera	Acrididae	*Anacridium melanorhodon*	East and West Africa	Leaves
Thysanoptera	Paleothripidae	*Leothrips sangularis*	North America	Buds
	Tripidae	*Frankliniella spp.*	Islands of the Caribbean region	Buds
		F. bispinosa	North America	Buds
		F. fusca	North America	Buds
		F. kelliae	North America	Buds
		F. occidentalis	Israel	Buds
		Heliothrips hemorroidalis	North America, Israel	Buds
		Scirtothrips mangiferae	Israel	Leaves
		Selenothrips rubrocinctus	North, Central and South America, East Africa, Southeast Asia	Leaves
		Retithrips syriacus	Israel	Leaves
		Thrips palmi	North America	Buds
		T. florum	North America	Buds

Additional insect species considered minor pests in mango in India are included in the following list (Reddy *et al*., 2018):

Common name	Scientific name	Damage
Blossom feeders and webbers	*Asura ruptofascia, Celama analis, C. fasciatus, Cosmostola laesaria, Gymnoscelis imparatalis, Eublemma* spp.	Webbing and feeding on the inflorescens
White grub beetles	*Holotrichia consanguinea, Anomala* sp.	Voracious feeding on leaves during night times
Mango black fly	*Aleurocanthus mangiferae*	Suck sap from leaves
Painted bug	*Coptosoma nazirae*	Suck sap from leaves, flowers
Black-eating caterpillar	*Indarbela tetraonis*	Feed on bark and make holes on stem
Fruit-sucking moths	*Eudocima maternal, E. fullonica*	Suck sap from fruits

Below we describe with more detail the different pests classified in terms of the tissues affected.

1.1.1. PESTS OF BLOSSOMS AND TENDER SHOOTS

LEAFHOPPERS (Cicadellidae):

Nymphs and adults congregate on panicles and tender shoots where they suck the sap. The continued feeding results in withering and dropping of florets, thus leading to failure of fruit setting. Besides, leafhoppers excrete honey dew which attracts sooty mould and affects photosynthetic efficiency (Butani, 1979). According to Reddy *et al*. (2018), leafhoppers are the major pests of mango with a potential to incur in total fruit losses.

A total of 18 species have been reported as pests affecting mango (Peña *et al*., 2009); 15 of them have been reported in Asia, but only 3-4 can be considered as relevant (Reddy *et al*., 2018):

- ***Idioscopus clypealis***: According to Peña (1997), it is present in Southeastern Asia, India and Pakistan; according to EPPO (https://gd.eppo.int/taxon/IDIOCL/distribution), it is present in India, Bangladesh and the Philippines, and according to CABI (https://www.cabi.org/isc/datasheet/28470#toDistributionMaps), in Australia, Southeastern Asia, India, Pakistan and the South Pacific.

- ***Idioscopus nitidulus*** (*Idiocerus nitidulus*; *Chunrocerus niveosparsus*): it was reported as *Chunrocerus niveosparsus* in Peña (1997) and EPPO, as *I. niveosparsus* in Peña *et al*. (2009) and as *Idioscopus nitidulus* in CABI and Reddy *et al*. (2018). According to Peña (1997) it is distributed in the South Pacific and according to CABI (https://www.cabi.org/isc/datasheet/28472#toDistributionMaps) in Australia, Southeastern Asia, India, Pakistan and South Pacific.
- ***Idisocopus nagpurensis***: According to Peña (1997) is present in India and Pakistan and according to CABI also in Sutheastern Asia (https://www.cabi.org/isc/datasheet/28471#toDistributionMaps)
- ***Amritodus atkinsoni***: reported in Peña (1997) and Reddy *et al*. (2018) in India and Pakistan.

MIDGES (Diptera, Cecidomyiidae)

Mango midges are important pests of mango across the World, but especially in Asia, where about 16 species of gall midges attack mango (Peña, 2002; Ahmed *et al*., 2005). The main species of this group are:

- ***Erosomya indica*** (mango midge): cited in Peña (1997), Peña *et al*. (2009), Ahmed (2005) and Reddy *et al*. (2018). According to Peña (1997), it is present in India and Pakistan but according to Ahmed (2005) it could be present in other regions as well.
- ***Erosomya mangiferae*** (mango gall midge o mango blister midge). Cited by Peña (1997), Peña *et al*. (2009) and Reddy *et al*. (2018). According to Peña (1997) it would be present in the Caribbean.
- ***Asynapta mangiferae***. According to Peña *et al*. (2009) it is present in the Caribbean.
- ***Gephyraulus mangiferae***. Reported in Peña *et al*. (2009) in the Caribbean.
- ***Procontarinia matteiana*** (leaf gall midge). According to Peña (1997), it is present in India and Pakistán, and according to Reddy *et al*. (2018), in India, Indonesia, Kenya, Mauritius, Oman, Reunion, South Africa ant the United Arab Emirates.
- ***Procontarinia mangiferae***. According to Peña (1997) it is present in Eastern Africa and Southeastern Asia.

  Procontarinia pustulata. According to Medina *et al*. (2017) it is present in the Phillipines. It has also been reported in northern Australia and Papua New Guinea (Koselik *et al*., 2009).

THRIPS (Thysanoptera):

Flankliniella occidentalis: reported in Peña (1997), Peña *et al*. (2009) and Reddy *et al*. (2018) in Israel. According to EPPO it would be present in all the continents (https://gd.eppo.int/taxon/FRANOC/distribution).

Frankiniella bispinosa and ***Frankiniella kelliae***: They have been reported in Peña (1997), Peña *et al*. (2009) and Reddy *et al*. (2018) as mango pests in Florida.

Frankiniella cubensis: reported in Peña *et al*. (2009) in Costa Rica.

Scirtothrips dorsalis: reported in Reddy *et al*. (2018) in India, Thailand and Malaysia. According to EPPO (https://gd.eppo.int/taxon/SCITDO/distribution) it is present in India, Pakistan, Southeastern Asia, Pacific Islands, Australia, some African countries (Ivory Coast, Kenya and Uganda), northern South America and Caribbean.

Thrips palmi: reported by Peña (1997) in North America and by Reddy *et al*. (2018) in India. According to EPPO (https://gd.eppo.int/taxon/THRIPL/distribution) it is also present in the Caribbean and several Central and South American countries.

Selenothrips rubrocinctus. Reported by Peña (1997) in Noth, Central and South America, Eastern Africa and Southeastern Asia. According to CABI (https://www.cabi.org/ISC/abstract/20056600136), it is present in Asia (China, Formosa, India, Malaisia, Philippine Islands), Africa (Congo, Fernando Poo, Ghana, Ivory Coast, Nigeria, Principe, Republic of Congo, Sao Thomé, Sierra Leone, Tanganyika, Uganda, Zanzibar), Australasia and Pacific Islands (Hawaii, Mariana Islands, New Caledonia, Papua and New Guinea, Solomon Islands, Wallis Island), Central America (Costa Rica, Honduras, Panama), West Indies and South America (Brazil, British Guiana, Ecuador, Peru, Surinam, Venezuela).

LEPIDOPTERA BLOSSOM FEEDERS:

The lepidopteran flower feeders are considered the second most important inflorescence pests of mango (Peña *et al*., 2009).

Chloropteryx glauciptera and ***Oxydia vesulia*** (Geometridae). Reported by Peña (1997) and Peña *et al*. (2009) in the Caribbean (Dominica).

Penicilllaria jocosatrix (mango shoot caterpillar; Noctuidae). According to Peña (1997) it is present in the South Pacific.

Pococera attramentalis (Pyralidae), ***Pleuroprocha insulsaria*** (Geometridae), ***Platynota rostrana*** (Torticidae), ***Talulla spp*** (Pyrallidae) and ***Racheospila gerularia*** (Geomatridae). According to Peña (1997) *P. attramentalis* is present in the Caribbean and *R. gerularia* in Central America. According to Peña *et al*. (2009) some of them could also be present in Florida.

Pleuroprucha asthenaria (Geometridae) and *Crytoblades gnidiella* (Pyralidae) reported by Peña *et al*. (2009) in Brazil.

1.1.2. PESTS OF FRUITS:

FRUIT FLIES (Tephitidae):

About 60 different fruit fly species affect mango and related species (Peña *et al*., 2009). The most important belong to the genera *Anastrepha*, *Bactrocera* and *Ceratitits*.

Anastrepha. The genus is present in the Americas, from the US to Argentina including the Caribbean (Peña, 2009). A total of 12 especies have been reported associated with mango.

- ***A. obliqua***: the most common speices in the Americas. According to Peña (1997) and Peña *et al*. (2009), it is present in Australia, Mexico, Costa Rica, Honduras, Guatemala, Cuba, Puerto Rico, Jamaica, El Salvador and Venezuela. According to CABI (https://www.cabi.org/isc/datasheet/5659#todistributionTable), in Australia, South America and the islands of the Caribbean.
- ***A. striata***: reported by Peña (1997), Peña *et al*. (2009) and CABI (https://www.cabi.org/isc/datasheet/5667#todistributionTable) in North, Central, South America and the Caribbean.
- ***A. serpentina***: reported by Peña (1997), Peña *et al*. (2009) and CABI (https://www.cabi.org/isc/datasheet/5665#todistributionTable) in North, Central, South America and the Caribbean.
- ***A. fraterculus***: According to Peña (1997) it is present in South America, according to Peña *et al*. (2009), in Brazil and Ecuador and according to CABI, it is also present in Central America, Mexico and the Caribbean (https://www.cabi.org/isc/datasheet/5648#todistributionTable).
- ***A. pseudoparalella***: reported by Peña (1997) and Peña *et al*. (2009) in South America.
- ***A. suspensa***: reported by Peña (1997) in North and Central America and by CABI (https://www.cabi.org/isc/datasheet/5668#todistributionTable) also in the Caribbean and French Guiana in South America.
- ***A. ludens***: reported by Peña (1997) in Central and South America and by CABI (https://www.cabi.org/isc/datasheet/5654#todistributionTable) in North America (Mexico) and Central America.
- ***A. turpiniae*** and ***A. zuelanie***: reported by Peña *et al*. (2009) in Brazil and Ecuador.

Bactrocera. About 33 species of this genus affect mango in Africa, Asia and Australia. The following are the most important:

- ***B. phillippiensis*** and ***B. occipitalis*** according to Peña *et al*. (2009) and CABI (https://www.cabi.org/isc/abstract/20073277417) they are present in Asia.
- ***B. invadens***: according to Peña *et al*. (2009) present in Western Africa.
- ***B. tryoni***: reported by Peña (1997) and Peña *et al*. (2009) in the South Pacific.
- ***B. zonata***: reported by Peña (1997) and Peña *et al*. (2009) in Southeast Asia, India, Pakistan and South Pacific and by CABI (https://www.cabi.org/isc/datasheet/17694#todistributionTable) in the Near East and Africa.

- ***B. dorsalis***: according to Peña (1997) it is present in the South Pacific and according to CABI (https://www.cabi.org/isc/datasheet/17685#todistributionTable) also in the Near East, Eastern Asia, India, Pakistan and Africa.
- ***B. neohumeralis***: reported by Peña (1997) and Peña *et al*. (2009) in Australia and by CABI (https://www.cabi.org/isc/datasheet/8727#todistributionTable) in Australia and Papua New Guinea.
- ***B. jarvisi***: reported by CABI (2020) in Australia (https://www.cabi.org/isc/datasheet/8715).
- ***B. papayae***: reported by CABI (https://www.cabi.org/isc/abstract/20063181726) and The Pacific Community (https://lrd.spc.int/species/bactrocera-papayae--drew-and-hancock-asian-papaya-fruit-fly) in Asia (Thailand, Peninsular Malaysia, East Malaysia, Singapore, Indonesia and Kalimata) and the Pacific (Papua New Guinea).
- ***B. frauenfeldi***: reported by Peña (1997) and Peña *et al*. (2009) in Australia, Southeastern Asia and South Pacific and by CABI (https://www.cabi.org/isc/datasheet/8712#todistributionTable) in Australia and South Pacific.

Ceratitis: several species have been reported to affect mango.

- ***C. capitata***: According to CABI (https://www.cabi.org/isc/datasheet/12367), it is present in Hawaii, mainland USA, Central and South America, Africa, Spain and other European countries, Australia and the Near East; absent Mexico, the Caribbean and Southeastern Asia.
- ***C. cosyra***: this is one of the three most common species of the genus in Africa. Reported by Peña (1997) and Peña *et al*. (2009) in Western Africa and by CABI (https://www.cabi.org/isc/datasheet/12370) in different African countries.
- ***C. fasciventris***: reported in Peña *et al*. (2009) as one of the three most common species of the genus in Africa.
- ***C. anonae***: cited by Peña (1997) and Peña *et al*. (2009) as one of the three most common speices of the genus in Africa. According to Peña (1997), present in Eastern Africa.
- ***C. catoirii***: reported by Peña (1997) and Peña *et al*. (2009) in Eastern Africa and Reunion.
- ***C. punctata***: reported by Peña (1997) in Eastern Africa and by CABI (https://www.cabi.org/isc/datasheet/12376) in Eastern and Western Africa.
- ***C. flexuosa***: cited by Peña (1997) in Eastern Africa.
- ***C. rosa***: reported by Peña (1997) and CABI (https://www.cabi.org/isc/datasheet/12378#todistribution) in Eastern and Southern Africa.
- ***C. silvestrii*** and ***C. quinaria***: reported by Peña *et al*. (2009) in Benin. According to CABI, (https://www.cabi.org/isc/datasheet/12377), ***C. quinaria*** would be present in Eastern and Western Africa.

SEED AND PULP WEEVILS:

Mango is not very susceptible to seed and pulp weevils except for some species (Reddy *et al*., 2018).

Sternochetus mangiferae (seed weevil). Reported by Peña (1997), Peña *et al*. (2009), Reddy *et al*. (2018), EPPO (https://gd.eppo.int/taxon/CRYPMA) and CABI (https://www.cabi.org/isc/datasheet/16434). It is distributed in most mango growing areas, except North and Central America. A map is available by EPPO (https://gd.eppo.int/taxon/CRYPMA/distribution).

Sternochetus frigidus (pulp weevil). According to Peña (1997) and EPPO (https://gd.eppo.int/taxon/CRYPGR/distribution), it is present in Southeastern Asia, India, Pakistan and the South Pacific.

***Deanolis sublimbalis* (*Noorda albizonalis*)** (mango seed borer/red-banded Caterpillar/Lepidoptera). According to Peña (1997) and Peña *et al*. (2009), present in Southeastern Asia, India, Pakistan and South Pacific.

Citripestis eutraphera (mango fruit borer (Lepidoptera : Pyralidae). Reported by Reddy *et al*. (2018) in India, Java, Indonesia and Northern Australia.

Deudores isocrates (pommegranate fruit borer/Lepidopera: Lycaenidae). Reported by Peña *et al*. (2009) in India and the Philippines.

Orgyia postica (cocoa tussock moth/Lepidoptera: Lymantridae). Reported by Peña *et al*. (2009) in the Philippines.

Conogethes punctiferalis (Lepidopeta: Pyralidae): cited by Reddy *et al*. (2018). According to EPPO (https://gd.eppo.int/taxon/DICHPU/distribution) it is present in several Asian countries (China, India, Indonesia, Japan, Korea, Malaysia, Myanmar, Sri Lanka, Taiwan and Vietnam), Australia and Papua New Guinea.

OTHER PESTS AFFECTING FRUITS:

Procontarinia frugivora (Diptera, Cecidomydae). Reported in the Philippines by Gagné & Medina (2004).

Aulacaspis tubercularis (Diaspididae): reported by Peña (1997) and Peña *et al*. (2009) in Australia, Eastern and Western Africa, North and South America and the Caribbean. According to EPPO (https://gd.eppo.int/taxon/AULSTU/distribution) it is also present in Europe (Portugal).

1.1.3. PESTS OF SHOOTS AND STEMS

MANGO SHOOT BORERS (Lepidoptera, Noctuidae):

Chlumetia tranversa (Lepidotera: Noctuidae; mango shoot borer). Reported by Peña (1997), in India, Pakistan and Southeastern Asia and according to Reddy *et al*. (2018) in India, Bangladesh, Sri Lanka, Java and the Philippines.

Other shoot borers cited by Reddy *et al*. (2018) include**: *Chlumeria alternans*** (Noctuidae), ***Gatesclarkeana erotias*** (Tortricidae; India, Sri Lanka, Timor and Thailand), ***Anarsia melanoplecta*** (Gelechiidae; India), ***A. lineatella*** [widespread according to CABI (https://www.cabi.org/isc/datasheet/5154#todistributionTable)], ***Chelaria spathota*** (Gelechiidae) and ***Dudua aprobola*** [Tortricidae; present in Africa, South and Southeastern Asia and Oceania (http://www.pestnet.org/fact_sheets/mango_flower_webworm_334.htm)].

MANGO STEM BORERS

The mango stem borers are mainly Coleoptera of different families:

Cerambycidae:

- ***Batocera rubus*** (mango loghorn beetle). Reported by Reddy *et al*. (2018), Peña (1997) and Peña *et al*. (2009) in India and Pakistan and according to EPPO (https://gd.eppo.int/taxon/BATCRB/distribution) present in different countries in Asia and the Pacific.
- ***B. rufomaculata***. Reported by Peña (1997) in Israel and by Reddy *et al*. (2018) also in India.
- ***B. numitor*** and ***B. titana*****.** Reported by Reddy *et al*. (2018) at least in India.
- ***Glenea multiguttata*** and ***Coptops aedificator***, reported by Reddy *et al*. (2018) in India.
- ***Niphonoclea capito*** (mango twig borer). According to Tenorio *et al*. (1989), it is present in the Philippines.

Scolytidae:

- ***Hypocryphalus mangiferae*** (mango bark bettle). Reported by Peña (1997) and Peña *et al*. (2009) in North and South America, Brazil and Oman and according to Reddy *et al*. (2018), also in Pakistan.
- ***Xylosandrus compactus***. Cited by Peña *et al*. (2009) and according to EPPO (https://www.eppo.int/ACTIVITIES/plant_quarantine/alert_list_insects/xylosandrus_compactus), widespread in many countries in America, Europe, Asia and Oceania.

Bostrichidae: ***Apate monachus***. Reported by Peña (1997) and Peña *et al*. (2009) in the Caribbean and by CABI (https://www.cabi.org/isc/datasheet/6071) also in Africa, India, Brazil and some European countries.

In addition, there are some Homoptera species of the Diaspididae family that can act as stem borers: ***Radionaspis indica*** and ***Morganella longispinas***. They were reported by Peña (1997) and Peña *et al*. (2009) in North America. Some reports suggest that the former could be present in Mexico, Panama, Ecuador, the Caribbean, Hawaii, Florida, India, Indonesia and Senegal (http://scalenet.info/catalogue/Radionaspis%20indica/) whereas the latter would be widespread (http://scalenet.info/catalogue/Morganella%20longispina/).

1.1.4. PESTS OF LEAVES AND BUDS

ARMORED AND SOFT SCALES:

Over 70 scale insects have been reported to affect mango (Reddy *et al*., 2018).

Aspidiotus destructor (Coccidae). Reported by Reddy *et al*. (2018) in India, Sri Lanka, China, Taiwan, Fiji and Mexico, by Peña (1997) in North and South America and Southeastern Asia and by CABI (https://www.cabi.org/isc/datasheet/7415) widespread in different continents.

Drossicha stebbingii (Margarodidae). Reported by Peña (1997) and Peña *et al*. (2009) in India and Pakistan. According to EPPO (https://gd.eppo.int/taxon/DROCST/distribution), it is also present in China and Bangladesh.

Rastrococcus invadens (Pseudococcidae). Reported by Peña (1997) and Peña *et al*. (2009) in Eastern and Western Africa and by EPPO (https://gd.eppo.int/taxon/RASTIN/distribution) also in Asia.

Aulacaspis tubercularis (Diaspididae): reported by Peña (1997) and Peña *et al*. (2009) in Australia, Eastern and Western Africa, North and South America and the Caribbean. EPPO (https://gd.eppo.int/taxon/AULSTU/distribution) increases the number of countries where the pest is present. As described above, it also affects the fruit.

Ceratoplastes rubens (Coccidae). Reported by Peña (1997) in Australia, Eastern Africa, Southeastern Asia, India and Pakistán, North America and the Caribbean. According to EPPO, it is also present in the South Pacific (https://gd.eppo.int/taxon/CERPRB/distribution).

There are other scale species such as ***Coccus viridis***, ***Coccus longulus***, ***Ceroplastes actiniformis***, ***Philephedra tuberculosa*** and the mango shield scales, ***Milviscutulus mangiferae*** and ***Viusonia stellifera***, reported by Peña *et al*. (2009) in Asia, Africa, Australia, Israel and the Americas.

MITES:

Aceria* (*Eriophyes*) *mangiferae: cited by Peña (1997), Peña *et al*. (2009) and Reddy *et al*. (2018). It may be a carrier of *Fusarium mangiferae*, which is recognized as the causal agent of mango malformation.

According to this link (http://www.agri.huji.ac.il/mepests/pest/Aceria_mangiferae/) it is present in Egypt and Israel, South Africa, southern Asia, Florida, Mexico and several Central and South American countries.

Oligonychus mangiferae: reported by Peña (1997) in India, Pakistan and Israel and by Venkata (2013) in India and other parts of Asia, Egypt, Mauritius, Peru and Israel.

O. punicae**:** reported by Peña (1997) in Central America and the Caribbean and by Venkata (2018) also in Australia.

O. coffeae: reportec by Reddy *et al*. (2018) in Central America and Australia.

Tetranychus bimaculatus: reported by Peña (1997) in the Caribbean.

Other relevant mite species include ***Metaculus mangiferae*****,** ***Polyphagus tarsonemus latus*****, *Brevipalpus phoenicis*****,** ***Oligonychus yothersi and Tetranychus tumidus*** reported by Peña (1997) in North America.

1.2. CHEMICAL CONTROL OF THE MAIN PESTS

According to Peña *et al*. (2009), the four key pests affecting mango (fruit flies, seed weevils, tree borers and mango leafhoppers) require annual control measures. Secondary pests generally occur at sub-economic levels but can become serious pests as a result of changes in cultural practices and cultivar or because of indiscriminate use of pesticides.

FRUIT FLIES

From the late 1960s, conventional control of fruit flies had involved mainly the use of sprays that combine proteinaceous baits with an insecticide (López *et al*., 1969; Soto-Manatiú *et al*., 1987; Mangan *et al*., 2006; Mangan and Moreno, 2007). For many years the standard insecticide had been malathion (Peck and McQuate, 2000; Burns *et al*., 2001), although other active ingredients, such as fenthion, deltamethrin, carbaryl or dimethoate, had also been extensively used.

Since the late 1990s, there has been a big effort to find environmentally friendly alternatives to broad-spectrum insectides (Peck and McQuate, 2000). Growth regulators (such as cyromazine), neonicotinoids (such as imidacloprid), soil microorganisms-derived compounds (such as abamectin and spinosad), plant-derived insecticides (such as azadiractins), and phototoxic dyes (such as Phloxine B) have been successfully tested against various fruit fly species (Díaz-Fleischer *et al*., 1996; King and Hennessey, 1996; Peck and McQuate, 2000; Vargas *et al*., 2002; Liburd *et al*., 2004; McQuate *et al*., 2005; Díaz-Fleischer *et al*., 2017). Spinosad-based baits have become one of the most popular alternatives to conventional insectides in fruit fly control. However, resistance and colateral damage (i.e. negative impact on natural enemies and other beneficial insects or problems with some fruit damage) have been documented (Wang *et al*., 2005; Hsu and Feng, 2006; Stark *et al*., 2004; Navarro-LLopis *et al*., 2012).

Decisions on the time of insecticide applications are usually based on monitoring fruit fly populations with baited traps. In Peru, control measures against *Anastrepha* in mango start when McPhail trap catches average two adults/trap/week (Herrera and Viñas, 1977). In Ecuador, Arias and Jines (2004) recommend a spray of malathion (1%) with protein (4%) once the fruit fly population reaches 0.14 fruit flies/trap/day (FTD). In contrast, studies in Costa Rica, applying at weekly intervals dipterex and malathion reduced damage up to 40% (Soto-Manitiu *et al*., 1987), while in Mexico, control starts when the fruit is 85-days-old and finishes 2 weeks before harvest (Cabrera *et al*., 1993).

In spite of the increasing restrictions on their use, insecticides are still widely used among mango growers and are present within many IPM programs for fruit fly control, either sprayed or in alternative strategies such as mass-trapping and atract and killl (AK) techniques, where they are used at a very low volumen and inside special devices. This ensures no pesticide application directly onto fruits and lower the risk of environmental contamination. The AK approach is very specific, targeting only the insect pests of interest allowing for highly effective crop protection with just small amounts insecticide that do not get in contact with the edible parts of the plants and minimize the risk to the environment. This method has proven to be an effective and affordable tool to control some fruit fly species, such as *Ceratitis capitata* (Navarro-Llopis *et al*., 2012; Bouagga *et al*., 2014).

STONE AND PULP WEEVILS (Curculionidae)

Chemical control has been used with some success for controlling mango weevils in different mango producing countries. In fact, since sanitation practices are usually labor intensive and these pests have few enemies, many mango growers rely mainly on chemical control measures to combat weevil infestations (Chin *et al*., 2001; Louw, 2009).

When using insecticides, the main approach is to attack diapausing adults by trunk applications or to use foliar sprays at the time of oviposition. During ovoposition the adults are active within the canopy, moving onto the fruits and then they can be targeted together with the newly laid eggs. Thus, treatments just before flowering and after initial fruit set have been recommended for seed weevil control (Chin *et al*., 2010; Prakash, 2012). Several insecticides have been evaluated and recommended (Balock and Kozuma, 1964; Shukla and Tandon, 1985; Louw, 2009; Bajracharya *et al*, 2012; Reddy *et al*., 2018). In lab and field tests, effective control of *Sternochetus mangiferae* was provided by the organochlorine endosulfan, the organophosphates fenthion and malathion, the pyrethroid deltamethrin, the carbamate carbaryl, the phenylpyrazole fipronil and the neonicotinoid thiamethoxam.

Reports on the use of environmentally friendly insectides for mango weevils control are not abundant and they sometimes show contradictory results. For example, Verghese *et al*. (2004) reported that commercially available azadirachtin was not effective for management of *S. mangiferae* in India, while Bajracharya *et al* (2012) found that azadirachtin was very effective in reducing pest infestation when compared to control treatment in Nepal.

FRUIT BORERS (Pyralidae)

Control measures against these pests in mango are still mainly depend on the use of pesticides (Istianto and Soemargono, 2015). According to Golez (1991), mango fruit become susceptible to fruit borers 60 days after flowering, and insecticide applications should start at that time. Additional treatments at 75, 90 and 105 days are often required to fully protect the fruit. In Indonesia, Istianto and Soemargono (2015) found that *Noorda albizonalis* began attacking mango fruits when fruits are at the young phase and the attack can occur until the fruits ripened.

Chemicals recommended for control of these pests are deltamethrin and cyfluthrin in the Philippines (Golez, 1991), and fenthion, deltamethrin, indoxacarb and dimethoate in India (Prakash, 2012; Reddy *et al*., 2018). Plantix recommends sprays with thiacloprid or chloripyriphos on marble fruit sizes, but always within an integrated approach (https://plantix.net/en/library/plant-diseases/600128/mango-fruit-borer). In Indonesia, the application of citronella essential oil reduced the rate of fruit borer attack and the production loss on mango (Istianto and Soemargono, 2015). Repellent, insecticidal, inhibitory, and ovicidal properties of the essential oils of citronella would be behind the effective control of mango fruit borers.

STEM/TRUNK BORERS (Coleoptera)

In India, recommendations for a proper management of mango trunk borers include cleaning the infected holes in the trunks, insert cotton wood soaked in a solution of dichlorvos, close the holes with mud paster, and spray the trunk with chlorpyriphos or imidacloprid or thiamethoxam five times at weekly intervals by changing the chemicals after the onset of monsoon (ICAR, 2014). Also, in India, sprays with carbaryl or quinalphos at fornight interval from the start of new flushes are recommended (Prakash, 2012). In Nepal, Upadhyay *et al*. (2013) concluded that mango stem borers could be managed by orchard sanitation and destruction of dry shoots from the tree followed by application of imidacloprid or thiomethoxame for 5 times starting from 2nd week of July at 15 days interval. In Florida, USA, pyrethroids have been found to provide control of attacking adults of ambrosia beetles if applied prior to the closing of the galleries with frass (Atkinson *et al*., 2017).

MANGO LEAFHOPPERS (Hemiptera: Cicadellidae)

Several pesticides have been tried for controlling mango leafhoppers (Tandon and Lai, 1979; Yazdani and Mehto, 1980; Shah *et al*., 1983; Shukla and Prassad, 1984; Islam and Elegio, 1997; Kudagamage *et al*., 2001). Khanzada and Naqvi (1985) reported that six sprays of fenitrothion/year were effective in Pakistan. Nachiappan and Baskaran (1986) tested eight insecticides: phasalone, endosulfan, carbaryl, penthoate, fenitrothion, monocrotophos, quinalphos and phosphamidom. Endosulfan provided the best control when spraying was done 1 week after flowering and another treatment 14 days later. Jhala *et al.* (1989) considered that sprays of carbaryl during the off-season maintained the hopper population at low-density levels. Godase *et al.* (2004) demonstrated that sprays of 0.05% monocrotophos at the first panicle emergence and a second spray 15 days later are essential to prevent yield loss. Kudagamage *et al.* (2001) found that imidacloprid controlled mango hoppers if applied just after flowering and again 10 days later. Verghese (2000) recommends using botanical insecticides, like azadirachtin, lemmon grass oil, and citronella oil, if leafhopper populations are low (<4/panicle). If leafhopper density is beyond 4/panicle, he recommends spraying imidacloprid at 0.3 ml/l or thiamethoxam at 0.5 g/l or lambda-cyhalothrin at 0.5 ml/l at panicle initiation stage. In both cases, spraying should be avoided when trees are on full bloom to avoid damage to pollinating insects (Verghese and Devi Thangam 2011).

BLOSSOM / LEAF / TWIG MIDGES (Diptera: Cecidomyiidae)

According to Ahmed *et al*. (2005), midges are commonly controlled by the heavy use of synthetic insecticides, although some less-common techniques to manage populations of these pests have been developed and tested over the last years (Muhammad *et al*., 2013). In India, spreading chlorpyrifos dust on soil below the tree canopy in April-May, and spraying dimethoate at bud burst stage are recommended (Prakash, 2012; Reddy *et al*., 2018). In Pakistan, Muhammad *et al*. (2017) found that the insecticides Imidacloprid and Nitenpyram were effective against mango gall midges' larval population, while the trees treated with the insectide Bifenthrin showed least development of galls and concluded that the use of these insecticides can be helpful for controlling mango gall midges.

SOFT AND ARMORED SCALES

In many cases, scale insects become a serious problem in mango orchards following the use of insecticides against other mango pests (Prakash and Patil, 2018). Most scale species can be often suppressed to economic levels by the application of horticultural oils or fish oil resin soap, that dissolves the wax coating and suffocate and kill them (Peña, 2004; Prakash and Patil, 2018). However, this is not always the case, since in India spraying dimethoate at 21 days intervals is a recommendation included in IPM programmes against two mango scales, *Cholopulvinaria polygonata* and *Aspidiotus destructor* (Prakash, 2012). Similarly, Prakash and Patil (2018) found that buprofezin, chlorpyriphos, acephate, lambda-cyhalothrin, profenophos, and dichlorvos were effective insecticides in controlling all stages of the scale *Hemilecanium imbricans* on mango under field conditions, and that the usage of fish oil rosin soap helped in enabling effective penetration of the insecticides.

1.3. BIOLOGICAL CONTROL OF THE MAIN PESTS

FRUIT FLIES

Biological control of fruit flies has mainly relied on parasitoids, especially Braconidae and, at a lesser extend, other families of Hymenoptera (Diapriidae, Chalcididae, Figitidae, Eulophidae, etc.). Classical biological control and augmentative releases of mass-reared parasitoids have been used to suppress *Anastrepha*, *Ceratitis* and *Bactrocera* populations (Wharton, 1978; Sivinski, 1996; Sivinski *et al*., 1996, 1997, 2000; Montoya *et al*., 2000). In Florida USA, Mexico, Costa Rica, Brazil, Colombia and Peru, parasitoid species (i.e. *Diachasmimorpha longicaudata* (Ashmead), *Fopius vandenboschi* (Fullaway) and *Aceratoneuromyia indica* (Silvestri)) have been imported and released for the control of *A. suspensa*, *A. ludens* and *A. fraterculus* (Ovruski *et al*., 2000).

Despite the widespread use of exotic parasitoids over the past 80–100 years, the current trend is to use native species in order to reduce environmental threats (García-Medel *et al*., 2007; Aluja *et al*., 2009). This has resulted in numerous studies of the natural enemies of different fruit fly species. For example, Bess *et al*. (1961) reported that the most important parasitoids affecting *Ceratitis capitata* in Hawaii were *Fopius vandenboschi*, *Biosteres oophilus* (= *Opius oophilus*) (= *F. arisanus*) and *B. longicaudatus*. In Brazil, mainly *Doryctobracon areolatus* (Szépligeti) (97%) and *D. longicaudata* (3%) parasitize fruit fly larvae attacking mango (Carvalho and De Queiroz, 2002). In Kenya, Ghana, Tanzania, Uganda and Cote d'Ivoire, the most important parasitoids of *Ceratitis* spp. affecting mango were *Diachasmimorpha fullawayi*, *Fopius caudatus* (Szépligeti), *Psyttalia cosyrae* (Wilkinson) and *Tetrastichus giffardianus* Silvestri (Lux *et al*., 2003). In Mexico and other parts of Latin America, the most common parasitoids attacking fruit flies that affect mangoes (*Anastrepha obliqua*, *A. ludens*, *A. pseudoparallela* and *A. turpiniae*) are *Doryctobracon areolatus*, *Doryctobracon brasiliensis* (Szépligeti), *Doryctobracon crawfordi* (Viereck), *Doryctobracon fluminensis* (Lima) and *Utetes anastrephae* (Viereck) (López *et al*., 1999; Ovruski *et al*., 2000; Zucchi, 2000). In Pakistan, the parasitoids attacking *B. zonata* include *Opius longicaudatus* (= *D. longicaudata*), *Dirhinus giffardii* Silvestri, and *Bracon* sp.; *O. longicaudatus* (= *D. longicaudata*), *D. giffardii* and *Spalangia grotiusi* Girault were reported to attack *B. dorsalis*, albeit in small numbers (Syed *et al.*, 1970).

Predators of fruit flies, especially ants, spiders and beetles, have also been identified and some ant species have been used to control fruit flies in mango orchards. Peng and Christian (2006) used the weaver ant, *Oecophylla smaragdina* (Fabricius) for control of *B. jarvisi* in mango orchards in Australia. Van Mele *et al*. (2007) claimed that an African weaver ant (*Oecophylla longinoda*) reduced infestations levels of fruit flies (*Ceratitis* spp. and *Bactrocera dorsalis*) in Benin. The use of these generalist predators could play an important role in biological control of mango pests particularly for resource-poor farmers in developing countries. High populations of natural fruit flies' predators could be linked to a good management of natural weed covers and a proper use of insecticides.

Use of microbial pathogens (fungi, bacteria and nematodes) in fruit fly control has been attempted with varying degrees of success. For example, *Metarhizium anisopliae* has been evaluated in small-scale mango orchards in Kenya and results do not show differences between use of pathogens and use of insecticides (malathion) (Lux *et al.*, 2003). Lezama-Gutierrez *et al*. (2000) also evaluated isolates of *M. anisopliae* against larvae of *A. ludens* with a 22–43%

reduction in adult emergence, depending on the soil where the larvae pupariates. De la Rosa *et al*. (2002) evaluated the fungus *Beauveria bassiana* (Bals.) under laboratory conditions and concluded that the highest control was achieved at the adult stage, while Dimbi *et al*. (2003) reported on the pathogenicity of *M. anisopliae* and *B. bassiana* on different species of *Ceratitis*. Robacker *et al*. (1996) and Toledo *et al*. (1999) tested various strains/isolates of *Bacillus thuringiensis* (Berliner) against larvae of *A*. *ludens*, *A*. *obliqua* and *A*. *serpentina*. Poinar and Hislop (1981), Lindegren and Vail (1986) and Toledo *et al*. (2006) have investigated the use of various nematodes, *Heterorhabditis bacteriophora*, *Heterorhabditis heliothidis* (Khan, Brooks and Hirschmann) and *Steinernema feltiae* Filipjev, against *Anastrepha*, *Bactrocera* and *Ceratitis.* The results were variable for each fruit fly species, with mortalities between 14 and 96%. Some studies suggest that soil type should be considered when selecting the nematode species and planning fruit fly control strategies (Lezama-Gutiérrez *et al*., 2006).

This biological control of fruit flies can be highly effective and specific when used in combination with autoinoculation devices and insect vectors such as sterile males (FAO/IEA, 2019).

STONE AND PULP WEEVILS (Curculionidae)

Mango weevils have few natural enemies. No parasitoids of *Sternochetus mangiferae* are known (Peña *et al*., 2009), while some larval parasitoids of *S. frigidus*, viz*, Apanteles* sp., *Angitia trochanterata*, and *Bracon brevicornis*, have been reported (Reddy *et al*., 2018). Adults may be susceptible to predation by rodents, lizards, birds, and, especially, ants (Hansen, 1993). In fact, in Southastern Asia and Australia, the weaver ant, *Oecophylla smaragdina* (Fabricius), has been reported as an effective predator of some insect pests in mango orchards, including *Sternochetus mangiferae* (Peng and Christian 2007; Van Mele, 2008). In Africa, Abdulla *et al*. (2015) found that *O. longinoda* was effective in suppressing *S. mangifera.*

Regarding control with microorganisms, Shukla *et al*. (1984) reported a baculovirus affecting the larvae of *S. mangiferae*, while in South Africa strains of *Beauveria bassiana* have been tested on mango seed weevil adults and in one laboratory test, two strains caused 30% mortality within 14 days, but in an orchard, neither strain had an effect on the mango seed weevil (Joubert and Labuschagne, 1995).

FRUIT BORERS (Pyralidae)

According to Waterhouse (1998) no natural enemies of mango fruit borers were detected in Java, Indonesia. However, in the Guimaras Islands of the Philippines, the vespid wasp, *Rychium attrisimum*, preys on the larvae, used to stock the wasps' nests as food for their young, as they exit the fruit to pupate and was suspected to contribute to the high larval disappearance in the field. Moreover, the egg parasitoids *Trichogramma chilonis* Ishii and *Trichogramma chilotreae* attack the pest in Luzon (Golez, 1991), and in India, larval parasitoids, such as *Apanteles* sp., *Angitia trochanterata*, and *Bracon brevicornis*, have been reported (Reddy *et al*., 2018). In spite of this, no references on biological control of these pests through augmentation releases has been found, just the suggestion to maintain natural populations of mango fruit borer predators and parasitoids as high as possible (https://plantix.net/en/library/plant-diseases/600128/mango-fruit-borer). This app also recommends, as part of the biological control approach, apply neem extracts at weekly intervals, starting when mango is flowering and for 2 months.

STEM/TRUNK BORERS (Coleoptera)

Few natural enemies have been reported for suppression of stem and trunk borer populations in mango (Peña *et al.*, 2009). Scheld (1962) recorded a curculionid species (*Scolytoproctus schaumi*) which acts as a nest parasite of the ambrosia beetle *Xylosandrus crassiusculus* in the Congo. However, it is unclear whether the ambrosia beetle is killed by the invader, and whether the ambrosia beetle brood continues to develop normally. Most mortality is probably during the dispersal of the adults, and during gallery establishment. The adults of ambrosia beetles are predated by lizards, clerid beetles and ants as they attempt to bore into the host tree (CABI, 2020).

MANGO LEAFHOPPERS (Hemiptera: Cicadellidae)

Several natural enemies of mango leafhoppers have been described from West and Southeastern Asia. Mohyuddin and Mahmood (1993) reported the egg parasitoids, *Gonatocentrus* sp., *Miurfens* sp. nr. *mangiferae* Viggiani and Hayat, *Centrodora* sp. nr. *scolypopae* Valentine, *Aprostocetus* sp. and *Quadrastichus* sp., and the adult ectoparasitoid *Epipyrops fuliginosa* Tames in Pakistan. Fasih and Srivastava (1990) reported that *Aprostocetus* sp., *Gonatocerus* sp. and *Polynema* sp. parasitize eggs. Five species of predators, including *Chrysopa lacciperda* (Kimmins), *Mallada boninensis* (Okomote), *Bochartia* sp. and two unindentified species (one each of Mantidae and Lygaeidae) prey on nymphs (Fasih and Srivastava, 1990). In India, Sadana and Kumari (1991) studied the efficacy of the lyssomanid spider, *Lyssomanes sikkimensis* on *I. clypealis.*

Classical biological control of mango hoppers has not been attempted. Whitwell (1993) described four genera of parasitoids from Dominica, the most common being *Aprostocetus* sp., followed by *Platygaster* sp., *Synopeas* sp. and *Zatropis* sp. Peng and Christian (2005a, b) reported that the weaver ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae) is an efficient biocontrol agent of *I. nididulus* in northern Australia. The entomopathogens, *Verticillium lecanii* (Zimmerman) Viegas, *Beauveria bassiana* Balsamo (Vuillemin) and *Isaria tax*, infect *I. clypealis* in India (Kumar *et al*., 1993; Srivastava and Tandon, 1986) while the effectiveness of *Metarhizium anisopliae* var. *anisopliae* was tested under laboratory conditions against *A. atkinsoni* (Vyas *et al*., 1993). Reddy *et al*. (2018) recommends the conservation of natural enemies of mango hoppers, especially coccinellids (e.g. *Coccinella septempunctata*, *C. transversalis* and *Menochilus sexmaculatus*) and spiders. This can be achieved by avoiding spray of broad-spectrum insecticides, and instead entomopathogens like *Metarhizium anisopliae* and botanicals should be used.

BLOSSOM FEEDERS (Lepidoptera)

According to Schreiner (1987), Dipel® reduced caterpillar damage, but careful monitoring or constant spraying was necessary to prevent significant damage. In Brazil, the pesticide *Bacillus* *thuringiensis* provided mortality rates of mango caterpillars similar to those of trichlorfon and lambdacyhalothrin (Barbosa, 2005).

Classical biological control of lepidopteran insects attacking mango in Dominica was initiated with the introduction of the wasps *Aleiodes* sp. and *Euplectrus* sp., and the fly *Blepharella lateralis* Macquart. Populations of the pest were reduced to 25% of pre-release levels; parasitization rates were 20–99%, with *Euplectrus* sp. being the most abundant parasitoid (Nafus, 1991). The parasitoid *Macrocentrus* prob. *delicatus* attacks *Pococera attramentalis*; however, the parasitism rate is unknown (Peña, 1993). In Brazil, *Cryptoblades gnidiella* is parasitized by *Brachymeria pseudoovata* Blanch (Hymenoptera: Chalcididae), while in Egypt, the endoparasitoid *Tachina larvarum* and the predator *Orius* sp. proved to be good biological control agents against this pest on mango orchards (Kareim *et al*., 2018).

BLOSSOM / LEAF / TWIG MIDGES (Diptera: Cecidomyiidae)

In India, recommendations for a proper management of cecidomyiid pests in mango include conservation of predators like *Formicai* sp., *Oecophila* sp. and *Camponotus* sp., and parasitoids like *Platygaster* sp., *Systasis* sp. and *Eupelmus* sp., associated with *Dasineura* sp., *Tetrastychus* sp., associated with *E. indica*, and the pteromalid *Pirene* sp., associated with *Procystiphora mangiferae* (Felt) (Reddy *et al*., 2018). In Pakistan, a survey of midges and their natural enemies associated with mango showed that *Procontarinia* sp. populations were drastically reduced because of increase in parasitism of *Closterocerus pulcherimus* and an unidentified parasitoid (CABI, 2009).

SOFT AND ARMORED SCALES

The populations of most scale species can be often reduced to manageable levels by biological control agents (Peña, 2004; Pradash & Patil, 2018). In fact, conservation of natural enemies (both parasitoids and predators) is a general recomendation for a proper control of scales on mango (Reddy *et al*., 2018) and, due to the activity of natural enemies, no chemical control or just well-timed insecticide interventions are required (Medina-Urrutia *et al*., 2017).

A good example of succesfull biological control of mango scales is *Aulacaspis tubercularis* in South Africa, achieved using the parasitoid *Aphytis chionaspis* and the predator *Cybocephalus binotatus* from Thailand. Close to 50% scale parasitism occurred, while *Cybocephalus binotatus* successfully controlled the remaining scale populations, reducing them to 2%. The release of 500–1000 Cyboc*ephalus binotatus* beetles per hectare was recommended for effective scale control (Joubert *et al*., 2000; Le Lagadec, 2004; Daneel and Joubert, 2009). Good control of mango scales have also been achieved using the predator *Aulerodothrips fasciapennis* and the parasitoid *Aspidiotiphagus citrinus* (Kfir and Rosen, 1980, cited by Iyer, 2004). In Ecuador, Arias *et al.* (2004a) observed *Coccidophilus* spp. (Coleoptera: Coccinellidae) and *Chrysopa* spp. preying on *A. tubercularis*; the exotic predator *Cybocephalus nipponicus* (Coleoptera: Nitidulidae) was introduced to supplement predation of the former scale (Arias *et al*., 2004b).

Mango scale (*Milviscutulus mangiferae*) can be controlled in Israel using parasitoids such as *Coccophagus lycimnia* (Iyer, 2004). The scales *Chrysomphalus aonidum* and *Aonidiella aurantii* have diiferent wasps as natural enemies: *Aphytis lingnanensis, Aphytis holoxanthus, Aphytis chrysompali (Hymenoptera: Aphelinidae*) and *Encarsia* spp., which are well distributed in the state of Veracruz, Mexico (Cabrera-Mireles and Ortega-Zaleta, 2004). A wasp, *Anicetus beneficus*, has been identified in Australia for the control of the pink wax scale (*Ceroplastes rubens*) (Cunningham, 1984). Several parasites have been recorded in Israel parasitizing the mango shield scale: *Coccophagus lycimnia* (Walker), *C. eritraensis* Compere, *C. scutellaris* (Dalman), *C. bivittatus* (Compere), *Microterys flavus* (Howard) and *Metaphicus flavus* Howard.

1.4. MANGO MANAGEMENT APPROACHES TO REDUCE THE INCIDENCE OF PESTS

Sampling methods for assessing the status of pest populations has been critical to develop and advance pest control technology (Pedigo and Buntin, 1993). Monitoring and sampling should provide information on pest densities, their dispersion, and dynamics. Through sampling, accurate information is obtained to make accurate decisions which should be based on knowledge of the pest's economic threshold (Peña, 2004). Unfortunately, useful reports on these subjects are scarce or incomplete.

FRUIT FLIES

The combination of several control tools is usually necessary to achieve a good control of fruit flies. A proper orchard management, quarantine treatments or use of the available host resistance could be a good complement to chemical and biological control. A review of some of these aproaches is included.

Cultural control

Fruit bagging is reported as one of the best solutions to prevent fruit fly attack of mango and other tropical fruits (Aluja, 1996; Peña *et al*., 1999). Success with mangoes can be quite high, but more research is needed to determine the type of bags to use for different mango varieties and the best time to bag fruit (Love *et al*., 2003).

Jirón (1995) reported that *A*. *obliqua* populations could be reduced by increasing planting distances in order to reduce RH and increase solar radiation within orchards.

A cultural control practice widely recommended and used in many mango producing areas is removal of fallen fruits. In India, this is usually complemented with inter-tree ploughing and raking (followed by insecticide cover sprays), which can reduce fruit fly infestation between 77% and 100% (Verghese *et al*., 2004).

The use of of potassium nitrate (KNO_3) sprays to accelerate and synchronize flowering of mango can, under certain circumstances, help control fruit flies, but it can also exacerbate the problem, so appropriate studies are needed in each producing area.

Mango germplasm

Differences on fruit fly damage between different mango varieties have been found in different fruit fly genus, such as *Bactrocera* and *Anastrepha.* For example, Yee (1987) reported that *B.*

dorsalis does not attack all mango cultivars to the same extent and that the most susceptible cultivars in Hawaii are 'Hawaiian', 'Pirie' and 'Sandersha'. Singh (1991) indicated that the damage caused by *Bactrocera* was highest in fully ripe fruit of 'Mallika' followed by 'Totapari', while frequency of injury in 'Dashehari' ranged from 3.6 to 10% in physiologically mature fruits and ranged from 10 to 25.9% in fully ripe fruit. Susceptibility of different mango cultivars to attack by *A. obliqua* was measured by Carvalho *et al*. (1996) who observed that 'Espada' showed no infestation by *A. obliqua*, whereas 'Carlota' was highly infested. In this study, the survival of adults of *A. obliqua* was lower when the larvae were fed on 'Espada' compared to 'Carlota'. Furthermore, 'Espada' had an adverse effect on the longevity of *A. obliqua* females, possibly due to the presence of toxic substances (Carvalho and De Queiroz, 2002) or absence of essential nutrients. Jirón and Soto-Manitiu (1987) also observed that susceptibility of mangoes to *A. obliqua* differed among cultivars. 'Rosinha', 'Coquinho' and 'Espada' were resistant to *A. obliqua* attack, whereas 'Smith' and 'Pope' were highly susceptible.

According to Joel (1980), the resin ducts in the exocarp of mango fruits confer protection against the vertical movement of the ovipositor and larval movement. Other studies have shown that resistance is related to degree of maturity (Díaz-Fleischer and Aluja, 2003; Aluja and Mangan, 2008); immature mango fruit are less susceptible to *A. suspensa* than mature mangoes when infested artificially (Hennesey and Schnell, 2001). It has been suggested that differences on attack by *A. ludens* to mango might be influenced by volatiles from green or yellow fruits (Garcia-Ramirez *et al*., 2004).

Quarantine treatments for fruits

Several quarantine treatments have been developed for harvested mangoes. Irradiation, vapor heat or hot water dipping are widely used (Sharp *et al*., 1988, 1989a, b, c; Hallman and Sharp, 1990; Nascimento *et al*., 1992; Mangan and Sharp, 1994; Mangan and Hallman, 1998; Shellie and Mangan, 2002a, b; Bustos *et al*., 2004; additional references in reviews by Mangan and Hallman, 1998 and Follet and Neven, 2006). In fact, in continental USA, quarantine treatments approved for control of fruit flies of the family Tephritidae in mango include irradiation, vapor heat treatments, inmersion in hot water, and high temperatures forced air (USDA, 2019). Some of these treatments are only for fruits from some specific countries. For example, vapor heat treatment protocols are developed for fruits from Mexico ("Manila" variety only), the Philippines, and Taiwan. In adittion, treatment conditions can be changed according to fruit origin. For instance, minimum irradiation doses are 150 Gy in fruits from Jamaica, Mexico and the Philippines, and 400 Gy in fruis from Dominican Republic, India, Pakistan, Thailand and Vietnam.

Fruit fly monitoring and mass-trapping

Monitoring of fruit flies is crucial to make decisions on when to apply a control or management approach. Moreover, it is key to determine populations dynamics, compare infestation levels and evaluate the effectivenes of a control tactic (Dias *et al*., 2018). Fruit fly monitoring in mango is mostly performed using traps for adults, because eggs and young larvae are often difficult to see in the fruit and because the primary aim of management programmes is to prevent fruit damage. These traps are also intended for control fruit fly populations when used at high densities, what is called mass-trapping. Mass trapping networks have contributed to significant reductions in some fruit fly species density (MARNDR, 2014), and have attracted interest due to their efficacy, specificity and low environmental impact.

In the case of *Anastrepha* and some *Bactrocera* species, the most widely used traps since the early 1970s for monitoring and controlling populations are glass and plastic versions of the McPhail trap, which is baited with a mixture of protein and water (Balock and Lopez, 1969; Jirón, 1995). More recently, human urine has been successfully tested as bait for McPhail and McPhail-type traps for resource-poor farmers in tropical countries (Piñero *et al*., 2003; Aluja and Piñero, 2004). The McPhail trap has provided different results in mango orchards. Balock and Lopez (1969) reported that high concentrations of McPhail traps reduced fly populations and protected mangoes from severe injury during certain periods of the year. However, Aluja *et al*. (1989), working in a mixed mango orchard in Chiapas, Mexico, found that only 31.1% of *Anastrepha* spp. flies landing on the McPhail trap were caught with many flies entering the trap but then escaping. Due to these results and other drawbacks of the McPhail trap, it is being replaced with other types of traps, such as Multi-Lure® traps. Dry synthetic-food-based lures have also been developed, i.e. BioLure® (Suterra LLC, Inc., Bend, Oregon) (Heath *et al*., 1995, 1997; Epsky *et al*., 1999) and Nu-Lure® (Advanced Pheromone Technologies) (Robacker and Warfield, 1993; Robacker *et al*., 1997; Robacker, 2001).

With regard to attractants, methyl eugenol is considered the most powerful male lure for oriental fruit flies. Methyl eugenol was used for successful monitoring, control and erradication of *B. dorsalis* in Oahu Hawaii (Steiner and Lee, 1955), Rota Island (Steiner *et al*., 1965) and Okinawa, Kume, Miyako and Uaekama Islands, Japan (Iwahashi, 1984). It has been used for monitoring *B. umbrosa* (F.) in the Philippines (Umeya and Hirao, 1975), and is used to lure *B. invadens* in Africa (Lux *et al*., 2003). In Palau, Pacific Islands, two lures are used to attract mango flies: *Bactrocera fraeunfeldi* (Schiner) is attracted to Cue-lure, and *B*. *occipitalis* and *B. philippinensis* Drew and Hancock to methyl eugenol (Secretariat of the Pacifi c Community, 2005). *Bactrocera dorsalis* and *B. umbrosa* were monitored and controlled by mass trapping of males with methyl eugenol and infestations were brought to sub-economic levels in Pakistan (Mohyuddin and Mahmood, 1993). However, concern over the carcinogenicity of methyl eugenol (Waddell *et al*., 2004) calls for the development of other para-pheromones to attract *Bactrocera* fruit flies. Trimedlure is still considered an important para-pheromone for the Mediterranean fruit fly, with the exception of *C. cosyra* adults, which are attracted to terpinyl acetate and not to trimedlure (Steck, 2003). The attractiveness of mango compounds has been also investigated. For example, some of the volatiles emitted by 'Tommy Atkins' mangoes, i.e. terpenes (*p*-cymene and limonene), are attractive to *C. capitata* adults (Hernández-Sánchez *et al*., 2001).

The debate is still open with respect to the optimal trap number and distribution and the proper time for trap placement in mango groves. Standardized trapping guidelines for area-wide management of fruit flies recommend 20 to 25 traps per ha for detection surveys (IAEA, 2003). However, Martinez- Ferrer *et al*. (2012) reported that a density of 25 traps per ha was sufficient as a stand-alone method to control the Mediterranean fruit fly (*Ceratitis capitata* Wiedemann; Diptera: Tephritidae) in Spain. Trap densities used in mass-trapping often represent a financial cost that cannot be supported by smallholders in developing countries (Burrack *et al*., 2008; Lasa *et al*. 2013; Malo & Zapien, 1994), and, therefore, the use of mass-trapping as a control tool depends on the desing of new cheap attractants and trap devices (Villalobos, 2017). In Haiti, Mertilus *et al*. (2017) evaluated the effectiveness of 2 inexpensive artisanal trap designs as an alternative to the standard McPhail trap for mass trapping fruit flies in mango orchards. They found that the mean number of flies captured in artisanal traps was similar to that captured in the McPhail traps, and that a density of 25 traps per ha was adequate to protect a mango orchard through the maturation phase of the mango season.

Behavioral control

This approach includes two main tactics, Sterile Insect Techique (SIT) and Male Annihilation Technique (MAT).

The SIT involves industrial-scale mass production of radiation-sterilized male insects, which do not lose the ability to fly, mate, and transfer sperm to wild females. Application of fruit fly SIT programmes in mango orchards have been reported in Chile and Brazil for *Ceratitis capitata*, in México for *Anastrepha obliqua* and *A. ludens* (Flores *et al*., 2014; Flores *et al*., 2017) and in Thailand for *Bactrocera dorsalis* and *B. correcta* (Sutantawong *et al*., 2002). SAT still faces challenges, such as the determination of sterile fly release densities requiered to achieve efective sterile wild ratios for the suppression or erraditacion of wild populations (Dias *et al*., 2018).

MAT involves the distribution of large numbers of dispensers impregnated with a male lure and a toxicant in order to reduce male abundance to such a low level that population suppression or eradication results. Although MAT may be used alone, it is often combined with other control methods, such as the sterile insect releases and/or protein bait sprays. The use of a highly attractive male lure is critical to MAT's effectiveness, and historically it has been most successfully used against ME-responding males and, in particular, the oriental fruit fly, *Bactrocera dorsalis* (Manoukis *et al*., 2019). The use of MAT against *B. dorsalis* in mango has been reported. In Kenia, Ndlela *et al*. (2016) found that the percentage of infested fruit was 25 and 18 times lower in MAT-treated orchards compared to the control and they recommended that MAT be adopted within a holistic Integrated Pest Management (IPM) approach in the mango agro-system, preferably covering large areas.

STONE AND PULP WEEVILS (Curculionidae)

Field sanitation and quarantine

Orchard hygiene and quarantine treatments are strategies widely recommended and used in mango weevils control programs as a complement to chemical control.

Field sanitation demands complete collection and destruction of fallen fruits and seed material from the orchard, since they will aid in minimising the infestation in following seasons. Trees located near the orchards are often untreated and pose a constant threat of infestation, so it is recommended either removing these trees or using with them a control program to suppress weevils similar to that used in the orchards. Field sanitation is very labour intensive and has been inconsistent in demonstrating efficient pest control (Peña *et al.*, 2009). For instance, in India, field sanitation reduced infestation of the mango nut weevil, *Sternochetus gravis* (Fabricius), by only 22% (De and Pande, 1987), while in Hawaii, field sanitation failed to reduce infestation rates (Hansen and Amstrong, 1990).

To maintain a mango producing area's weevils free status, common key recommendations are avoid bringing any mango fruit suspected of harbouring weevils within the fruit into the area (for instance, to re-export fruit), and restrictions on movement of plant material from affected sites. Imported mangoes from countries where stone and pulp weevils occur can be subjected to a quarantine treatment. Irradiation is pointed out as the most effective method of killing or sterilizing weevils within fruit (Follet, 2001). In South Africa, irradiation of ripe, marketable fruit protected it from damage and prevented *S. mangiferae* adult emergence (Kok, 1979). In the Philippines, irradiation treatment with a minimum absorbed dose of 165 Gy provides quarantine security for *S. frigidus* in exported mangoes (Obra *et al*., 2014). In continental USA, minimum irradiation doses approved for control of mango weevils are 165 Gy for *Sternochetus frigidus* in fruits exported from the Philippines, and 300 Gy for *S. mangiferae* in fruits exported from Hawaii, Australia and the Philippines (USDA, 2019). Hot and cold treatment of fruit has also been tried but gave unreliable results and proved phytotoxic (Balock and Kozuma, 1964; Shukla and Tandon, 1985).

FRUIT BORERS (Pyralidae)

General control measures recommended for control of mango fruit borer include collection and destruction of affected and fallen fruits, avoid weed plants that serve as alternative hosts, using light traps (1 per ha) to monitor the activity of adults and fruit bagging at 55-65 days after pollination (Peña *et al*., 2009; Reddy *et al*., 2018).

STEM/TRUNK BORERS (Coleoptera)

Orchard sanitation, visual inspections, destruction of dry wood, and pruning and destroying affected branches are general recommendations for the control of this group of pests. In India, stem wrapping with a nylon mesh during May-August helps in capturing freshly emerging adult beetles (Reddy *et al*., 2014). In adittion, a formulation called “sealer cum healer”, developed by the Indian Institute of Horticultural Research and applied on the stem along with an insecticide and a fungicide, helps to protect trunks from egg laying by adults (Shivananda *et al*., 2012). Removing grubs from the infected trunk holes by using iron wire/hook and kill them is also recommended (Reddy *et al*. 2018).

Some success in the detection of ambrosia beetles has been obtained by using traps baited with ethanol in and around port facilities where infested material may be stored, and around nurseries with plants susceptible to attack (CABI, 2019). Nevertheless, the evaluation of new traps as tools for managing ambrosia beetles on mangoes is necessary in order to reduce their damage in newly established groves (Peña *et al*., 2009).

MANGO HOPPERS (Hemiptera: Cicadellidae)

Reddy *et al*. (2018) recommends avoiding dense planting and maintain tree architecture in such a way that adequate light is penetrated. They also suggest regulating the number of flushes mainly by pruning.

Significant differences in the hopper incidence among genotypes were recorded indicating the scope of host plant resistance (Nachiappan and Bhaskaran 1983; Devi Thangam *et al*., 2013).

BLOSSOM / LEAF / TWIG MIDGES (Diptera: Cecidomyiidae)

Collection and proper disposal of infested panicles and twigs, and deep plughing of orchards to expose pupae and diapausing larvae to sun´s heat and natural enemies are general recommendations for a proper integrated management of mango cecidomyiid pests in India (Reddy *et al*., 2018). In Pakistan, Muhammad *et al*. (2013) evaluated the efficiency of colored sticky traps and plastic sheets in capturing adults of *Procontarinia mangicola*. They found that orange colored traps attracted the highest numbers of adults compared to all other traps.

SOFT AND ARMORED SCALES

Pruning to open the tree and a prompt destruction of severely affected leaves and twigs prevent the population buildup of scales on mango (Reddy *et al*., 2018). These authors also recommend the use of planting material free from scales to minimize the scale population. Removal of attendant ants in order to avoid disturbances on natural enemies of mealy bugs and soft scales is also included in mango IPM programmes (Prakash, 2012).

2. MAIN DISEASES AFFECTING MANGO

Diseases are serious constraints to mango production throughout the subtropics and tropics (Ploetz and Freeman, 2009). They can affect tree vigor and survival, canopy and root growth, fruit set, yield and pre and post-harvest quality of fruit. Although anthacnose, malformation and sudden decline are considered as the main mango diseases worldwide (Ploetz, 2017), many additional fruit, foliar, floral and soil-borne diseases have been described in different countries and, therefore, could become potential risks in the international mango commercial trade. Taking all this into account, we review the most important diseases that affect mango production worldwide, differentiating among those that affect the fruit, the leaves and flowers and soil diseases.

2.1. DESCRIPTION OF THE MAIN DISEASES

2.1.1. FRUIT DISEASES

MAIN FRUIT DISEASES

Among the postharvest diseases of mango fruits, anthracnose is the most prevalent in regions with humid climates, where incidence can affect almost 100% of the fruits. Other common postharvest diseases of mango in humid areas are stem-end rot and black mould rot. Mango black spot is prevalent mainly in dry conditions (Prusky *et al*., 2009)

Anthracnose

Anthracnose is the most important disease of mango in humid production areas (Lim and Khoo, 1985; Arauz, 2000; Ploetz, 2003, 2018; Ploetz and Freeman, 2009). Although fruit losses can occur in the field, post-harvest losses are most significant (Ploetz, 2018). Anthracnose of mango is caused by species of the genus *Colletotrichum*. In the past, *C. gloesporioides* (telemorph: *Glomerella cingulata* (Stoneman) Spauld. & H. Schrenk) was considered the main pathogen associated with this disease (Dodd *et al*., 1997), but, as the ability to distinguish different species using molecular tools has improved significantly, *Colletotrichum gloeosporioides* has become a species complex with 22 species [e.g. *C. asianum*, *C. fructicola*, *C. gloeosporioides* (*sensu stricto*), *C. queenslandicum*, *C. theobromicola* and *C. tropicale*) (Weir *et al*., 2012)]. A mango biotype in the *Colletotrichum gloeosporioides* complex, *C. asianum*, may be the most important species (Ploetz, 2018). To date, *C. asianum* has been reported in Australia, Brazil, Florida (USA), Ghana, Mexico, Panama, Philippines, South Africa and Thailand (Honger *et al*., 2014; Lima *et al*., 2013; Sharma *et al*., 2013; Tarnowski, 2009; Udayanga *et al*., 2013; Weir *et al*., 2012). Other species complexes, such as *C. acutatum* (*C. fioriniae* and *C. simmondsii*), *C. boninense* (*C. cliviae* and *C. karstii*), *C. siamense* [*C. dianesei* (syn. *C. melanocaulon*) and *C. endomangiferae*), may play secondary roles.

Bacterial black spot (BBS)

In India this disease is known as bacterial canker. This can be the most important mango disease in areas where most other fungi diseases are well managed. Three genetically and pathologically distinct groups of the bacteria responsible of this disease have been identified (Ploetz, 2017a) :

Group I: from Africa, Europe and Asia. *Xanthomonas citri* pv. *mangiferaeindicae* sensu novo.

Group II: from Brazil. *X. axonopodis* pv. *Anacardii.*

Group III. From the French West Indies. *X. axonopodis* pv. *Spondiae.*

Black spot is widespread throughout the world, especially in Asia (Japan, India, Malaysia, Thailand, the Philippines, etc.), Australia, the United Arab Emirates, islands in the Indian Ocean (the Comoros, Reunion, etc.), and East and Southern Africa (Kenya, South Africa, etc.) (https://agritrop.cirad.fr/570027/2/document_570027.pdf.)

Stem-end Rots

The stem-end rot diseases may produce heavy losses during fruit storage and are caused by a diversity of fungal pathogens. According to Prusky *et al*. (2009), *Dothiorella dominicana* (anamorph of *Botryosphaeria dothidea*), *Dothiorella mangiferae*, *Lasiodiplodia theobromae* (*Botryodiplodia theobromae*), *Phomopsis mangiferae* and *Pestalotiopsis mangiferae* would be the dominant pathogens. Ploetz (2018) considered *Lasiodiplodia theobromae* as the most common and widespread pathogen associated with this disease; in adittion, *L. pseudoheobromae*, *Neofusicoccum parvum*, *N. mangiferae*, *Botryosphaeria dothidea* and *Neoscytalidium hyalinum* have wide geographical distributions and significantly impact mango.

Alternaria Rot or Black Spot

Alternaria alternata (Fr.) Kreissler (synonyms: *Alternaria fasciculata* (Cooke and Ellis) L. Jones and Grout, *Alternaria tenuis* Nees, and *Macosporiufasciculatum* Cooke and Ellis, no teleomorph known) causes black spot on mango, alternaria leaf spot and lesions on inflorescences (Prusky *et al*., 1983; Cronje *et al*., 1990). Although the fungus is cosmopolitan and has a large number of host plants (Neergaard, 1945; Domsch *et al*., 1980), its effects on mango are most prevalent in arid environments. In Israel, it is a more important disease on fruit than in leaves (Prusky *et al*., 2009). According to Dodd *et al*. (1997), it has been reported in Australia, Egypt, India, Israel and South Africa.

Black mildew, Sooty Moulds, Sooty Blotch (dothidiomycetes)

Several ascomicetes produce dark, usually superficial growths on stems, leaves and fruits of mango (Ploetz, 2018). Black mildews are caused by a group of tropical obligate plant pathogens (Ploetz, 2018), especially *Meliola mangiferae* (Lim and Khoo, 1985). In contrast, the fungi behind sooty molds are diverse saprophytes that develop in the presence of insects that produce honeydew (e.g., aphids, mealybugs, scales, etc). On the other hand, sooty blotch refers to diseases not associated with honeydew and caused by several groups of dothidiomycetes (Batzer *et al*., 2005; Johnson *et al*., 1997; Ploetz *et al*., 2000).

OCCASSIONAL FRUIT DISEASES

In addition to the main diseases affecting mango fruits, here we include some additional diseases that have been reported occasionally but that rarely cause extensive losses (Snowdon, 1990). Thus, Dodd *et al*. (1997) include: Bacterial rot (*Erwinia* spp.), Blue mold (*Penicillium* spp.), Charcoal rot (*Macrophoma phaseolina* Goidi), Macrophoma rot (*Macrophoma mangiferae* Hingorani and Sharma), Mucor rot (*Mucor* spp.), Phyllosticta rot (*Guignardia mangiferae* Roy.), Phytophthora rot (*Phytophtora nicotianae* var. *parasitica* Waterh.), Rhizopus rot (*Rhizopus* spp.). In addition, Prusky *et al*. (2009) include: Black mold (*Aspergillus* spp.) and Transit rot (*Rhizopus* spp.)

2.1.2. FOLIAR AND FLORAL DISEASES

Algal Leaf Spot (Red Rust)

Algal leaf spot, also known as red rust, is caused by *Cephaleuros virescens* Kunze and, less frequently, by *C. parasiticus* (family Trentepohliaceae, division Chlorophyta (Lim and Khoo, 1985).

Anthracnose (described previously); it was considered previously as a synonym of Blossom Blight but, according to Ploetz (2018) **"**Blossom blight, which has been attributed to one of the anthracnose agents but is also caused by other fungi".

Alternaria Leaf Spot (it has been described previously)

Apical necrosis
This desease is caused by a bacterium, *Pseudomonas syringae* pv. *syringae*. It has been reported in Spain, Israel, Portugal and, possibly, Egypt (Cazorla *et al*., 1998, 2006). Apical buds, leaves and panicles are susceptible, but not the fruit (Cazorla *et al*., 1998). A dark brown to blackish necrosis develops on vegetative floral buds and can extend from affected buds to leaf petioles causing, in conditions of high damage, the kill of large portions of the canopy and much of the tree´s bloom (Ploetz and Freeman, 2009, and Ploetz, 2018)

Bacterial Black Spot (described previously)

Black-banded Disease
This is a relatively unimportant disease that can affect mango leaves and branches (Reddy *et al.*, 1961). The causal fungus, *Rhinocladium corticola* Massee (described as '*corticolum*') (teleomorph: *Peziotrichum corticolum* (Massee) Subrumanian), was described on the bark of trees in Poona, India (Hughes,1980; Prusky *et al*., 2009).

Black Midew, Sooty Mould and Sooty Blotch (described previously)

Decline Disorders
Diverse biotic and abiotic factors may be primary causes of decline symptoms (McSorley *et al.*, 1980; Kadman and Gazit, 1984; Schaffer *et al.*, 1988; Ploetz and Prakash, 1997). Among the biotic factors, several different fungi cause, or are associated with, decline symptoms worldwide; most are endophytes that have *Botryosphaeria* or *Botryosphaeria*-like teleomorphs (Botryosphaeriaceae). Stress and wound predisposition are usually associated with symptom development (Prusky *et al*., 2009; Ploetz, 2018). The most important are *Lasiodiplodia theobromae* and *Neofusicoccum parvum*.

The following table from Dodd (1997) shows the main pathogens associated with decline disorders in mango.

LOCATION	KEY REFERENCES	MAJOR CAUSES	PREDISPOSING FACTORS
Australia	Johnson *et al*., 1991	*Dothiorella dominicana*	None
Brazil	Batista, 1947	*Diplodia recifiensis*	Injury, insects
Brazil	Ribiero (1980)	*Ceratocystis fimbriata*	Injury, insects
Egypt	Acuña and Waite (1977)	*Lasiodiplodia theobromae*	None
El Salvador	Acuña and Waite (1977)	*L. theobromae*	Drought, hardpan soil
India	Verma and Singh (1970)	*L. theobromae*	None
India	Das Gupta and Zacchariah (1945)	*L. theobromae*	High temperatures
Indonesia	Muller (1940)	*L. theobromae*	Sun scorch
Malaysia	Lim and Khoo (1985)	*L. theobromae*	Weakened tres
Niger	Reckhaus and Adamou (1987)	*Neoscytalidium dimidiatum* = *Hendersonula turoloidea*	Water stress
Puerto Rico	Alvarez-García et López-García (1987)	*L. theobromae*	Sun scorch, high RH
South Africa	Darvas (1993)	*Dothiorella dominicana*	None
USA (Florida)	Ploetz *et al*. (1996a)	*Colletotrichum gloeosporioides, Neofusicoccum parvum, L. theobromae* and *Phomopsis spp.*	Nutritional def. frost, physical damage
USA (Florida)	Ramos *et al*. (1991)	*Botryosphaeria ribis*	

Gall and scarly bark

Gall and scarly bark disorders of mango are usually minor problems but can cause a general loss of vigour (Ploetz, 2018). *Fusarium decemcellulare* C. Brick (synonym: *Fusarium rigidiuscula* (Brick) Snyd. and Hans.) causes these diseases in Florida (USA), Mexico and Venezuela (Malaguti and de Reyes, 1964; Angulo and Villapudua, 1982; Ploetz *et al.*, 1996b; Prusky *et al*., 2009).

Grey leafspot

Pestalotiopsis mangiferae (Henn.) Steyaert (synonym: *Pestalolia mangiferae* Henn.; no teleomorph of the fungus is known) causes grey leafspot and stemend rot of mango fruits (Lim and Khoo, 1985; Johnson, 1994b). It is a weak pathogen that usually requires wounding in order to infect mango. Grey leafspot is usually unimportant and occurs mainly on unhealthy or poorly maintained trees. *Pestalotiopsis mangiferae* produces abundant conidia in acervuli that develop in grey leafspot lesions and necrotic areas on fruit (Lim and Khoo, 1985).

Two other species of *Pestalotiopsis* that affect mango are *Pestalotiopsis mangifolia* Guba and *Pestalotiopsis versicolor* Speg. (synonyms: *Pestalotiopsis cliftoniae* Tracy and Earle and *Pestalotiopsis coccolobae* Ellis and Everh.). (Prusky, 2009)

Leaf blight

This disease has been reported in India and Nigeria (Hingorani *et al.*, 1960; Cook, 1975; Okigbo, 2001; Okigbo and Osuinde, 2003), and the causal fungus, *Macrophoma mangiferae* Hingorani and Sharma (Ascomycota), has also been detected in shipments to the USA from Mexico (Systematic Mycology and Microbiology Laboratory, USDA-ARS, Beltsville) although it seems that it is not a serious problem (Prusky, 2009)

Malformation

Malformation is one of the most destructive mango diseases (Ploetz, 2001). Although trees are usually not killed, the vegetative phase of the disease affects canopy development and the infection of the flowers dramatically reduces fruit yield (Prusky *et al*., 2009).

Malformation was first described in India in 1891 (Kumar and Beniwal, 1991). It is now widely distributed worldwide and continues to spread to the remaining disease-free production areas (e.g. Crespo *et al*., 2012). To date, the disease has been reported in Australia, Brazil, Myanmar, China, Egypt, El Salvador, India, Israel, Malaysia, Mexico, Nicaragua, Oman, Pakistan, Senegal, South Africa, Sri Lanka, Sudan, Spain, Swaziland, Uganda and the United States (Flechtmann *et al*., 1973; Crookes and Rijkenberg, 1985; Liew *et al*., 2016; Lim and Khoo, 1985; Kumar and Beniwal, 1991; Ploetz, 2001; Ploetz and Freeman, 2009; Kvas *et al*., 2008; Crespo *et al*., 2012; Senghor *et al*., 2012; Sinniah *et al*., 2012; Zhan *et al*., 2012)

In 1966, *Fusarium moniliforme* was shown to be the agent behind malformation in India (Summanwar *et al*., 1966). Subsequently, that pathogen, renamed *F. mangiferae* (Britz *et al*., 2002), has been reported from Australia, China, Egypt, Florida (USA), Israel, Malaysia, Oman, South Africa, Spain and Sri Lanka. Since the description of *F. mangiferae*, a growing list of additional species have also been described as causal agents, including *F. mexicanum* (Otero-Colina *et al*., 2010) and *F. pseudocircinatum* in Mexico (Freeman *et al*., 2014a); *F. sterilihyphosum* in Brazil and South Africa (Britz *et al*., 2002); and *F. tupiense* in Brazil, Senegal and Spain (Freeman *et al*., 2014b; Lima *et al*., 2012). In addition, other described [e.g. *F. proliferatum* in Australia, China and Malaysia) and undescribed (in Australia, Mexico and Spain) species in the genus have been associated with the disease (Marasas *et al*., 2006; Zhan *et al*., 2010).

Seca and sudden decline

A disease called “Seca” was first reported in 1938 in Pernambuco, Brazil (Viegas, 1960; Rossetto *et al*., 1996) and later it was also found in the states of Bahia, Goias, the Federal District, Rio de Janeiro and Sao Paulo (Ribeiro, 1997; Colosimo *et al*., 2000; Silveira *et al*., 2006). Neighbouring states in Brazil are threatened due to the movement of the pathogen via infected propagation materials and pruning equipment, and a beetle vector (Ploetz, 2018). In 1998, a very similar disease, “sudden decline”, was reported in Oman, Pakistan and the United Arab Emirates (UAE) (Al Adawi *et al*., 2006). Due to their similarities, they are considered as the same disease in different mango diseases reviews (Ploetz, 2017). It is a lethal fungal disease. *Ceratocystis fimbriata* Ellis and Halst. *sensu lato* (*s.l.*) (anamorph: *Thielaviopsis* sp.) was reported in Brazil in the 1930s (Viegas, 1960; Ribiero, 1980; Silveira *et al.*, 2006), and it is recognized as the primary cause of seca. *Diplodia recifiensis* Batista (=*Lasiodiplodia theobromae*?) was also reported as the cause of Recife sickness in Brazil (Batista, 1947), but it probably plays no role or a secondary role in the development of this disease (Prusky, 2009).

Two other species have been described for sudden decline in the Oman Gulf Region, *Ceratocystis omanensis*, which is a minor pathogen (Al Subhi *et al*. 2006), and the primary sudden decline agent in Pakistan and Oman, *C. manginecans* (Ploetz, 2018).

Powdery mildew

Powdery mildew is caused by the host-specific fungus *Oidium mangiferae* Berthet (Prakash and Srivistava, 1987; Ploetz and Freeman, 2009). It was first described in Brazil (Berthet, 1914), and it is now reported in most mango producing regions (Palti *et al.*, 1974; Ploetz, 2018).

Phoma blight

Phoma blight caused by *Phoma glomerata* (Corda) Wollenw. and Hochapf (Prakash and Singh, 1977; Prusky *et al*., 2009) is widespread in India (Prakash and Singh, 1977). It occurs only on old leaves. Initially, lesions are minute and yellow-brown (Prakash and Singh, 1977). As they expand, they darken to brown or cinnamon, become irregular, and may ultimately develop dark margins and dull-grey centres. In severe cases, necrotic patches as large as 13 cm in diameter may develop causing defoliation.

Phoma leafspot

Another *Phoma* sp., *Phoma sorghina* (Sacc.) Boerema. Doren. and Vankest, is the agent behind phoma leafspot, a disease also present in India (Prakash and Singh, 1976). On young leaves, it causes irregular to roughly circular, watersoaked spots, up to 2.5 mm in diameter. Lesions are brown with a yellow to brown margin. Lesions on midribs are elongated and more conspicuous and may coalesce to up to 14 cm in diameter. The symthomps can be confused with those caused by anthracnose (Prusky *et al*., 2009).

Pink disease

A basidiomycete, *Erythricium salmonicolor* (Berk. and Broome) Burdsall (synonyms: *Corticium salmonicolor* Berk. and Broome, and *Phanerocbaete salmonicolor* (Berk. and Broome) Jülich; anamorph: *Necator decretus* Massee) causes pink disease. Pink disease affects many economically important woody plants in the humid tropics, where it is one of the most destructive diseases of mango (Holliday, 1980). The disease is also known as cobweb, rubellosis and thread blight (Prakash and Srivistava, 1987). It has been mainly studied on rubber, *Hevea brasiliensis*, an important host in Southeastern Asia (Rao, 1975). On mango, pink disease can significantly reduce tree vigour and yield, especially in young trees (Lim and Khoo, 1985; Prusky *et al*., 2009).

Scab

Elsinoë mangiferae Bitancourt and Jenkins (anamorph: *Sphaceloma mangiferae* Bitancourt and Jenkins) causes scab on mango (Bitancourt and Jenkins, 1943; Cook, 1975). The disease was first described in Cuba and Florida (USA) in the 1940s and it is now widespread in the western hemisphere. Scab is important in nurseries, since young tissues are the most susceptible, and because high humidity promotes infection (Ruehle and Ledin, 1955; Prusky *et al*, 2009).

2.1.3. SOIL-BORNE DISEASES

Soil-borne diseases of mango are relatively less important than foliar and floral diseases, but they can cause significant damage to seedlings, nursery stocks and mature trees.

Phytophthora Diseases

Phytophthora palmivora (E.E. Butler) (Oomycota) causes diseases of mango in several regions of the world: wilt, crown rot, root rot and the death of nursery has been reported in Arizona, the Philippines and Thailand (Kueprakone *et al*., 1986; Matheron and Matejka, 1988; Tsao *et al*., 1994); damage to trunks of field-grown, mature trees has been reported in the Ivory Coast (Lourd and Keuli, 1975); damage to fruits in Australia, Malaysia and West Africa (Turner, 1960; Cooke, 2007). Recently, a *Phytophthora* sp. was isolated in Spain from mango trees that were wilted, chlorotic and had sparse canopies and cracked bark (Zea-Bonilla *et al.*, 2007; Prusky *et al*., 2009).

Root Rot and Damping off

The oomycete *Pythium vexans* de Bary can cause root rot and wilt of seedlings (Lim and Khoo, 1985). Symptoms include wilting of foliage, which initially becomes pale green, but later develops necrotic patches. Roots develop a wet, blackened necrosis that begins in finer roots and progresses to larger roots and the root collar. Prakash and Singh (1980) reported that the basidiomycete *Rhizoctonia solani* Kuhn [teleomorph: *Thanatephorus cucumeris* (Frank) Donk] caused root and damping off of seedlings in India (Prusky *et al*., 2009)

Sclerotium Rot

The causal fungus is *Sclerotium rolfsii* Sacc. (teleomorph: *Athelia rolfsii* (Curzi) Tu and Kimbrough; synonyms: *Corticium rolfsii* Curzi and *Pellicularia rolftii* E. West) (Prusky *et al*., 2009). This disease has been reported in Brazil (Almeida *et al.*, 1979), India (Prakash and Singh, 1976) and the Philippines (Palo, 1933).

Verticillium Wilt

The disease was originally attributed to *Verticillium albo-atrum* Reinke and Berth., but later the causing agent became *Verticillium dahliae* Kleb. (Prusky *et al*., 2009). The disease was first reported in Florida (Marlatt *et al.*, 1970).

White Root Disease

The disease is caused by *Rigidoporus lignosus* (Klotzsch) Imazeki, a basidiomycete that is common in soils of the humid tropics of Africa and Asia (Holliday, 1980). More recently, *Rosellinia necatrix* was reported as the causal agent of White Root Rot in mango trees in Spain (Arjona-Girona and Lopez-Herrera, 2018).

2.2. CHEMICAL CONTROL OF THE MAIN DISEASES

FRUIT DISEASES

ANTHRACNOSE

Although resistance to anthracnose is variable depending on the mango cultivar, even the most tolerant cultivars must be protected by fungicides in humid environments (Lim and Khoo, 1985; Jefferies *et al*., 1990). In situations where mango fruits develop entirely under disease-favouring conditions, seasonal applications of up to 25 sprays of protective and systemic fungicides have been used (Dodd *et al*., 1997). However, fungicide use is constrained by the limited number of efficient available products, and by regulations that exist in the producing and/or destination countries (Ploetz, 2018). In general, copper fungicides are the most popular, but their efficacy is often low (Arauz, 2000), and they are usually applied with other fungicides. For example, monthly applications of copper oxychloride combined with mancozeb has been shown as effective for most post-harvest diseases in South Africa (Lonsdale and Kotze, 1993), although the registration of dithiocarbamate fungicides, such as mancozeb, varies among production areas. Preventive treatments with fungicides based on copper or triazoles are the most common decisions of mango growers in Brazil to control anthacnose (Pinto *et al*., 2004). Another contact fungicide, chlorothalonil, is effective but phytotoxic to fruit larger than a golf ball and, as a result, it should not be used after early fruit set (Ploetz, 2018).

With regard to systemic fungicides, only few are available. The benzimidazoles, primarily benomyl and carbendazim, provided excellent anthracnose control before resistance to them developed (Akem, 2006). Two imidazoles, prochloraz and imazalil, are used in some countries for pre- and post-harvest anthracnose, respectively, since they are moderately effective against this disease, but they are ineffective against stem-end rot (Ploetz, 2018). The stobilurins are effective against anthracnose and several other post-harvest diseases, but to avoid the development of fungicide resistance, no more than three stobilurin applications should be made per season, preferably alternating or combining with fungicides that have a different mode of action (Brent and Hollomon, 2007). Some pre-harvest spray programs used in the control of anthracnose in mango fruits are shown below. Those of Australia, Malaysia and the Philippines are included in Uddin *et al*. (2018), while that proposed for Honduras is described in Huete & Arias (2007).

Country	Pesticides	Number of sprays	Spray timing
Australia	Mancozeb + copper	13	Panicle emergence onwards
Malaysia	Mancozeb + insecticide	Every 10 days	Flower bud onwards
Australia	Prochloraz + copper (applied strategically)	Variable but significantly reduced in dry years	Panicle emergence onwards
Philippines	Mancozeb/chlorothalonil + copper + insecticide	6	Five sprays from induction to fruit set
Honduras	Trifloxystrobin + Propiconazole Thiophanate-methil Carbendazim Benomyl Mancozeb Chlorotalonil Copper oxychloride	7 Alternating contact and systemics fungicides	Blossom start onwards

Anthracnose forecasting models have been developed to schedule, and reduce, fungicide applications (Fitzell *et al*., 1984; Dodd *et al*., 1991). Akem (2006) noted differences between the time prediction of each model; he suggested to use caution when a model was used in an area other than where it was developed. Forecasting would be most useful in seasonally dry situations (where infection occurs only after significant rainfall) (Arauz, 2000). Calendar-based application schedules are needed wherever regular rainfall occurs (Ploetz, 2018).

Fungicide applications usually focus on reducing damage to fruit, but foliar disease control is indicated in some situations and on inflorescences in most situations (Ploetz, 2018). Since infected foliage and branch terminals are important reservoirs of inoculum, fruit set and anthracnose control on fruit are enhanced if applications are made prior to flowering (Jefferies *et al*., 1990). Off-season control measures are especially beneficial in production environments that receive significant rainfall (Ploetz, 2018). Although pre-harvest sprays and especially fruit-sanitation techniques can eliminate all pathogens on the fruit surface, most of them may have already penetrated the fruit, and, therefore, further treatments to control post-harvest diseases are needed.

Several fungicides have been tested as dip treatments. Benomyl was found effective against quiescent infections of anthracnose of mango in hot water (Peak, 1986), but the application of benomyl after harvest has been banned (Alkan *et al*., 2018). Post-harvest application of prochloraz in hot and cold dips effectively controls *C. gloeosporioides* and *A. alternata* during storage at low temperature and ripening at 20°C for the cultivars Tommy Atkins, Keitt, Lilly and Haden (Prusky *et al*., 1999), but it does not provide good control for stem-end-rot (SER). Prochloraz is a well-recognized fungicide that is used commercially to control postharvest diseases of mango fruit. In Australia, prochloraz at 250 ppm is applied and in Israel it is applied at 300 ppm by overhead spray (Alkan *et al*., 2018). Other fungicides have been also used successfully for certain mango varieties including thiophanate-methyl and hot imazalil (Secretariat Commonwealth, 1987; Dodd *et al*., 1991b) The main disadvantage of imidazoles (i.e. prochloraz and imazalil) is that they are less effective at controlling SER pathogens than benzimidazoles (i.e. benomyl and thiabendazole) (Estrada *et al*., 1996).

With the appearance of various fungicide-resistant isolates, no single fungicide can provide complete protection against anthracnose, alternaria rot and SER, and, consequently, a combination of treatments must be applied to cope with post-harvest pathogens (Alkan *et al*., 2018). One combination used in Australia is hot water treatment with benomyl followed by a prochloraz spray, which provides effective control of anthracnose, SER and alternaria rot during long storage (Johnson *et al*., 1990). Another combination applied in Israel includes chlorine sanitation, hot-water brushing (15–20 s) and then a spray of 50-mM hydrochloric acid (HCl), alone or in combination with prochloraz. This combination improved the control of anthracnose and alternaria rot (Prusky *et al*., 2006). Trials using gamma irradiation to control mango anthracnose have concluded that incorporation of hot fungicide dip is necessary to improve disease control afforded by irradiation [Chadha, 1989). Appropriate post-harvest treatments have to be selected for individual mango cultivars and possibly even for the same cultivar in different environments (Uddin *et al*., 2018).

ALTERNARIA ROT

Preharvest treatments with dithiocarbamate fungicides inhibit the development of latent infection. Three sprays with the protectant fungicide maneb, starting 2 weeks after initial fruit set, seem to be most effective (Prusky *et al*., 1983). However, since quiescent infections do not develop until after harvest and ripening, the application of a postharvest treatment by spraying the fruits on the packing line with prochloraz is simpler and more efficient than the preharvest fungicide treatment (Prusky *et al*., 2009).

Control of alternaria rot is significantly improved by a combination of physical and chemical treatments. The physical treatment includes a 15–20 seconds hot water spraying and brushing (HWB) treatment at temperatures between 50 and 55°C (Prusky *et al*., 1999). This approach improved fruit quality and, at the same time, reduced disease incidence. If a prochloraz spray follows this physical treatment it can further improve disease control. Prusky *et al*. (1999) concluded that the type and strength of the postharvest treatment should be optimized according to the level of quiescent infection of *A. alternata* at harvest time. Although prochloraz is very effective for postharvest disease control, a milder postharvest treatment, such as chlorine, can be applied to fruits in which a low incidence of quiescent infections is found at harvest (Prusky *et al*., 2002). This postharvest physical-chemical treatment has been further improved in light of the finding that *A. alternata* pathogenicity may modulate the pH of the host environment to promote colonization (Eshel *et al*., 2002; Prusky and Yakoby, 2003; Prusky and Lichter, 2007). Application of a combination of HWB for 15–20 s, followed by spraying with 50 mM hydrochloric acid (HCl), effectively controlled alternaria rot in stored mango fruit. Similar HWB treatments followed by spraying with reduced concentrations of prochloraz at 45 µg/ml in 50 mM HCl inhibited alternaria rot development better than treatment with HCl alone (Prusky *et al*., 2006).This technology provides a simple treatment for the control of diseases that alkalinize the host environment, including both alternaria rot and anthracnose (Prusky *et al*., 2009).

STEM END ROT

Postharvest control of *Botryosphaeria* spp. was achieved by postharvest dipping, spraying or ultra-low-volume application of benomyl (where possible). Prochloraz or sodium hypochlorite also effectively suppressed postharvest rot of mango (Plan *et al*., 2002; Korsten, 2006). A combined treatment of wax and hot water (55°C) provide very effective control of most postharvest pathogens (Sangchote, 1998), but in some cases partial-vacuum infiltration improved disease control, which suggests that control efficiency may have been reduced because the fungicide did not reach the pathogen (Plan *et al*., 2002).

BACTERIAL BLACK SPOT (BACTERIAL CANKER)

Bacterial Black Spot can be difficult to control on susceptible cultivars, as the available chemicals are marginally effective (Pruvost *et al*., 1989). During rainy weather, applications of copperbased bactericides are recommended. Their application should focus on protecting fruit and should vary according to the lenght of the time during which the fruits are exposed to wet conditions (Manicom and Pruvost, 1994). Agricultural antibiotics, such as streptomycin sulphate or nitrate, have been effective (Misra and Prakash, 1992; Viljoen and Kotze, 1972), but their long-term effectiveness is reduced by resistance that develops after continued use.

FOLIAR AND FLORAL DISEASES

SECA AND SUDDEN DECLINE

According to Ploetz (2018), managing these diseases with fungicides is still a challenge, especially on susceptible cultivars. External applications of protectant or systemic fungicides would probably be ineffective given the internal location of the pathogens. In areas where partially resistant cultivars are grown, the removal and burning of affected branches and treatment of the exposed branch stubs with copper fungicides are recommended (Ribeiro *et al*., 1995; Ribeiro, 1997). Alternatively, injecting fungicides might be effective, as it has been done to control Dutch elm disease (Ploetz, 2018).

MALFORMATION

The internal location of the pathogen in affected trees makes it difficult to control this disease with chemicals (Ploetz, 2018). Thus, although a diverse array of pesticides, hormones and growth regulators have been tested against malformation, only few have shown some potential. In India, spray with carbendazim every fifteen days has been recommended (Misra *et al*., 2000). In Pakistan, Iqbal *et al*. (2011) found that clipping malformed branches at 45 cm distance followed by spray of benomyl showed the best results with a 70% decrease over previous years damage. Freeman *et al*. (2014b) described the use of prochloraz applications in conjunction with sanitation measures. Although significant reductions in malformation were reported, prochloraz is not approved for use in mango in some producing (i.e. the United States) and importing countries. Darvas (1987) reduced the percentage of malformed inflorescences from 96% to 48% by injecting 'Keitt' trees with the fungicide fosetyl-Al, although no significant increase in fruit yield was observed. Recently, more extensive applications of phosphonates (the active ingredient of fosetyl-Al) were shown to be effective against malformation in South Africa. Nonetheless, the efficacy of intensive phosphonate applications needs to be demonstrated in other areas, and its adoption would need to address phosphonate residue tolerance limits that are imposed in some importing countries (Ploetz, 2018). In Egypt, foliar application of nano-chitosan on mango trees improved the vegetative growth and fruit quality, increased yield and decreased the incidence of malfomation (Zagzog *et al*., 2017).

POWDERY MILDEW

A large number of fungicides have been used against this disease in different mango growing countries. Apart from dormant sprays, several applications of suitable fungicides at 15-20 day-intervals are required to effectively control the disease. Initially, inorganic copper or sulfur-based chemicals were used and then a broad range of organic and systemic fungicides, which acted as eradicants, protectants or both, were introduced (Nasir *et al*. 2014). These authors reviewed the main groups of chemicals used against the powdery mildew of mango: copper-based fungicides, sulphur fungicides, chlorothalonil, nitro compounds, and systemic fungicides (benzimidazols, imidazole, morpholines, organophosphorus, oxathiins, piperazine, pyridimines, strobilurins and triazoles).

Sulfur fungicides, as dusts or sprays, are widely used and provide reasonable protectant control of powdery mildews (Palti *et al*., 1974; Gupta and Yadav, 1984; Prakash and Misra, 1986; Kawate, 1993; Prakash and Raoof, 1994; Desai, 1998; Chavan *et al*., 2009), although they can burn flowers and young fruits during warm, sunny conditions (Johnson, 1994a). Systemic fungicides in general are very effective in reducing the disease (Ihsan *et al*., 1999). In addition, some fungicides, such as dinocap, fenbuconazole and hexaconazole, can reduce pollen germination (Dag *et al*., 2001), and, consequently, their use should be limited during the flowering season. Application of phosphate solutions is a new and safer approach in the control strategies of powdery mildews in several vegetables and fruit trees (Nasir *et al*., 2014). In mango, foliar sprays of K2HPO4 and KH2PO4, especially in alternation with systemic fungicides, were effective against powdery mildew (Nofal and Haggag, 2006; Reuveni *et al*., 1998).

2.3. BIOLOGICAL CONTROL OF THE MAIN DISEASES

FRUIT DISEASES

ANTHRACNOSE AND STEM-END-ROT

Bacillus licheniformis, on its own or alternated with copper oxychloride (allowed in organic famring management), has been evaluated as a preharvest spray treatment to control mango fruit diseases (Prusky *et al*., 2009). Preharvest applications of *B. licheniformis* at 3-week intervals from flowering until harvest controlled moderate levels of anthracnose and of soft rot caused by *Botryosphaeria*, which suggests a potential treatment for comercial preharvest applications (Silimela and Korsten, 2007).

Post-harvest biological control agents have been the focus of considerable research (Droby *et al*. 2016). A number of microorganisms with *in vitro* or *in vivo* activity against *C. gloeosporioides* have been isolated (Jeffries and Koomen, 1992), but few examples have been used commercially in the field until Korsten (2004) isolated *Bacillus licheniformis* from leaf and fruit surfaces, and effectively controlled anthracnose of mango. This product was used either alone or in combination with hot water treatments for 5 minutes at 45°C and with low doses of prochloraz or sodium hypochlorite, although only when used alone could be considered in organic agriculture (Govender *et al*., 2005). The yeasts *Rhodotorula minuta* (Patino-Vera *et al*., 2005) and *Debaryomyces nepalensis* (Luo *et al*., 2015) have also been suggested as potential biocontrol agents of anthracnose, but they have not been widely applied commercially (Droby *et al*., 2016). Other approaches to anthracnose control using biological methods included the use of a non-pathogenic strain of *Colletotrichum magna* that colonizes the fruit endophytically and prevents infection by *C. gloeosporioides* (Prusky *et al*., 1993), and the expression of an antifungal peptide in the yeast *Saccharomyces*, which controlled postharvest diseases caused by *C. coccodes* (Jones and Prusky, 2001). Recently, Luo *et al*. (2015) found that the yeast *Debaryomices nepalensis* decreased the decay incidence to anthracnose while maintained storage quality of mango fruits. In Thailand, Rungjindamai (2016) found that two isolates of epiphytic bacteria, identified as *Bacillus* sp. MB61 and *Bacillus* sp. LB72, reduced the size of the lesions caused by *C. gloeosporioides*.

BACTERIAL BLACK SPOT (BACTERIAL CANKER)

Biological control measures against Bacterial Black Spot have not been widely studied (Prusky *et al*., 2009). In India, Kishun (1994) indicated that a strain of *Bacillus coagulans* from the phylloplane of mango was effective against strains of the pathogen, although control of bacterial black spot in the field was not reported.

MALFORMATION

Some attempts to control mango malformation through biopesticides have been reported in India. Three different species of *Trichoderma* i.e., *Trichoderma viride*, *T. virens* and *T. harzianum,* were tested against the *F. moniliforme* var. *subglutinans* (Kumar *et al*., 2012). The three bioagents varied in their efficacy against *F. moniliforme* var. *subglutinans*, but, in general, all of them were effective in decreasing the growth of all evaluated isolates of *Fusarium*. Kumar *et al*. (2009) evaluated antifungal activity against *F. moniliforme* var. *subglutinans* of leaf extracts from different plants. Although all the leaf extracts limited the radial growth of the fungus, extracts of *Azadirachta indica, Achyrenthes roseus* and *Calotropis gigantea* were found more effective. Usha *et al*. (2009) also reported antifungal activity of *Dhatura stramonium*, *Calotropis gigantean* and *Azadirachta indica* against floral malformation pathogens.

In South Africa, several bacterial isolates obtained from mango orchards as well as other environments, were screened for their antifungal properties against *Fusarium* and five (identified as *Alcagenes faecalis*) were able to significantly inhibit the growth of the pathogen (Veldman *et al*., 2017). The authors suggest that the modes of action of these bacteria involved a combination of competition for space and production of secondary metabolites, such as volatiles, phenolic compounds and siderophores.

POWDERY MILDEW

Sztejnberg *et al*. (1989) reported that an isolate of *Ampelomyces quisqualis* parasitized powdery mildew of mango and reduced the disease in field trials. He also found that *A. quisqualis* was tolerant to many fungicides currently used to control powdery mildew. Nofal and Haggag (2006) reported that in vitro application of biocontrol agents as *Verticillium lecanii*, *Bacillus subtilis* and *Tilletiopsis minorto* leaf disks before inoculation with *O. mangiferae* markedly decreased conidial germination and leaf infection. In field trials, the application of those agents at 15 days intervals effectively controlled *O. mangiferae* on blossom clusters and fruit set on naturally powdery mildew infected cultivars Alphonso and Seddek. Mixing kaolin and monopotassium phospate with biocontrol agents increased their efficacy. In Egypt, Azmy (2014) found that spraying with the bio-fungicide AQ10 (*Ampelomyces quisqualis*) at the rate of 0.005% after harvesting the crop showed good reduction of powdery mildew severity on mango trees with an increase of fruit yield. Kaur *et al*. (2018) found that among six biocontrol agents evaluated by giving three sprays (starting from two weeks after the panicle emergence) at 15 days intervals against powdery in mango, two antagonists, namely *Bacillus subtilis* and *Ampelomyces quisqualis,* exhibited high degree of disease control, when tested over two different locations. The mechanisms implicated in biological control of powdery mildew fungus include mycoparasitism, antibiosis, competition, and induced resistance.

2.4. MANGO MANAGEMENT APPROACHES TO REDUCE THE INCIDENCE OF DISEASES

FRUIT DISEASES

ANTHRACNOSE, STEM-END ROT AND ALTERNARIA ROT

Pre-harvest control measures

Post-harvest diseases can be reduced by various pre-harvest control measures, including the use of tolerant cultivars, orchard hygiene, manipulation of flowering and integrated management using chemical, physical and biological controls (Johnson *et al*., 1989; Ploetz, 2004; Akem, 2006).

Since the development of mango anthracnose is dependent on high humidity, mango orchards should ideally be established in areas with a well-defined dry season, to allow for fruit development under conditions unfavourable for disease development (Prusky *et al*., 2009). In the tropics, mango flowering usually occurs during the dry seasons, and the incidence and severity of mango anthracnose can be close to zero in fruits that develop completely in the dry season, without the need of any additional control measures (Arauz, 2000). However, anthracnose incidence of > 90% is common in fruits that develop during the rainy season (Arauz, 1999). Thus, modifying flowering time to a less sensitive period could be an appropriate option. Flowering can be advanced by several weeks by applying potassium nitrate sprays to mature foliage (Núñez-Elisea, 1985). The growth retardant paclobutrazol, alone or followed by potassium nitrate sprays, can also be used to advance flowering (Núñez-Elisea *et al*., 1993) although its use is not allowed in some countries.

Sanitation of the tree in the field is a difficult practice since elimination of dry panicles and mummified fruits is time consuming. Bagging can result in reduced anthracnose severity, but it also reduces the red colour of the fruit of some varieties, which could reduce consumer appeal in some markets (Hofman *et al*., 1997).

Although all commercial mango cultivars are susceptible to anthracnose, some varieties are less susceptible than others. Thus, 'Tommy Atkins' and 'Keitt' seem to be less susceptible than 'Irwin', 'Kent', 'Haden' and 'Edward' (Campbell, 1992). Consequently, cultivar selection should be taken into account in areas with high incidence of the disease.

Regarding stem-end rot, Johnson *et al*. (1992) demonstrated that infection of mango fruits before harvest occurred through endophytic colonization of the pedicel tissues by *Botryosphaeria* spp. present from previous growth flushes. The possibility of pruning to promote new growth flush was tested as a means to reduce inoculum in the stem tissue from which new-season inflorescences emerged. Cooke *et al.* (1998) reported that the levels of endophytic organisms such as *Botryosphaeria* spp. were reduced significantly when a pruning programme was implemented in mango orchards as a preharvest control measure. Korsten (2006) found that prevention of water stress during fruit development and maturation, and avoidance of placing fruits on the ground suppressed disease development. He also suggested that fruits should be cooled to 13°C immediately after harvest and stored in a well-ventilated place.

Physical control

Growing public demand for chemical residue-free fruits has encouraged the development of alternative technologies, such as irradiation, heat treatment and cold-temperature storage. Cold storage of mango fruit (10–12°C) is one of the best ways of delaying fruit ripening and, thus, decreasing post-harvest decay (Sivankalyani *et al.*, 2016). Shortwave infrared radiation treatments reduce anthracnose damage in mango (Saaiman, 1996) and this approach can also be considered for the organic market.

Heat treatment is known to reduce post-harvest diseases. Different approaches have been used, such as hot-water dipping and rinsing, and hot water vapour and dry-air treatments (Schirra *et al*., 2000). There are many benefits to heat treatments, such as reduction in post-harvest decay, killing of pests, colour and flavour preservation and shelf-life improvement, among others (Lurie, 1998; Schirra, 2000; Fallik, 2004). Hot-water brushing at 50–60°C for 20 seconds after harvesting reduces decay development via both surface cleansing and induction of fruit resistance against pathogens (Prusky *et al*., 1996a; Fallik, 2004); this method is applied in Israel. Hot-water dipping for 3–7 minutes has been recommended and is moderately efficient at delaying post-harvest rot (Johnson, 1994). Hot-water dips, or spray can control fungal infections such as anthracnose and alternaria rot better than stem-end-rot (Johnson, 1994). Trials using gamma irradiation to control mango anthracnose have concluded that incorporation of hot fungicide dip is necessary to improve disease control afforded by irradiation (Chadha, 1989).

Regarding stem-end rot, for high-value fruit, especially those destined for export, various post-harvest treatments have been beneficial (Ploetz, 2018). For example, Alvindia and Acda (2015) reported a 48–61% reduction in stem-end rot of 'Carabao' fruits after 20 min in 53°C water. Terao *et al*. (2015) indicated that a low dose (< 3 kJ m^{-2}) of UV-C irradiation helped manage post-harvest diseases of mango caused by *B. dothidea*, *L. theobromae*, *A. alternata* and *C. gloeosporioides*, even though a direct impact on the pathogens was not evident. Santos *et al*. (2015) suggested that a dose of 0.45 kGy of gamma irradiation reduced disease caused by *L. theobromae.*

Fruit sanitizers

The purpose of fruit sanitizers is to wash and kill the microorganisms on the fruit surface. Traditionally, the sanitizers consisted of water with or without chemicals. One of the most extensively used and studied sanitizers is chlorine (water pH 6.5–7.5; chlorine concentration 100–150 ppm). In addition to chlorine, sulphur dioxide has also been used as fungal disinfectant (Johnson *et al*., 1997; Tefera *et al*., 2007). Different forms of chlorine, such as sodium hypochlorite, calcium hypochlorite and chlorine gas, control a wide range of post-harvest pathogens (Boyette, 1995). In the past, elevated chlorine dosages were frequently used due to the misconception that chlorine leaves no residues on the fruit. Common alternatives to chlorine are ozone (O_3), oxidized water and hydrogen peroxide. Ozone and ozonated water were recognized in 1997 by the FDA as safe food disinfectants and were proven to control post-harvest rots of mango (Monaco *et al*., 2014). Recently, ozonated water has been reported as a sanitizer for mango cv. Palmer as it increases antioxidant activity (Minas *et al*., 2012; Lima *et al*., 2014, Monaco *et al*., 2016).

Electrolyzed water has also been suggested as a sanitizer for the industry (Colangelo *et al*., 2015). Electrolyzed water is produced by adding sodium chloride (as an electrolyte) to tap water and passing an electrical current through an anode or cathode to produce oxidizing (acidic) and reducing water (alkaline), respectively. The high electrolyzed water potential works against both bacteria (Pinto *et al*., 2015) and fungi (Guentzel *et al*., 2010). Hydrogen peroxide has also been recommended as an effective disinfectant against several fungi (Boyette, 1995).

BACTERIAL BLACK SPOT (BACTERIAL CANKER)

Resistance to Bacterial Black Spot varies greatly among mango cultivars, and resistant cultivars should be used where disease pressure is high (Manicom and Pruvost, 1994). Pathogen-free planting material should be utilized when new orchards are established. The pathogen moves only short distances in wind-blown aerosols (usually within orchards) (Gagnevin and Pruvost, 2001), and long-distance dissemination occurs almost entirely via infected propagation material and less frequently in surface-contaminated seeds (Manicom and Pruvost, 1994). Windbreaks should be used to reduce wounding and infected twigs should be removed from the canopy.

FOLIAR AND FLORAL DISEASES

SECA AND SUDDEN DECLINE

Given the destructive impact of these diseases, preventing the dissemination of these pathogens to new areas should be a high priority (Ploetz, 2018). Pathogen-free propagation material is needed whenever new plantings are established and germplasm is moved. Clean pruning tools should be used in affected areas and should be frequently disinfested with bleach, formalin or other disinfectants (Junqueira *et al*., 2002). Trees that have been killed by the disease should be removed and destroyed because they are significant reservoirs of the vector and pathogens.

The use of resistant or tolerante genotypes is an appropriate alternative. Various levels of tolerance have been observed and resistant materials have been developed. However, pathogenic variation in the causal fungus in Brazil has hindered progress (Rossetto *et al*., 1996; Junqueira *et al*., 2002; Silveira *et al*., 2006). In Brazil, the disease responses of some genotypes vary in different production areas, but 'Manga Dagua', 'Pico', 'IAC 101', 'IAC 102', 'Edwards', 'Van Dyke' and 'Carabao' show resistance to two pathotypes, while 'Rosa', 'Sabina', 'Sao Quirino', 'Oliveira Neto', 'Jasmim', 'Sensation',' Irwin' and 'Tommy Atkins' are generally tolerant (Ribiero, 1997; Junqueira *et al*., 2002). 'Espada' is also reported to be tolerant, but old trees are attacked. Colosimo *et al*. (2000) reported that 'Oliveira' was the most resistant, while 'Carlota', 'Imperial', 'Extrema' and 'Pahiri' had intermediate resistance. Carvalho *et al*. (2004) described two new cultivars, 'IAC 103 Espada Vermelha' and 'IAC 109 Votupa', with moderate resistance to seca. 'IAC 103 Espada Vermelha' also had moderate resistance to powdery mildew but was susceptible to anthracnose, and both cultivars were susceptible to malformation.

In Oman, 'Hindi Besennara', 'Sherokerzam', 'Mulgoa', 'Baneshan', 'Rose' and 'Alumpur Baneshan' developed significantly less disease when challenged with *Ceratocystis maginecans* (Al Adawi, *et al*., 2013).

MALFORMATION

Management of malformation can be difficult and mainly relies on proper sanitation and hygiene in the orchards. Thus, new plantings should be established with pathogen-free nursery stock and, consequently, scion material should never be taken from affected orchards, and any affected plants observed in the nursery should be removed and burned. Once the disease is found in an orchard, all affected terminals and the subtending three nodes must be removed from the trees and burned (Prusky *et al*., 2009). Good results have been observed following this recommendation, as those reported by Schoeman *et al*. (2018), who found that continuous removal of infected inflorescences over a four-year period resulted in a significant decline of disease incidence. However, it may be difficult to apply this treatment on large trees (Prusky *et al*., 2009).

The selection of resistant varieties can play a vital role in reducing the malfomation incidence, especially in the most severely affected areas (Katoch *et al*., 2019). Variation in the susceptibility to malformation of different varieties has been reported (Prakash and Srivistava, 1987; Fayyaz *et al*., 2002). In some cases, results have been inconsistent (Ploetz, 2001), but some local cultivars that have consistently been deemed resistant, such as 'Bhadauran' in Brazil and India, 'Primor' in Brazil and 'Zebda' in Egypt, should receive wider attention (Ploetz, 2018).

POWDERY MILDEW

Reduction of inoculum potential of the pathogen at early stages is likely to decrease disease incidence (Joubert, 1991). Regular inspection of mango orchards and removal/pruning of infected leaves and malformed panicles reduce the load of primary inoculum and improve fungicidal control (Prakash and Misra, 1992, 1993a; 1993b; Prakash and Raoof, 1994).

Mango cultivars vary in their resistance to powdery mildew (Palti *et al.*, 1974). 'Zill', 'Kent', 'Alphonso', 'Seddek' and 'Nam Doc Mai' are very susceptible; 'Haden', 'Glenn', 'Carrie', 'Zebda', 'Hindi be Sennara', 'Ewaise' and 'Keitt' are moderately susceptible; and 'Sensation', 'Tommy Atkins' and 'Kensington' are slightly susceptible (Ploetz *et al.*, 1994; Nofal and Haggag, 2006). In India, Tiwari *et al.* (2006) reported that 'Baigan Phalli', 'Barbalia', 'Dabari', 'Dilpasand', 'Khirama', 'Nagarideeh', 'Oloor' and 'Totapari' were highly resistant and 'Amrapali' was most susceptible.

3. CAN AGROHOMEOPATHY BE USED TO EFFICIENTLY MANAGE OR CONTROL PESTS AND DISEASES IN MANGO?

Homeopathy is based on the principle that a substance which in a massive dose generates pathological symptomatologies has the possibility to cure a disease, if applied in the minimum doses obtained by dilution and intense agitation. This notion was proposed in 1796 by Samuel Hahnemann (Toledo *et al*., 2011). Thus, the central tenet of homeopathy is that "like cures like". Homeopathic remedies are prepared ('potentized' or 'dynamized') in steps of alternately diluting and succussing a homeopathic stock, known as 'mother tincture', untill they reach calculatory dilutions beyond Avogadro's number, implying a non-molecular action of remedies with specific healing properties. One of the most paradigmatic and controversial aspects of homeopathy is if these serial dilutions would have a measurable effect even when they are given to an animal or a plant in infinitesimal doses (Mazón-Suastegui *et al*., 2019), although the Swiss chemist Louis Rey found that the structure of hydrogen bonds in homeopathic dilutions of salt solutions is very different from that in pure water, probably due to vigorous shaking of solutions that takes place during homeopathic 'succussion' (Rey, 2003). Products labeled as homeopathic and currently marketed in the U.S. have not been reviewed by the FDA (USA Food & Drugs Administration) for safety and effectiveness to diagnose, treat, cure, prevent or mitigate any diseases or conditions, and, therefore, there are no FDA-approved products labeled as homeopathic (FDA, 2020). In fact, homeopathy is considered by the scientific community as a pseudoscientific system of alternative medicine (Smith, 2012).

Agrohomeopathy, or the application of homeopathic principles and remedies to agriculture, has drawn emerging interest over the last years, since it could represent an ecological alternative to decrease or eliminate agrochemical use (Abasolo-Pacheco *et al*. 2020). However, no reports on this practice can be found in the main horticultural journals and, consequently, the results reported so far in more obscure journals should be taken with caution.

Homeopathic preparations have been described as relatively cheap, with few or no ecological side-effects, and seemingly harmless, which would make this discipline optimally suited to the holistic approaches of organic and, above all, biodynamic agriculture (Carpenter-Boggs *et al*., 2000). According to Bonato (2007), the use of high dilution preparations following homeopathy could work on plants by improving their physiological status, inducing resistance and favouring multiple biological interactions in the way that healthy plants are tolerant to pests and diseases and promptly response for optimal production (Bonato, 2007). Positive results from the use of homeopathic medicines on different plant species have been claimed in seed germination, emergence and initial growth (Abasolo-Pacheco *et al*., 2020), in overall production (Rossi *et al*., 2007), in remediation of soils affected by heavy metals (Dos Santos et a., 2016), in mitigation of the effects of abiotic stress, such us salinity (Giardini-Bonfim et al., 2012) or hot and dry weather (Pelikan and Hunger, 1971), and to control plant pests and diseases (Modolon et al., 2012; Ramaia & Kumar, 2015). Studies on plant diseases control using homeopathic preparations report experiments based on phytopathological models (plants naturally infected or artificially inoculated with fungi, viruses, bacteria, nematodes), in vitro spore germination and growth models, and field trials (agronomical and phytopathological experimentations) (Betti *et al*., 2009). In fruit crops, experimental effort has mainly focused on fruit rot diseases control. For instance, Baviskar and Suryawanshi (2015) found that *Arsenicum album* had an inhibitory activity against fungi responsible for fruit rot diseases in apple. Kehri and Chandra (1986) evaluated some homeopathic treatments against *Lasidiplodia theobromae*, (Pat.) Griffon & Maubl., a severe pathogen that causes postharvest rot of guava (*Psidium guajava* L.), and reported that all the tested potencies of *Arsenicum album* completely suppressed in vitro spore germination and, in adittion, largely reduced fruit rots when applied as a pre-inoculation dip treatment of guava fruits. Yadav *et al*. (2013) reported good results with Methyl jasmonate 200 for Fusarium fruit rot of banana.

Specific studies on the sue of agrohomeopathic approaches in mango are scarce. Khanna and Chandra (1978) determinated the fungitoxicity of 10 homeopathic drugs against *Pestalotia mangiferae* Henn., the causal agent of mango fruit rot in India, in terms of the inhibition of spore germination. To do this, spores of the pathogen were suspended in different potencies (1-200) of the drugs and the hanging drop technique of Hoffman (Hoffman, 1869) was employed. The drugs that completely inhibited spore germination after 8-12 hour-time incubation were screened for their efficacy in controlling fruit rot. For this purpose, healthy freshly picked mango fruits of cv. ´Dusehri´ were injured with a sterilized needle, artificially inoculated with a spore suspension, and dipped, in pre-and post-innoculation treatments, for 3-5 min. in each drug or sterilized distilled water (control). The authors claimed that, although several drugs were able to completely inhibited spore germination of the pathogen, only *Lycopodium clavantum* potency 190 was effective in reducing fruit infection percentage and rot percentage after 8 days, and thus, they suggested that it may be safely recommended for the control of mango fruit rot caused by *P. mangiferae*.

More recently, Alam *et al*. (2017) tested 72 homoeopathic solutions containing anti-fungal properties, each with 5 Centesimal Hahnemannian potencies, to control mango anthracnose caused by *Colletotrichum gloeosporioides* (Penz. & Sacc.). They made two types of experiments. One, using Petri dishes, where the solutions were tested individually against mycelial growth of *C. gloeosporioides* using Oat Meal Agar (OMA) medium by food poisoning method. Another, with recently harvested fruits from three cultivars treated by dipping for 10 minutes in a solution with the best solutions selected in the Petri dish experiment. The authors claimed that the results from the in vitro study pointed out that all the homeopathical drugs showed remarkable efficacy for inhibition of *Colletotrichum gloeosporioides* mycelia growth, especially *Arsenicum album* Q at 10000 ppm, with a 96.40% inhibition percent. *Arsenicum album* Q at 10000 ppm concentration was used in the fruits experiment, and eighteen days after treating inhibition of Percent Disease Incidence was different in each cultivar: 18.2% in cv. ´Himsagar´, 8% in cv. ´Amrapali´ and 0% in cv. ´Langra´, although lession size and lession cover were significantly reduced by the homeopathic treatment in all three cultivars. The authors concluded that these results may suggest the potential of homeopathic medicines for controlling anthracnose of mango and other fruits.

Although these results could seem to be promising and agrohomeopathy has been proposed as an alternative to the widespread use of herbicides, pesticides and other chemicals in agriculture, basic and applied research on efectiveness of homeopathic treatments in crops is scarce and does not often provide sufficient information to be interpreted properly. No significant works in this field are found in relevant horticultural journals and, consequently, caution should be taken on the possible effects of these treatments in agriculture. A more appropriate approach to reduce the use of chemical treatments could probably be the use of organic agriculture.

4. WHAT KIND OF ALTERNATIVE CAN THE KNF (KOREAN NATURAL FARMING) PRESENT AS POTENTIAL STRATEGY TO CONTROL OR MANAGE PESTS AND DISEASES IN MANGO?

Basic principles of Korean Natural Farming (KNF) include using indigenous microorganisms (IMO), maximize the potential of natural environment, minimize the use of synthetic fertilizers, practice no till, eliminate emission of livestock waste effluents and increase production with less inputs (Wang *et al*., 2012). Therefore, this farming approach, developed by Han Kyu Cho from Janong Natural Farming Institute in South Korea (Cho and Cho, 2010), maximizes the use of on-farm resources, recycles farm waste, and minimizes external inputs while fostering soil health (Wang *et al*., 2012). KNF has been practiced for decades in Asia and was introduced to Hawaii at the end of 1990s, where it has been gaining popularity among farmers who are interested in sustainable agriculture (Wang *et al*. 2012).

Cultivation of IMO from the farm instead of introducing alien beneficial organisms is a key practice of KNF (Wang *et al*., 2012). This involves a four-step process of capturing, cultivating, and preserving IMO, to create products that are often referred to as IMO 1, IMO 2, IMO 3, and IMO 4 (Keliikuli *et al*., 2019). A list of natural inputs used to make the IMOs and a thorough description of how to prepare them can be found in Park and Duponte (2008) and Keliikuli *et al*. (2019). The final product, IMO 4, should be used as a top dressing, gently mixing 150 kg/0.1 ha into the topsoil, and covering the inoculated soil with mulch (i.e., bamboo leaf litter, wood chips, etc.) (Keiikuli *et al*., 2019). It is recommended that IMO 4 be applied to the soil seven days before seeding or transplanting and two to three hours prior to sunset, since treating the soil in the late afternoon gives the microbes more time to adjust to the environmental changes, particularly the increase in temperature (Cho and Cho 2010).

Foliar sprays of composts made from various herbs or farm wastes is another key practice of KNF (Wang *et al*., 2012). According to these authors, the application of nutrient sprays may be environmentally friendly since the nutrients are directly delivered to the plant in limited amounts, and involves benefits to young seedlings with smaller root systems, reductions in the amount of N application, better nutrient uptake during the reproductive stage due to a decrease in root activity, and the ability to modify the nutrient inputs accordingly.

Studies in Hawaii, where farmers' plots for vegetable production using KNF practices were compared to control plots using conventional or organic farming, found that KNF did significally improved some conditions of plant and soil health, especially in plots with soybean, and required less irrigation than conventional farming, probably due to the soil mulching required by KNF (Wang *et al*., 2012). Nevertheless, KNF did not protect plants from insects and diseases.

Scientific evidence of the benefits of KNF has been limited (Wang *et al*., 2012), and, a far as we know, there are no references about the effects of KNF on control of fruit crops diseases. Probably, the approach closest to IMOs, one of the foundations of KNF, could be the use of indigenous biocontrol agents (BCAs) as a tool to reduce or exterminate pathogen populations (AbuQamar *et al*., 2017; Syed Ab Rahman *et al*., 2018). This is since epiphytic microbes that live on plant surfaces without causing any symptoms to the plants are known for their efficacy to inhibit plant pathogens (McGrath and Andrews 2005; Janisiewicz *et al*. 2010; Janisiewicz *et al*. 2013). We have found some references of disease control with BCAs in mango. For instance, In Mexico, Bautista-Rosales *et al*. (2014) evaluated the effectiveness of the antifungal yeast *Cryptococcus laurentii* [(Kuff.) C.E. Skinner] strain L5D, isolated from the surface of local ´Ataulfo´ mango fruits, against the causal agent of anthracnose, *Colletotrichum gloeosporioides* ((Penz.) Penz. & Sacc.) and they found that *C. laurentii* showed a high antagonistic potential in vivo, with significant inhibition of anthracnose (75.88%), probably due to competition for nutrients and for space. In Thailand, Rungjindama (2016) reported that two isolates of epiphytic microbes (bacteria and yeasts) from healthy leaves and fruits of local mangoes reduced lesion sizes caused by *C. gloeosporioides* compared to control treatment. In the United Arab Emirates (UAE), Kamil *et al*. (2018) found that 19 actinobacterial isolates obtained from mango rhizosphere soils in the UAE showed antagonistic activities against *Lasidiplodia theobromae* (Pat.) Griffon and Maubl., causal agent of mango dieback disease in different areas of the world, including Brazil, Korea, India, Oman, Pakistan, USA and the UAE. All those isolates were screened in vivo for their abilities to reduce lesion severity on fruits inoculated with *L. theobromae*, and the three isolates showing the strongest inhibitory effect against this pathogen were inoculated on mango seedlings, 1 week before inoculation with *L. theobromae,* and exhibited very high levels of disease protection against the pathogen. According to these authors, the indigenous strains identified in this study were safe, inexpensive, long lasting, and well-suited to extreme harsh conditions, which make them suitable to be incorporated into sustainable IPM strategies to manage dieback disease in mango orchards in diferent countries.

According to these promising results, it seems that the use of indigenous BCAs, alone or combined with some practices including in KNF to increase plant and soil health (such as soil mulching, foliar sprays with core solutions, etc.), could be potential strategies to manage diseases of mango. In fact, some principles of KNF, such as enhancing soil microbial activity and fertility, increasing microbial diversity or maximizing the use of on-farm resources, are also found in other types of organic farming and, consequently, organic mango production could be an interesting way for pest and disease control. This is an area where additional work is clearly needed and should be included in a holistic organic management.

5. FUTURE AREAS AND LINES OF RESEARCH FOR THE CONTROL OF MANGO PESTS AND DISEASES

Significant advances have been made in the last decades in optimizing the control of different pests and diseases combining chemical, biological and management approaches. However, new pests and disesases are constantly appearing in different countries and globalization is helping the spread of pests and diseases to new areas. Consequently, internationally coordinated efforts are required to optimize pest and disease control along different areas and lines of research. A holistic approach combining biological and chemical control, cultural practices, and plant selection and breeding should be combined. Examples of lines of research where information are still needed include the following:

- Biological control: research is needed on identifying additional pest and disease native natural enemies and on optimizing their populations through appropriate orchard management to minimize damage.
- Cultural practices: agroecology is a field in which additional research is needed including different topics such as ecological landscaping, crop rotations, use of cover crops, optimize water use or developing strategies to improve pest and disease monitoring. In this sense, new technologies (drones, 5G) can be useful for early damage identification.
- Chemical control: minimize the use of synthetic products and increase the range of available naturally occurring biopesticides (pheromones, insect growth regulators, etc.).
- Genetics and diversity: selection and development of tolerant and resistant varieties including the use of biotechnological approaches (genetics, genomics, in vitro culture).
- Appropriate control of imports of fruits and plant material, including periods under quarantine if necessary, should be prioritized with fast protocols for pest and diseases detection.
- Increase the investment for reseach in developing countries where most of the mango production is based and resources devoted for pest and disease control are scarce.
- Studies are needed on the effect of climate change on pest and disease control and management.

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