

REVIEW

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# Progress towards an eco-friendly insect pest management approach in subtropical agro-ecosystems (South Africa)

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## Abstract

South Africa is a known exporter of subtropical fruit (avocado, litchi and mango). The main production areas for subtropical fruit in South Africa are parts of Limpopo, Mpumalanga and KwaZulu-Natal. The avocado and litchi industries are export orientated while the majority of mangoes produced are processed. The main export markets are the European Union and the United Kingdom. Subtropical fruit production is susceptible to various insect pests that significantly contribute to yield losses. Twenty years ago mainly broad spectrum insecticides (organophosphates and pyrethroids) had been registered for control of pests and progress was made in adopting eco-friendlier management approaches. The lowering of maximum residue levels for pesticides on food products by importing countries provide new challenges for growers. Here, details are provided on the important insect pests of subtropical crops and the current management strategies use for controlling these pests. An integrated pest management strategy should aim to use interventions that lower maximum residue levels. A challenge that still remains is the sucking bug complex on avocado and more environmentally friendly strategies used for suppression need to be developed. An effective trapping system to monitor adult sucking bugs coming into the orchards will be important for effective management. Challenges that still remain are the litchi moth, *Cryptophlebia peltastica* (Meyrick) (Lepidoptera: Tortricidae) on litchi, and the citrus thrips, *Scirtothrips aurantii* Faure (Thysanoptera: Thripidae) and the mango seed weevil, *Sternochetus mangiferae* (Fabricius) (Coleoptera: Curculionidae) on mango. The development and testing of mating disruption products, attract and kill products, and biological control products for litchi moth is important. Biological control products also need to be tested against citrus thrips on mango. The mango industry needs to find more environmentally safe suppression methods that can be used with sanitation to manage mango seed weevil as it is a pest of phytosanitary concern. The set of economic thresholds for the important pests also need some attention. The use of botanical pesticides has not yet been tested on a large scale and could possibly contribute to the control of pests in the future.

**Keywords:** Insect pests, Integrated pest management, Environmental-friendly pest management, Avocado pests, Litchi pests, Mango pests, Pest management strategies

## Background

South Africa is a known exporter of subtropical fruit (Fruit South Africa (2020) 2019). The main production areas for subtropical fruit (avocado, litchi and mango) in South Africa are parts of Limpopo, Mpumalanga and KwaZulu-Natal. The South African Subtropical Growers' Association (Subtrop) manages and administers the

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affairs of the South African Avocado Growers' Association (SAAGA), the South African Litchi Growers' Association (SALGA), and the South African Mango Growers' Association (SAMGA). Table 1 gives a summary of the subtropical fruit industry. The planted area is approximately 21,501 ha and the estimated crop value is 2.645 billion. Table 2 gives production statistics for the

three commodities for the past 5 years. The South African avocado industry is export oriented. In 2020, total production was estimated at 132,881 t, of which 60,057 t were exported. The litchi industry is the smallest of the three members of the Subtropical Growers' Association and is also export orientated. South Africa produced 7872 t during the 2020/2021 season of which 4197 t were

**Table 1** Overview of the avocado, litchi and mango industries in South Africa as provided by the South African Subtropical Growers' Association

	Avocado	Litchi	Mango	Total
Number of commercial farmers	± 360	± 100	± 120	± 580
Number of emerging farmers	62	32	78	172
Area planted (2020)	14,7000 ha	1549 ha	5252 ha	21,501 ha
Annual expansion	± 900 ha	± 50 ha	± 100 ha	1050 ha
Annual production	± 125,000 t	± 6000 t	± 75,000 t	± 206,000 t
Annual value (FOB Cape Town + Local)	± R2.06 billion	± R185 million	± R400 million	± 2.645 billion
Employment (seasonal and permanent)	± 11,500	± 2400	± 5000	± 18,900

**Table 2** Production statistics for subtropical fruit (avocado, litchi mango) in South Africa

Avocado production statistics (South African Avocado Growers' Association 2022a)							
Year	Export (tons)	Processing: oil (tons raw product)	Processing: guacamole (tons raw product)	Sales to informal market (tons) (estimated)	National fresh produce markets (tons)	Direct to retailer (tons)	Total (tons)
2016	54,324	6063	9416	20,000	22,770	9470	122,043
2017	41,415	1828	5220	20,000	20,178	12,736	101,377
2018	83,941	8399	9000	20,000	32,723	15,180	169,243
2019	56,218	3763	8060	20,000	24,067	9048	121,156
2020	60,057	6608	7437	20,000	23,787	14,992	132,881
Litchi production statistics (South African Litchi Growers' Association 2022a)							
Year	Export (tons)	Processing (tons)	Sales to informal market (tons) (declared sales)	National fresh produce markets (tons)	Direct to retailer (tons)	Total (tons)	
16/17	3458	3586	87	1307	26	8464	
17/18	4323	5858	95	1322	326	11,924	
18/19	3222	368	93	1302	546	5531	
19/20	2280	757	90	890	347	4365	
20/21	4197	1396	78	1624	576	7872	
Mango production statistics (South African Mango Growers' Association 2022a)							
Year	Export (tons)	Processing: dried (tons)	Processing: achar (tons) (estimated)	Processing: juice (tons)	National fresh produce market (tons)	Direct to retailer (tons)	Total (tons)
15/16	2287	5382	29,000	11,303	13,942	3058	64,972
16/17	4674	14,078	30,000	15,526	27,772	869	92,918
17/18	4497	12,695	30,000	10,087	22,726	1072	81,078
18/19	6039	9906	25,000	15,547	29,655	5956	92,102
19/20	3846	17,218	30,000	9087	22,900	2224	85,275

exported (Table 2). The mango industry processes the biggest part of the crop and small volumes are exported. During the 2019/20 season 85,275 tons were produced and 3846 t were exported. The main export markets are the European Union and the United Kingdom.

Subtropical fruit production is susceptible to various insect pests that significantly contribute to yield losses (Prinsloo and Uys 2015). The subtropical fruit industry is committed to sustainable agriculture. Growers that export fruit have to comply with Good Agricultural Practices (GAP) standards which encourages environmentally sustainable farming practices and minimization of the use of agro-chemicals to benefit growers, retailers and consumers. Pest monitoring is essential and important for compliance with GAP standards. Pesticides used, must be applied according to label directions and the appropriate withdrawal period (time necessary between application of pesticide and harvest) must be followed to avoid residue on the fruit. If a residue level exceeds the set Maximum Residue Level (MRL) the product is not permitted to be sold or exported. The MRL is the maximum concentration of a pesticide residue (expressed as mg/kg) to be legally permitted in or on food commodities and animal feeds. MRLs are based on Good Agricultural Practice (GAP) data (Food and Agriculture Organization of the United Nations 2022a).

The Food and Agriculture Organization (FAO) of the United Nations promotes Integrated Pest Management (IPM) as a pillar of sustainable agriculture. The definition of IPM by the FAO states that 'IPM is the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations. It combines biological, chemical, physical and crop specific (cultural) management strategies and practices to grow healthy crops and minimize the use of pesticides, reducing or minimizing risks posed by pesticides to human health and the environment for sustainable pest management'. Integrated Pest Management emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms (Food and Agriculture Organization 2022b). IPM requires competence in three areas: prevention, monitoring and intervention (Croplife International 2014). Prevention is the use of strategies to prevent pest populations from building up to economically-damaging levels. Protecting natural habitats near orchards is the best way to conserve biodiversity, including many natural enemies of pests. Monitoring involves scouting for pests to determine if intervention should take place. In addition to giving supporting data for making a management decision, regular monitoring is also important for evaluating the success or failure of control strategies. Various

methods of intervention can be used which include chemical, biological, cultural, sanitary and mechanical controls. The effect of intervention methods on both pests and their natural enemies needs to be considered.

To minimize health risks, the European Union (EU) has set MRLs for pesticides in and on food products. Under the European Green Deal, and particularly the new 'chemicals for sustainability', 'farm to fork' and 'biodiversity' strategies, EU legislation on these issues will be revised in the near future (European Commission 2022). These provide new challenges for subtropical fruit growers which have to adjust production practices in response to evolving policies and regulations governing maximum residue levels of pesticides on agricultural products. This can negatively affect growers' costs and access to export markets. This review provides details on the important pests of subtropical crops (avocado, litchi and mango) and progress towards the use of ecologically friendlier management strategies. To give an indication how the industry progressed, Table 3 gives insecticides that were registered for the control of the important pests 20 years ago. Mainly broad-spectrum insecticides (organophosphates and pyrethroids) were registered. Registered products for fruit flies included bait stations, bait sprays using organophosphates and sugar or protein hydrolysate and a cover application with fenthion. Registered products for thrips control included mercaptothion, sulphur, fipronil and methamidophos. Scales were controlled with buprofezin, phenthoate, prothiofos and pyriproxyfen. Beta-cyfluthrin was registered for the control of sucking bugs on avocado. Teflubenzuron and triflumuron were registered for litchi moth control on litchi. Registered products for weevil control on mango were deltamethrin, esfenvalerate, fenthion and triflumuron. During that time, efforts were already made to use more environmentally friendly control methods (Joubert et al. 2000, 2004, Bruwer 2001, 2006).

#### **Avocado production in South Africa**

Avocado production in South Africa has traditionally been concentrated in the warm subtropical areas of Limpopo and Mpumalanga. Currently, production is expanding into KwaZulu-Natal and the Eastern and Western Cape (South African Avocado Growers' Association 2022b). The majority of fruit is harvested from March to September. Dark-skinned 'Hass' and 'Hass'-type cultivars such as 'Carmen', 'GEM<sup>®</sup>', 'Lamb-Hass' and 'Maluma' are the important cultivars currently being planted.

#### **Avocado pests**

Damage to avocado fruits by insect pests in South Africa has been well documented (De Villiers et al. 2015). The damage caused by insect pests is one of the primary

**Table 3** Insecticides registered against important pests on Avocado, Litchi and Mango during 2002 (Nel et al. 2002)

Pest	Pesticide, formulation, active ingredient	Chemical group <sup>a</sup>
Avocado		
Fruit flies	Alpha-cypermethrin/protein hydrolysate RB 0.01/5 g/bait station	Sodium channel modulators pyrethroids
	Mercaptothion EC 500 g/l and sugar or protein hydrolysate	Acetylcholinesterase (AChE) inhibitors
	Mercaptothion WP 250 g/kg and sugar or protein hydrolysate	organophosphates
	Trichlorfon SP 950 g/kg and sugar or protein hydrolysate	Acetylcholinesterase (AChE) inhibitors
		organophosphates
Fruit sucking bug	beta-cyfluthrin EC 50 g/l	Sodium channel modulators pyrethroids
Heart shaped scale	Buprofezin WP 500 g/kg	Inhibitors of chitin biosynthesis, type 1 growth regulation
Thrips	Mercaptothion EC 500 g/l	Acetylcholinesterase (AChE) inhibitors
	Mercaptothion WP 250 g/kg	organophosphates
	Sulphur WP 980 g/kg	
	Sulphur WG 800 g/kg	
	Sulphur WP 800 g/kg	
Litchi		
Pest	Pesticide, formulation, active ingredient	Chemical group <sup>a</sup>
Fruit flies	Alpha-cypermethrin/protein hydrolysate RB 0.01/5 g/bait station	Sodium channel modulators pyrethroids
	Mercaptothion EC 500 g/l and sugar or protein hydrolysate	Acetylcholinesterase (AChE) inhibitors
	Mercaptothion WP 250 g/kg and sugar or protein hydrolysate	organophosphates
	Trichlorfon SP 950 g/kg and sugar or protein hydrolysate	Acetylcholinesterase (AChE) inhibitors
		organophosphates
Litchi moth	Teflubenzuron SC 150 g/l	Inhibitors of chitin biosynthesis affecting CHS1 benzoylureas
	Triflumuron SC 480 g/l	Inhibitors of chitin biosynthesis affecting CHS1 benzoylureas
Mango		
Pest	Pesticide, formulation, active ingredient	Chemical group <sup>a</sup>
Fruit flies	Fenthion EC 500 g/l	Acetylcholinesterase (AChE) inhibitors
		organophosphates
	Alpha-cypermethrin/protein hydrolysate RB 0.01/5 g/bait station	Sodium channel modulators pyrethroids
	Mercaptothion EC 500 g/l and sugar or protein hydrolysate	Acetylcholinesterase (AChE) inhibitors
	Mercaptothion WP 250 g/kg and sugar or protein hydrolysate	organophosphates
	Trichlorfon SP 950 g/kg and sugar or protein hydrolysate	Acetylcholinesterase (AChE) inhibitors
		organophosphates
Scale	Mineral oil (light narrow) EC 790 g/l	
	Phenthoate EC 500 g/l	Acetylcholinesterase (AChE) inhibitors
		organophosphates
	Prothiofos EC 960 g/l	Acetylcholinesterase (AChE) inhibitors
		organophosphates
	Pyriproxyfen EC 100 g/l	Juvenile hormone mimics growth regulation
Thrips	Fipronil SC 200 g/l	GABA-gated chloride channel blockers phenylpyrazoles
	Methamidophos AL 500 g/l (non-bearing trees)	Acetylcholinesterase (AChE) inhibitors
		organophosphates
Weevil	Deltamethrin EC 25 g/l	Sodium channel modulators pyrethroids
	Esfenvalerate EC 50 g/l	Sodium channel modulators
	Esfenvalerate EC 200 g/l	pyrethroids
	Fenvalerate EC 200 g/l	Sodium channel modulators pyrethroids
	Fenthion EC 500 g/l	Acetylcholinesterase (AChE) inhibitors
		organophosphates
	Triflumuron SC 480 g/l	Inhibitors of chitin biosynthesis affecting CHS1 benzoylureas

<sup>a</sup> Classification according to Insecticide Resistance Action Committee (<https://irac-online.org/>)

factors leading to reduced production. A packhouse survey conducted in Mpumalanga in 1991, showed that 12.66% of fruit examined had insect damage. The estimated loss to the South African avocado industry was estimated at R 2.93 million per annum at that stage (Erichsen and Schoeman 1992). In 2019 the percentage loss of avocado fruit due to insect pests was determined at 12.58% according to the South African Subtropical Growers' Association. The important insects are the sucking bug complex (Hemiptera: Heteroptera), scale insects (Hemiptera: Coccoidea), thrips (Thysanoptera: Thripidae), the false codling moth, *Thaumatotibia leucotreta* (Meyrick) (Lepidoptera: Tortricidae) and fruit flies (Diptera: Tephritidae). To avoid losses and to make informed decisions on intervention, various methods are used for the monitoring of avocado pests (Schoeman 2020).

#### Sucking bug (Heteroptera) complex

The sucking bug pest complex is one of the most important pest complexes of avocado. The estimate loss for the avocado industry due to the stink bug complex was estimated at R 6.3 million in 2016 (Nortjé et al. 2017). This complex includes the avocado bug (*Taylorilygus* spp.) (Hemiptera: Miridae), various stink bug species (Hemiptera: Pentatomidae) and various Coreidae including the coconut bug, *Pseudotheraptus wayi* Brown (Schoeman 2014, Schoeman and Botha 2015).

The avocado bug is present in most orchards and is the most damaging heteropteran after the coconut bug (De Villiers et al. 2015). Adults and nymphs of the avocado bug feed on flowers and young fruit. Damage to the flowers is minimal, due to the large number of flowers produced. Fruit are damaged soon after fruit set and white sugary exudates can be seen at the feeding sites. Feeding on the young fruit leads to the development of protrusions on the fruit. To monitor the pest, a sequential sampling technique using a beating tray was developed. The use of coloured sticky traps is also an effective technique to monitor the avocado bug (Alberts 2009). No natural enemies have yet been identified that contribute to the natural control of the pest.

During 1991 the loss of avocado fruit due to the coconut bug in South Africa amounted approximately R 1.37 million (Erichsen and Schoeman 1992). According to Van Der Meulen and Schoeman (1994) damage in unsprayed orchards ranged from 1.7% on aborted fruit to 76.02% on ripe fruit, with means of 6.6% damage on aborted fruit and 15.9% on harvested fruit. Damage to avocado is caused by both adults and nymphs as they extract sap from the fruit. Internal lesions are formed and fruit malformation can also occur due to the feeding. The monitoring of coconut bug and other stink bugs remains

problematic. These insects are heterogeneously distributed and the only detection method is to search for damaged fruit. Soft options and natural products were evaluated for sucking bugs (Bruwer 2006) but were not registered at that time due to high numbers of damaged fruit when compared with acephate and beta-cyfluthrin. Acephate, beta-cyfluthrin and pymetrozine are insecticides registered for control of the fruit-sucking bug complex, and the industry is currently under pressure to find alternatives. Beta-cyfluthrin and pymetrozine may not be approved for use by some supermarkets in the EU and the EU MRL for pymetrozine was lowered. Pruning has a drastic effect on the incidence of stink bugs, and optimizes the penetration and coverage of sprays applied (Schoeman 2016, 2017). The Entomopathogenic fungus (*Beauveria bassiana* strain PPRI 5339) were tested for control of the complex, but results were inconclusive as the trial was ongoing (Schoeman 2017).

#### Scales and mealybugs

Scales and mealybugs are normally naturally controlled, but heavy infestations are sporadically observed and sometimes occur due to the use of broad-spectrum insecticides. Broad-spectrum insecticide application may negatively affect natural enemy communities and may cause secondary pest outbreaks (Hill et al. 2017). The heart-shaped scale, *Protopulvinaria pyriformis* (Cockerell) (Hemiptera: Coccidae) is a soft scale that feeds on the undersides of leaves. Excessive quantities of honeydew are secreted on which sooty mould develops which results in the staining of fruit and leaves (De Villiers et al. 2015). Photosynthesis is compromised, which may lead to crop reduction and heavy infestation may cause leaf drop. Various natural enemies play an important role in natural control of the heart-shaped scale. The following Hymenopteran parasitoids of heart-shaped scale were recorded from avocado in South Africa: *Metaphycus galbus* Annecke (Hymenoptera: Encyrtidae), *Metaphycus helvolus* (Compere), *Metaphycus stanleyi* (Compere), a *Tetrastichus* sp. (Encyrtidae), *Coccophagus basalis* (Aphelinidae) and *Coccophagus pulvinariae* (Du Toit et al. 1991, De Villiers et al. 2015). The *Metaphycus* species were the dominant parasitoids during late summer and autumn, but were succeeded in winter by *Coccophagus* and *Tetrastichus*. Predators include the Coccinellidae beetles (Coleoptera), *Chilocorus angolensis* Crotch and *Hyperaspis senegalensis hottentotta* Musant. An unidentified Cecidomyiidae fly (Diptera) and a Chrysopidae larva (Neuroptera) also occasionally fed on the scale. Dust interferes with effective parasitism and it is advised that dust on dirt rows alongside avocado orchards be reduced to prevent the build-up of the scale population. Buprofezin and Spirotetramat are registered for control



of heart-shaped scale. An alternative to chemical intervention is the use of a predatory beetle, *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae), which is a natural enemy of the heart-shaped scale and can be obtained in South Africa from Koppert and BioBee.

Avocado scale or palm fiorinia scale, *Fiorinia fioriniae* (Targioni Tozzetti) (Hemiptera: Diaspididae) infests avocado leaves and fruit, affecting marketability (De Villiers et al. 2015). The scale usually occurs on the undersides of the leaves, especially along leaf veins. The pest causes chlorosis of the leaf tissues at the feeding sites, by injecting toxic saliva while feeding. Small brown spots develop where nymphs feed. In South Africa, avocado scale is regarded as a minor pest of avocado. However, severe outbreaks have been observed occasionally. No insecticide is registered for control of the pest and the natural enemy complex has not been studied in South Africa. The palm scale, *Hemiberlesia lataniae* (Signoret) (Hemiptera: Diaspididae) also occurs in avocado orchards where it attacks branches, twigs, leaves and fruit. Various parasitic wasps and predatory beetles have been recorded in southern Africa which normally keep the pest in check (De Villiers et al. 2015). The long-tailed mealybug *Pseudococcus longispinus* (Targioni Tozzetti) (Hemiptera: Pseudococcidae) is also present in avocado orchards and various parasitic wasps acting as natural enemies keep this pest under control (Prinsloo and Uys 2015).

### Thrips

Two species of thrips (Thysanoptera: Thripidae) are documented as causing damage to avocado, i.e. the black tea thrips, *Heliothrips haemorrhoidalis* (Bouché), and the redbanded thrips, *Selenothrips rubrocinctus* (Giard) (De Villiers et al. 2015). The above mentioned thrips species accounted for a loss of 1.51% of fruit during 1991 (Erichsen and Schoeman 1992). These pests feed on the leaves and fruits causing extensive browning of plant tissue, thus interfering with the physiology of the affected plant. Distinctive blackish spots of excreta are also present on damaged areas. These thrips are sporadic pests on avocado fruit. Various naturally occurring enemies contribute to the control of the above mentioned thrips. A predatory anthocorid bug (Hemiptera), *Orius tripoburus* (Hesse) and the parasitic wasp, *Thripobius javae* (Girault) (Hymenoptera: Eulophidae) were recorded as natural enemies to the black tea thrips. Over the past few years the South African citrus tea thrips, *Scirtothrips aurantii* Faure (Thripidae) became troublesome in avocado orchards and showed an infestation index of 4.82% in KwaZulu-Natal (Bara 2019). The thrips cause scarring damage, making the fruit unsuitable for export. Thrips management is complicated because of the multiple and protracted flowering patterns. Fruit are susceptible to infestation when

young and prolonged flowering result in continuous supply of young fruit for population build-up. In addition, widespread pesticide resistance of thrips, and the negative environmental effects along with minimum residue levels for export fruit, limit the application of pesticides for thrips control. Yellow sticky cards are recommended as a monitoring tool (Bara and Laing 2020). In addition, fruit inspection can be done. As the fruit becomes larger, they are less susceptible. Various natural enemies have been recorded for citrus thrips, which include predatory phytoseiid mites, a predatory anthocorid, predatory thrips, predatory lacewings (Neuroptera: Chrysopidae) and a parasitoid (Hymenoptera: Eulophidae) (Grout and Moore 2015). Insecticides registered include abamectin in combination with mineral oil, spinetoram, various formulations of sulphur and *Metarhizium anisopliae*, a biological control product (South African Avocado Growers Association 2022c). Biological control agents are available from Koppert and BioBee, which include predatory bugs and predatory mites. The industry is currently evaluating more options for intervention that include the use of predatory mites, entomopathogenic nematodes and entomopathogenic fungi.

### False codling moth

The false codling moth is native to South Africa and a significant pest of fruit trees and field crops, and also attacks avocado (Grové et al. 2010). The pest is regarded as a major phytosanitary threat when it occurs in commodities exported to countries where it is absent and can possibly become established. A survey conducted in the Mpumalanga during 1991 indicated that the false codling moth was responsible for 1.32% damage (Erichsen and Schoeman 1992). During 2002 and 2006 a survey conducted on 'Hass' determined that infestation was between 0 and 3.6% in Mpumalanga and Limpopo (Grové et al. 2010). Avocado fruit are susceptible to damage from early in the season until harvest. Female moths lay eggs on the fruit and newly hatched larvae penetrate into the fruit and cause lesions. The avocado fruit is not considered a good host for the development of larvae and larvae do not develop to maturity in fruit on the tree (Grové et al. 2010). Penetration of larvae is superficial and larvae are predominantly found in the area just below the skin. Various natural enemies in orchards play an important role in suppressing this pest. The small egg parasitoid, *Trichogrammatoidea cryptophlebiae* (Trichogrammatidae) is an important natural enemy in South Africa. There are also several species of larval parasitoids that play a role in suppression (Moore 2021). Entomopathogenic nematodes and virus species also reduce populations. Adult male moths can be monitored using pheromone-based trapping and fruit can be inspected for

lesions. Registered products for control on South African avocados include: granuloviruses; the fungus, *Beauveria bassiana*; the insecticides chlorantraniliprole, spinetoram and methoxyfenozide; and mating disruption products (South African Avocado Growers' Association 2022c). The egg parasitoid can be obtained from Vital Bugs, BioBee and Koppert in South Africa. The Sterile Insect Technique for false codling moth has been commercially implemented in the citrus and table grapes industries, but not yet in subtropical orchards (Moore 2021). The use of entomopathogenic nematodes for controlling false codling moth was evaluated in subtropical fruit orchards and showed potential in managing the pest (Steyn et al. 2017, 2019) but has not been implemented yet as commercial production of a native species has not been optimised at the time of writing.

### Fruit flies

In South Africa, the Mediterranean fruit fly, *Ceratitidis capitata* (Wiedemann) (Diptera: Tephritidae), the Marula fruit fly, *Ceratitidis cosyra* (Walker), the Natal fruit fly, *Ceratitidis rosa* Karsch and the Cape fruit fly, *Ceratitidis quilicii* De Meyer, Mwatawala and Virgilio are four fruit fly species associated with avocado production (Grové and De Beer 2019). The Natal fruit fly was split into two species and the Cape fruit fly was described as a new species (De Meyer et al. 2015; 2016). All the above-mentioned fruit flies are indigenous to South Africa. The Mediterranean fruit fly is considered to be of lesser importance and numbers are usually lower in orchards in comparison with the other *Ceratitidis* spp. (Grové 2017, 2018, Grové and De Beer 2019). The Oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Tephritidae), was reported for the first time in South Africa in 2010 in the northern part of the country (Manrakhan et al. 2011). The Oriental fruit fly is an invasive species of Asian origin and still has limited distribution in South Africa. Some provinces are still pest free. Producers have to apply for a removal permit from the Department of Agriculture, Land Reform and Rural Development if moving host fruit from an area where Oriental fruit fly is present, to an area which is pest free. The avocado is a climacteric fruit that ripens after harvest. Some fruit fly species are not able to penetrate the hard exocarp of avocado fruit with their ovipositor and therefore can not lay eggs inside the fruit. (De Graaf 2009; Ware et al. 2016). The avocado is also not a good host for the development of fruit fly species and, under normal orchard practices, no larval development takes place in fruit on the tree (De Graaf 2009; Ware et al. 2016). A survey conducted in the Limpopo province during 2016 and 2017 indicated that percentage fruit with fruit fly lesions varied between 0 and 2% and no live larvae were found in fruit sampled from the trees (Grové 2017, 2018).

Various traps and lures are available for monitoring fruit flies (Joubert et al. 2015). Bait sprays containing spinosad and M3 $\alpha$  bait stations can be used for the suppression of fruit flies. Various products containing methyl eugenol and insecticides are registered to attract and kill males of the Oriental fruit fly (South African Avocado Growers' Association 2022c). Invasive host plants that serve as a breeding ground and source of fruit flies must be eradicated when found in the vicinity of the orchards. Wild growing guava is an example of a weed that acts as a host of fruit flies in South Africa. Various parasitoids of fruit flies have been identified in South Africa (Harran et al. 2019). Parasitoids and predators that can contribute to the suppression of fruit flies are present in fruit agroecosystems. Efforts to conserve natural enemies in commercial orchards through more efficient management may contribute to the overall suppression of fruit flies. Currently, efforts are being made to import the parasitic wasp, *Fopius arisanus* (Sonan) (Hymenoptera: Braconidae), which is an egg-larval parasitoid used in control programmes of the Oriental fruit fly.

### Litchi production in South Africa

The main production regions are located in the frost-free areas of Mpumalanga and Limpopo in the north of the country. In Mpumalanga, 67% (1034 ha) of litchis are produced followed by Limpopo with 28% (441 ha) of South African plantings. KwaZulu-Natal makes up 5% of the industry (73 ha). The most important cultivar is 'Mauritius', followed by 'McLeans Red' (South African Litchi Growers' Association 2022b). Litchi fruit are harvested from October to February in South Africa.

### Litchi pests

Fruit flies, moth pests and stinkbugs (Hemiptera: Pentatomidae and Coreidae) are important for litchi production, and other pests are considered of minor importance (Grové et al. 2014, 2015).

### Moths

The litchi moth, *Cryptophlebia peltastica* (Meyrick) (Lepidoptera: Tortricidae) and the false codling moth are two important pests of litchi production in South Africa (Grové et al. 2014, 2015). The damage caused by both moths is similar. The female moths lay eggs singly on the surface of the litchi fruit. The rate of oviposition is low during early stages of fruit development, but increases as the fruit colours to red and starts to ripen. The neonate larva finds a place to penetrate the litchi fruit and feeds its way through the fruit flesh and into the seed. Larval activity is detected by the presence of granular excreta on the fruit surface. More damage is caused by *C. peltastica* in comparison with *T. leucotreta*. Litchi fruit were

sampled from the 2009/2010 season to the 2012/2013 season in various production areas in Limpopo and Mpumalanga. The mean percentages of fruit infested with larvae for the three seasons were 1.7; 0.8 and 0.01. The highest infestation rate recorded was 13.1% (Grové and De Beer 2017a). In addition to the damage caused by these moths, both are considered pests of quarantine importance by some countries.

Moth species can be monitored using parapheromones in litchi orchards (Grové and De Beer 2005). In the past, two chitin synthetic inhibitors, viz. teflubenzuron and triflumuron, were used to control litchi moth and false codling moth. Registered products for control of false codling moth on South African litchis include: a granulovirus; two products containing the fungus, *Beauveria bassiana*; the insecticides chlorantraniliprole and methoxyfenozide; and four mating disruption products; and one attract and kill product (South African Litchi Growers' Association 2022c). A nucleopolyhedrovirus of litchi moth was discovered (Marsberg et al. 2018) and will likely be commercialized for the industry. Moth eggs on litchi were parasitized by a *Trichogrammatoidea* sp. (Hymenoptera: Trichogrammatidae) (Newton and Crause, 1990). According to Newton and Crause (1990), augmentative releases of trichogrammatid egg parasitoids early in the season may present an alternative to chemical control of moth species. On litchi, paper bags offer protection against moths and other pests. Bags must be tied around fruit clusters after the November drop. The bags should remain around the fruit until harvest. However, this method is very labour intensive and not practical on a large scale.

#### Fruit flies

Fruit fly species that are important for litchi production include the Mediterranean fruit fly, the Cape/Natal fruit fly complex and the Oriental fruit fly (Grové and De Beer 2014). The females lay eggs under the skin of the fruit by inserting their ovipositors which puncture the fruit creating oviposition holes through which pathogens enter the fruit and cause massive deterioration. However, the litchi is a poor host of the fruit flies and rarely allows completion of the life cycle. Fruit fly numbers are usually very low during the beginning of the fruiting period and increase as the fruit colour and mature (Grové and De Beer 2014). Monitoring and control strategies used for fruit flies are the same as those described for avocado (South African Litchi Growers' Association 2022c).

#### Stinkbugs

The coconut bug has piercing and sucking mouthparts and causes fruit drop of young fruit and necrotic lesions (Schoeman 2010). Both nymphs and adults feed on the

fruit. A survey conducted in 2007 indicated that 20.83% of aborted litchi fruit was affected by the coconut bug. Small fruit abort relatively soon after being stung while stung mature fruit usually do not drop. A study conducted by Schoeman and Morey (2016) indicated that the coconut stink bug was not the dominant stink bug on litchi but rather *Coenomorpha nervosa* Dallas (Hemiptera: Pentatomidae) and *Pseudatelus raptorius* (Germar) (Hemiptera: Pentatomidae) which represented nearly 80% of the individual insects that were recovered. Damage previously ascribed to the coconut bug may actually be caused by *C. nervosa* and possibly *P. raptorius*. When feeding on mature litchi fruit, very little damage is done to the fruit flesh and most of the feeding takes place in the seed. No insecticides are registered for the control of the stinkbugs. Another problem is the lack of an effective monitoring system for adults, and it is difficult to observe the pest in the orchard as the adults are elusive. Radzilani et al. (2014) investigated the use of trap crops and concluded that trap crops can solve the monitoring dilemma. *Anastatus* sp. (Hymenoptera: Eupelmidae) and a *Trissolcus* sp. (Hymenoptera: Scelionidae) are egg parasitoids identified of coconut bug in South Africa (Bruwer 1992).

#### Mango production in South Africa

The most important production area is Hoedspruit, making up 44% of the total with 2 325 ha (South African Mango Growers' Association 2022b). Letaba is second with 1 128 ha (22%) followed by Nkomazi with 785 ha (15%). Most growers top work old trees to new cultivars rather than plant new orchards, resulting in the industry size remaining unchanged, unlike with other industries that are expanding. The majority of mango fruit is harvested from November to February. 'Tommy Atkins' is an important commercial cultivar.

#### Mango pests

Various insect pests are of importance for mango production (Grové et al. 2015a, b; Grové and De Beer 2017b). The important pests are: fruit flies; the mango seed weevil, *Sternonchetus mangiferae* (Fabricius) (Coleoptera: Curculionidae); the mango scale, *Aulacaspis tubercularis* (Newstead) (Hemiptera: Diaspididae); the citrus thrips; the mango gall fly, *Procontarinia matteiana* Kieffer and Cecconi (Diptera: Cecidomyiidae); the African bollworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae); and the coconut bug. Other pests of minor importance are also found on mango.

#### Mango seed weevil

The mango seed weevil is an important pest and the economic impact is primarily based on the fact that it is a major phytosanitary pest, restricting access to new



foreign markets and contributing to substantial rejections of fruit destined for existing export countries (Louw 2013; Grové et al. 2015a, b). A study conducted over two seasons in Limpopo indicated that 39.86% and 23.64% of ‘Tommy Atkins’ fruit were infested with mango weevil eggs if uncontrolled (De Graaf 2010). Adult weevils are nocturnal and eggs are laid on the fruit. The larvae burrow through the pulp to the seed and develop inside the seed. The entry burrows disappear as the fruit grows, and the larvae excavate cavities within the seeds and pupate. The flesh of ripe fruit is damaged when the adult emerges, leaving an unattractive hole. However, many fruits are consumed without any awareness of weevils in the seed. Adult weevils become reproductively active when mango flowers begin to bloom. The eggs are laid on the green fruit, and the majority are laid between September to November (Louw 2013). The eggs are covered with a brownish exudate and an incision is usually made at the top allowing the latex to cover the egg. Chemical control is required for fruit that is destined for export. Various insecticides are registered for control. A systemic neo-nicotinoid, thiamethoxam applied as a soil drench during flowering is effective under South African conditions but can no longer be used on export fruit due to the lowering of the MRL (Louw et al. 2009). The use of kaolin alone and in combination with sulphur and lime sulphur were effective against mango seed weevil (Joubert et al. 2004). However, kaolin led to mango scale and long-tailed mealybug, *Pseudococcus longispinus* (Targioni Tozzetti) (Hemiptera: Pseudococcidae) repercussions, which was lowered when using the product in combination with sulphur. The mango industry is currently evaluating alternative products. As there are no known alternative host plants of the mango weevil, regular orchard sanitation is an extremely important component of the control strategy.

#### Fruit flies

In South Africa, four *Ceratitis* species are known to attack mango, i.e. Mediterranean fruit fly, the Marula fruit fly, the Cape fruit fly and the Natal fruit fly (Grové and De Beer 2017b). The invasive Oriental fruit fly is also present in the main mango production areas. Damage begins when females puncture the skin of fruit and lay eggs underneath it. Decay is caused by the larvae feeding on the flesh of the fruit, which renders the fruit unmarketable. Losses are also indirect due to quarantine restrictions and loss of market opportunities. Mango fruit destined for the EU is produced under a systems approach for fruit flies to comply with EU regulations. Monitoring of fruit flies is also very important for mango production. Fruit fly numbers are suppressed by the use of the bait application technique in the form of bait

sprays or bait stations. Bait sprays and bait stations suppress *Ceratitis* fruit flies as well as the Oriental fruit fly. The male annihilation technique involves the attraction and killing of male fruit flies using a high density of bait stations or substrates consisting of a male lure combined with an insecticide to reduce the male population to such a low level that mating does not occur. In production areas where the Oriental fruit fly is present, producers use the male annihilation technique in combination with the bait application technique and orchard sanitation. The male annihilation technique can also be used against *Ceratitis* species and the product Last Call™ F.F. is registered and contains enriched ginger oil as an attractant. Orchard sanitation, a cultural method of control, is also a very important way to suppress fruit fly numbers. Mango fruit are usually not infested during the early fruiting period, but are markedly more prone to attack closer to harvest. Fruit flies can lay eggs in green fruit, but it is more likely that ripe fruit will be infested. Harvesting fruit at the mature green stage rather than leaving fruit to ripen on the tree will contribute towards avoiding high levels of infestation (Grové et al. 2009).

#### Mango scale

The most important scale on mango in South Africa is the mango scale (Grové et al. 2013). The scale is prominent on mango leaves but also feeds on mango twigs, branches and fruit. Heavy infestations on leaves cause yellowing or die-back of the leaves and on infested fruit, pink or yellow blemishes develop. Infestations of young trees can suffer from leaf loss and twig die-back. Migration of scale from leaves and twigs to fruit usually occurs in spring. On late cultivars, the scale is of greater economic importance because crawlers that move to the fruit can produce another generation before harvest. The mean fruit infestation of the late cultivar, ‘Keitt’ was 62.08% in a survey conducted in Mpumalanga and Limpopo (Grové et al. 2013). An indigenous parasitic wasp *Encarsia citrina* (Craw) (Hymenoptera: Aphelinidae), two predatory ladybird beetles, viz. *Chilocorus nigrinus* (F.) (Coccinellidae) and *Rhyzobius lophantae* (Blaisdell) (Coccinellidae) and a predatory thrips, *Aleurodothrips fasciapennis* (Franklin) (Thysanoptera: Phlaeothripidae) are natural enemies of the scale (Grové et al. 2015a, b). The larvae of the family Cecidomyiidae (Diptera) and lacewing larvae have also been documented. Two natural enemies, i.e. a parasitic wasp, *Aphytis chionaspis* Ren of the family Aphelinidae and a predatory beetle, *Cybocephalus binotatus* Grouvelle (Coleoptera: Cybocephalidae) were imported from Thailand during 1995 and successfully established (Daneel and Joubert 2009). Since biological control is easily disrupted by chemical sprays, it is important to implement an integrated pest management

programme by making use of selective and not broad-spectrum insecticides. Various insecticides are registered for control of mango scale (South African Mango Growers' Association 2022c).

### Thrips

The most important thrips species on mango is the South African citrus thrips (Grové and De Beer 2017b). The larvae and adults cause damage by feeding on small fruit and causing blemishes on the rind. When the fruit are small and high numbers are present, the entire fruit surface may be damaged and may also cause fruit drop. Fruit with lesions are not suitable for export. Leaf malformation and stunting of new growth are also caused. The citrus thrips numbers increase during periods of vegetative growth and when fruit are small. High numbers are present on fruit from fruit set until fruit are 50 mm in length. Fruit can be inspected visually to determine population levels, in which case both adults and nymphs are counted. Yellow sticky card traps can also be used for assessing adult levels in mango orchards. Treatment levels based on fruit counts or monitoring with yellow sticky traps have been established (Grové et al. 2000). Fipronil is the only registered insecticide and the industry is currently evaluating alternative insecticides and biological control products. Fipronil tends to cause scale and mealybug repercussions (Joubert et al. 2004). The use of kaolin alone and in combination with sulphur and lime sulphur proved to be effective against citrus thrips (Joubert et al. 2004).

### Mango gall fly

The mango gall fly causes galls on leaves and heavy infestations can lead to deformation of the leaves and even to leaf drop (Grové et al. 2015a, b). Galls on mango leaves have been found to be associated with both anthracnose and bacterial black spot. Different cultivars show differences in susceptibility to gall fly (Augustyn et al. 2010). Eggs are laid on the leaves and only new growth is attacked. The newly hatched larva bores into the leaf tissue on which it feeds and induces a small wart-like gall that appears on the leaf about two weeks after the egg is laid. Pupation takes place within the gall. The adults live for only a day and do not feed. There are two generations per year. Generally, larvae are found in the galls during the winter months, whereas both larvae and pupae are present during the rest of the year. The flushes that appear after harvest are usually very heavily infested in susceptible cultivars. The larvae of gall fly are sometimes heavily parasitized by *Closterocerus pulcherrimus* (Kerrich) (Eulophidae), a minute parasitic wasp. No insecticides are currently registered for control but trials are being conducted to evaluate insecticides (Louw

2021). Pruning after harvest and the removal of infested branches are recommended to reduce gall fly infestation.

### African bollworm

The African bollworm is a highly polyphagous and a destructive pest that attacks many cultivated crops in South Africa, including the mango (Grové and De Beer 2017b). African bollworm is a noctuid moth and the larvae feed on young leaves, flowers and young fruit and affect yield. The bollworm causes superficial scars to deep holes in the fruit and seriously damaged fruit drop prematurely. Monitoring for African bollworm is best accomplished through scouting for eggs and larvae on mango inflorescences and young fruit. This pest sometimes warrants the use of insecticide for control. Three *Helicoverpa armigera* nucleopolyhedroviruses are registered for biological reduction of the pest (South African Mango Growers Association 2022c). Numerous indigenous parasitoids, mainly tachinid flies and parasitic wasps, together with predators attack the African bollworm in South Africa (Bennett 2015).

### Coconut bug

The coconut bug has pierce-sucking mouthparts that extracts plant sap. The bug attacks young mango fruit and feeding damage can be seen as watery spots on the fruit that later darken and a dent occurs (Grové and De Beer 2017b). Affected fruit usually drop off. Lesions are usually near the fruit stem. The eggs are laid singly on fruit, twigs and flower stems. The adults are elusive, well camouflaged and difficult to observe in orchards. Kaolin alone and in combination with sulphur and lime sulphur can be used against coconut bugs on mango (Joubert et al. 2004). No insecticide is registered for control of the coconut bug.

### Conclusion

Subtropical fruit growers in South Africa are encouraged to use an IPM strategy in order to produce a healthy and safe crop with the least possible disruption to agro-ecosystems. If insecticide application is needed, it is important to take the characteristics, applications and costs of insecticide into consideration. Select the one that provide the most cost-effective treatment with minimal undesirable effects. More selective insecticides can be used opposed to insecticides with a broad-spectrum activity. Selective insecticides that only target a few types of pests are less likely to affect non-target organisms (Croplife International 2014). Insecticides application can cause the development of resistance by pests and cause problems with residues on fruit and in the environment. To minimize the reliance on insecticides is the best solution for a healthy environment. The lowering of MRLs in

**Table 4** Eco-friendly pest management options than can be used for the suppression of important pests on avocado, litchi and mango in South Africa

Host plant	Pest species	Eco-friendly pest management options	References
Avocado	African bollworm	1. Registered products <i>Helicoverpa armigera</i> Nucleopolyhedrovirus (HaNPV) (Bolldex <sup>®</sup> , Graboll)	(South African Avocado Growers' Association 2022c)
Avocado	False codling moth	1. Registered products <i>Cryptophlebia leucotreta</i> granulovirus (Cryptex <sup>®</sup> , Cryptogran <sup>™</sup> ) <i>Beauveria bassiana</i> (Eco-Bb) Mating disruption (CheckMate FCM-F, Isomate <sup>®</sup> FCM, RB Splat FCM, X-Mate <sup>™</sup> FCM) 2. Parasitoid <i>Trichogrammatoidea cryptophlebiae</i> (BioTrichogramma, Tri-mX <sup>®</sup> , Tripar-C) 3. Sanitation 4. Sterile Insect Technique (Xsit FCM SIT)	(Moore 2021; South African Avocado Growers' Association 2022c; Website BioBee, Website Koppert; Website; Vital Bugs; Website X Sterile Insect Technique (Pty) Ltd)
Avocado	Fruit flies	1. Registered products Bait spray (GF-120 <sup>™</sup> NF) <sup>1</sup> Bait stations (M3a Fruit Fly Bait Station <sup>2</sup> ) Male annihilation technique for <i>Bactrocera dorsalis</i> (Invader-b-Lok <sup>™3</sup> Static Spinosad ME <sup>4</sup> , Bi-ME mat blocks <sup>3</sup> ) 2. Sanitation	(South African Avocado Growers Association 2022c)
Avocado	Mealybugs	1. Parasitoids <i>Anagyrus vladimiri</i> (BioAnagyrus, Citripar) <i>Coccidoxenoides perminutus</i> (BioPerminutus, Permipar, Per-mX <sup>®</sup> ) 2. Predators <i>Cryptolaemus montrouzieri</i> (BioCryptolaemus, Cryptobug, Cryptobug-L) <i>Nephus bipunctatus</i> (BioNephus) <i>Nephus</i> sp. (Nephubug)	(Website BioBee, Website Koppert, Website Vital Bugs)
Avocado	Scale	1. Parasitoid <i>Aphytis melinus</i> (Aphytis, BioAphytis) 2. Predator <i>Cryptolaemus montrouzieri</i> (BioCryptolaemus, Cryptobug, Cryptobug-L)	(Website BioBee; Website Koppert)
Avocado	Thrips	1. Registered products Sulphur (Buster 800 WDG, Cosavet, Dusting Sulphur, Eco Fungimite, Flowable Sulphur, Kumulus WG, Microthiol Special, Saffron, Striker, SunFlo 800 SC, Sulfoman, Sulfo-maxx, Sulphur 800 WDG, SulfoPlus, Sulfostar, ThiovitJet, Wetttable Sulphur) Fungus, <i>Metarhizium anisopliae</i> (Real Metarhizium 69) 2. Predators <i>Amblydromalus limonicus</i> (Limonica) <i>Amblyseius swirskii</i> (Swirski-Mite, Swirski-Mite LD, Swirski-Mite Plus, Swirski Ulti-Mite) <i>Macrocheles robustulus</i> (Macro-Mite) <i>Neoseiulus cucumeris</i> (Thripex, Thripex-Plus) <i>Orius</i> sp. (BioOrius) <i>Orius</i> sp. + BioArtFeed (premium Artemia cysts) (BioOrius Combo) <i>Orius laevigatus</i> (Thripor-L)	South African Avocado Growers Association 2022c; Website BioBee; Website Koppert)
Litchi	African Bollworm	1. Registered products <i>Helicoverpa armigera</i> nucleopolyhedrovirus (HaNPV) (Graboll, Bolldex <sup>®</sup> )	(South African Litchi Growers' Association 2022c)

**Table 4** (continued)

Host plant	Pest species	Eco-friendly pest management options	References
Litchi	False codling moth	1. Registered products <i>Beauveria bassiana</i> (strain PPRI 5339) (BroadBand) <i>Beauveria bassiana</i> (Eco-Bb) <i>Cryptophlebia leucotreta</i> granulovirus (CrLeGV-SA) (Cryptogran™) Mating disruption (CheckMate FCM-F, Isomate® FCM, RB Splat FCM, X-Mate™ FCM) 2. Parasitoid <i>Trichogrammatoidea cryptophlebiae</i> (BioTrichogramma, Tri-mX®, Tripar-C) 3. Sterile Insect Technique (Xsit FCM SIT)	(Moore 2021; South African Litchi Growers' Association 2022c; Website BioBee; Website Koppert; Website Vital Bugs; Website Sterile Insect Technique (Pty) Ltd)
Litchi	Fruit flies	1. Registered products Bait spray (GF-120™ NF) Bait stations (M3a Fruit Fly Bait Station) Male annihilation technique for <i>Bactrocera dorsalis</i> (Invader-b-Lok™, Bi-ME mat blocks, Static Spinosad ME)	(South African Litchi Growers' Association 2022c)
Litchi	Litchi moth	1. Parasitoid <i>Trichogrammatoidea cryptophlebiae</i> (Tripar-C)	(Website Koppert)
Mango	African Bollworm	1. Registered products <i>Helicoverpa armigera</i> nucleopolyhedrovirus (HaNPV) (Bolldex®, Graboll)	(South African Mango Growers' Association 2022c)
Mango	Fruit flies	1. Registered products Bait sprays (Cura Fly Fruit Fly Bait <sup>1</sup> , GF-120™ NF, FF240 Fruit Fly Bait <sup>1</sup> ) Attract and Kill (Last Call™ F.F.3) Bait stations (M3a Fruit Fly Bait Station) Male annihilation technique for <i>Bactrocera dorsalis</i> (Invader-b-Lok™, Static Spinosad ME, Bi-ME mat blocks) 2. Sanitation 3. Harvesting fruit at the mature green stage	(Grové and De Beer 2017; South African Mango Growers' Association 2022c)
Mango	Mango weevil	1. Sanitation	(Grové and De Beer 2017)
Mango	Mealybugs	1. Parasitoids <i>Anagyrus vladimiri</i> (BioAnagyrus, Citripar) <i>Coccidoxenoides perminutus</i> (BioPerminutus, Permipar, Per-mX®) 2. Predators <i>Cryptolaemus montrouzieri</i> (BioCryptolaemus, Cryptobug, Cryptobug-L) <i>Nephus bipunctatus</i> (BioNephus) <i>Nephus</i> sp. (Nephubug)	(Website BioBee; Website Koppert; Website vital bugs)
Mango	Scales	1. Parasitoid <i>Aphytis melinus</i> (Aphytis, BioAphytis) 2. Predator <i>Cryptolaemus montrouzieri</i> (BioCryptolaemus, Cryptobug, Cryptobug-L)	(Website BioBee; Website Koppert)
Mango	Thrips	1. Predators <i>Amblydromalus limonicus</i> (Limonica) <i>Amblyseius swirskii</i> (Swirski-Mite, Swirski-Mite LD, Swirski-Mite Plus, Swirski Ulti-Mite), <i>Macrocheles robustulus</i> (Macro-Mite) <i>Neoseiulus cucumeris</i> (Thripex, Thripex-Plus) <i>Orius</i> sp. (BioOrius,) <i>Orius</i> sp. + BioArtFeed (premium Artemia cysts) (BioOrius Combo) <i>Orius laevigatus</i> (Thripor-L)	(Website BioBee; Website Koppert)

Contains spinosad 0,24 g/ℓ

Bait station contains alpha-cypermethrin 0,01 g/bait station

Block contains mercaptothion 5 mL/block

Contains permethrin 60 g/kg

Contains spinosad 20 g/ℓ

certain markets will increasingly place pressure on growers. An IPM strategy should therefore aim to use interventions that lower MRLs.

The South African subtropical industry has over the past 20 years made progress to adopt more environmental friendly intervention methods and moved away from the heavy reliance on broad-spectrum chemical intervention. Registered products on subtropical crops still include chemical insecticides (South African Avocado Growers' Association 2022c; South African Litchi Growers Association 2022c; South African Mango Growers' Association 2022c). However, biological control, microbial control, cultural control, behavioral control and chemical control management options (Dara 2019) that are eco-friendly are now available (Table 4). A nucleopolyhedrovirus can be used against African bollworm. False codling moth can be suppressed by using granuloviruses, entomopathogenic fungi, mating disruption, release of egg parasitoids, sanitation and sterile insect technique. Against fruit flies, bait techniques, male annihilation techniques, attract and kill products and sanitation can be used. Eco-friendly option for thrips suppression include the natural chemical sulphur, an entomopathogenic fungus and the release various predators. Mealybugs and scales can be suppressed by the release of parasitoids and predators.

The sucking bug complex on avocado remains a challenge and more environmentally friendly strategies need to be developed. Currently, except for pruning of trees, the management is based on cover applications with insecticides. An effective trapping system to monitor adult sucking bugs coming into the orchards will be important for effective management. With regard to litchi, the development and testing of mating disruption products, attract and kill products, and biological control products for litchi moth is important. The mango industry need to test biological control products against citrus thrips. Attention should also be given to find more environmentally safe suppression methods that can be used with sanitation to manage mango seed weevil, as it is a pest of phytosanitary concern. The set of economic thresholds for the important pests also need some attention. The use of botanical pesticides has not yet been tested on a large scale and could possibly contribute to the control of pests in the future.

#### Abbreviations

EU: European Union; FAO: Food and Agriculture Organization; GAP: Good Agricultural Practices; IPM: Integrated Pest Management; MRLs: Maximum Residue Levels; SAAGA: South African Avocado Growers' Association; SAMGA: South African Mango Growers' Association; SALGA: South African Litchi Growers' Association; Subtrop: South African Subtropical Growers' Association.

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