EVALUATION OF DIFFERENT INTEGRATED PEST MANAGEMENT STRATEGIES FOR THE MANAGEMENT OF THRIPS IN AVOCADO ORCHARDS

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INTRODUCTION

Thrips are tiny, slender insects with "grater-like" mouth parts and a stylet that sucks plant juice from soft plant tissue (Palmer *et al*., 1989). Thrips belong to the order Thysanoptera and family Thripidae, which includes over 5 000 species. Only a few species cause economic damage to food crops. For example, in citrus orchards, western flower thrips, *Frankliniella occidentalis* (Pergande) do not damage the fruitlets, while citrus thrips, *Scirtothrips aurantii* (Faure), are the most significant pest and feeding causes great economic loss. Although the morphology of the mouthparts differs between families, the feeding behaviours and characteristics are generally similar (Borden, 1915; Loomans *et al*., 1995). Thrips are either partially or totally parthenogenetic, which means they can reproduce without fertilization. Larvae that are soft-bodied and wingless hatch from eggs laid in the soft tissue under the epidermal layer of a plant. The two larval stages (instars), especially the second larval stage (Grout, 2019), feed on plant tissue, causing scarring and damage to some crops (Lewis, 1973; Loomans *et al*., 1995). Hence the larval stage is known to be most destructive. When the larval stages are complete, the thrips larvae drop to the soil and pupate, completing this stage in organic matter, tree cracks or crevices.

Thrips are causing economic losses on many crops throughout the world (Kirk and Terry, 2003). The Australian macadamia industry reported high numbers of thrips and mite infestations in orchards where beta-cyfluthrin has been applied consecutively or where growers have solely relied on beta-cyfluthrin for the control of fruit spotting bug and macadamia nut borer (Bright, 2015). In mango orchards, *Scirtothrips aurantii* (citrus thrips) and *Thrips tenellus* (Trybom) were found in high numbers on flowers, however far more citrus thrips were identified on the fruit set beyond 9 mm diameter. Economic damage was ascribed to citrus thrips presence on fruitlets, and not *T. tenellus* (Grové & Giliomee, 2001). It was reported that *T. tenellus* was common on *Acacia* spp., mango and citrus flowers and probably feeds on pollen, as fruit abortion and yield losses were not affected by its presence (Grové and Giliomee, 2001; Gilbert, 1990).

On avocado, Bara and Laing (2019a) reported that citrus thrips emerged from avocado fruitlets, hence driving economic concern in avocado orchards. *Thrips gowdeyi* (Bagnall) was found on avocado, mango and citrus flowers, but at much lower rates than citrus thrips and *T. tenellus* (Bara and Laing, 2019a; Gilbert, 1990; Grové and Giliomee, 2001). Indeed, thrips have been described as pollinators of flowers and fruit crops, and some species have already been described as successful contributors to nut set in macadamias (Meyer, 2016).

During November 2017, Deon Begemann taxonomically verified the most prevalent species on scarred avocado fruit as citrus thrips, according to the keys provided by Mound and Stiller (2012) and Faure (1929). The photographs he provided (Fig. 1) show the main features of male citrus thrips identified from scarred avocado fruit in Levubu, Limpopo.

Integrated pest management (IPM) is the recommended approach to controlling pest populations in avocado orchards, and includes cultural practices leading to reduced pest pressure (e.g., cultivar selection, tree stress management), pest identification and quantification (i.e. scouting), biological intervention (often applied to keep population numbers low or to combat resistance), physical interventions (e.g., pruning and beating) and chemical applications (according to product registration recommendations). In principle, growers are advised to plant pest-resistant cultivars in a region that yields high crop tonnages with high kernel recovery percentages. Plantings should be done on suitable soils, preferably ridged, with soil health retained to keep the nutritional state of the trees intact and improve resilience in hot and dry conditions.

Introduction of biological control agents, pathogens or nematodes are advised before pests reach economic damaging levels. The timing of product application should be according to informed pest monitoring. Minimising chemical use will help maintain natural enemies (Jones, 2002; O'Hare *et al*., 2004; Grass *et al*.,

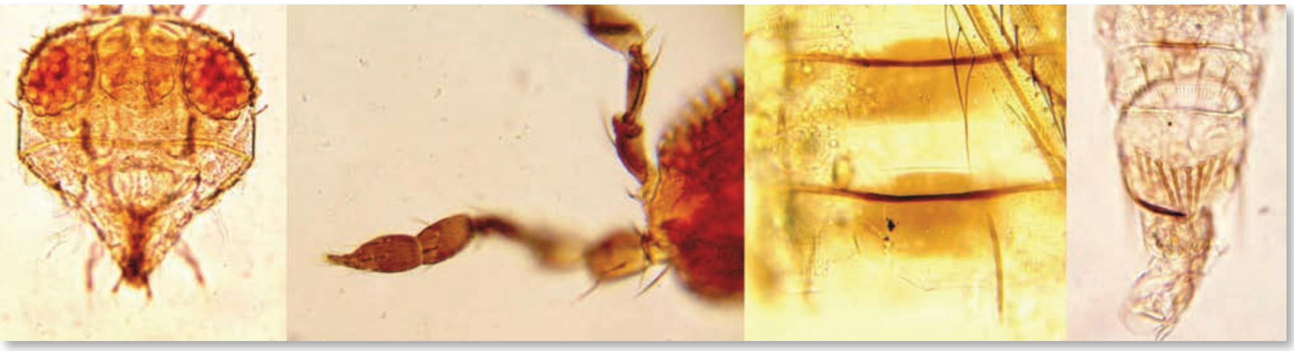

Figure 1: The main features of male citrus thrips identified from scarred avocado fruit in Levubu, Limpopo. From left to right: *Scirtothrips aurantii* head, antennae, terga with drepanae (Photographs supplied by Deon Begemann).

2018) and broad-spectrum chemicals shall only be applied when the pest population reaches a specified economic damage level (i.e. threshold) and should be done to such an extent that it does not harm beneficial organisms e.g. honeybees during the flowering period. The development of an IPM approach requires the incorporation of a team with knowledge in entomology, horticulture, plant pathology, weed science and economics (Jones, 2002). Hence, the establishment of a successful IPM programme can be a slow process due to the time taken to prove efficacy of an integrated system when so many factors can influence the outcome.

Thrips monitoring

Thrips control poses various challenges. Despite limited insecticide registrations and the vast development of resistance to insecticides, spray programmes are costly and not always effective. Pest monitors are advised to time the applications of products better, and to test the efficacy of the intervention. An effective way to scout for thrips in avocado orchards can be a "beating method" or through insect trapping (e.g. with yellow sticky cards for citrus thrips). The latter approach, however, does not consider the most damaging larval life stage, as it traps thrips in flight. The beating method entails that replicated avocado fruit are individually tapped 5 times repeatedly on an A4-page size dark flat surface so that thrips adults and larvae on the fruit are dislodged from the plant part and can be counted.

Thrips control

Much of the problem arising in avocado orchards results from adjacent macadamia cultivation and the repeated sprays, resulting in reduced natural enemies. There are limited registered chemical actives available to avocado growers against thrips. Some chemical actives like spinetoram (spinosyn), formetanate (carbamate), tartar-emetic, abamectin (avermectin) and many more have proven to result in successful control of thrips on crops. Due to the fast turnover of stages, thrips develop resistance to chemicals rapidly. Resistance by citrus thrips has been reported after applications with organophosphate, carbamate, pyrethroid and tartar emetic (Grout, 2019). Moreover, thrips are classic repercussion pests, occurring in high numbers where natural enemies are absent. Natural enemies of thrips include predatory mites (e.g. *Amblyseius swirskii* or *Neoseiulus cucumeris),* predatory bugs (e.g. *Orius thripoborus* and *O. naivashae)*, predatory thrips (e.g. *Haplothrips* spp.), endopathogenic nematodes (e.g. *Steinernema feltiae*), endopathogenic fungi (e.g. *Bacillus subtillis, Beauveria bassiana, Metarhizium anisopliae*), lacewings, spiders, and parasitoids (e.g. *Goetheana incerta*).

Depending on predatory mite numbers relative to thrips larvae, mites can play an important role in reducing larval numbers and hence, crop damage. Schoeman and Linda (2019) suggested releasing predatory mites and a predator bug (*O. insidiosus*) against thrips in subtropical orchards. Both *N. cucumeris* and *A. swirskii* have been successful in reducing thrips numbers on peppers (Arthurs *et al*., 2009). *Goetheana incerta* parasitised about 10% of *S. aurantii* in citrus orchards (Grout, 2019). A rich spider fauna was present when a survey was conducted in avocado and macadamia orchards in the Mpumalanga Province, which contributed to reduced thrips numbers (Dippenaar-Schoeman *et al*., 2001, 2005). Endopathogenic fungi like *B. bassiana* can be incorporated into an IPM programme to mitigate resistance build-up and reduce the number of chemical sprays (Bara and Laing, 2019b).

AIMS AND OBJECTIVES

In this study we aim to understand the thrips that causes damage to avocado fruit. We furthermore aimed to couple fruit damage with scouted numbers to obtain a threshold and measure and quantify the yield impact. It is furthermore one of the major outcomes of this study to develop (by statistical experimentation) an effective control programme that can be implemented in IPM against thrips on two avocado cultivars.

Specific objectives:

- Determine which thrips species are most abundant on scarred fruit;
- Establish if thrips presence significantly impacted on fruit quality;
- Control thrips, i.e. lower the number of thrips and reduce the damage by means of IPM.

METHODS

Thrips monitoring

Thrips larvae (immature life stage that hatched from eggs) and adults (winged stage) were counted per fruit repeatedly (N = 12 fruit from 10 data trees in two cultivars across three orchards). Thrips damage was recorded upon harvest during the 2020/21 season, and those results are summarised in this report. The two avocado cultivars used were 'Hass' and 'Fuerte'.

Thrips control

Three different control combinations (Combos) were evaluated across farms on the two avocado cultivars. A description of each Combo is given in Table 1. Combos 1 and 2 are IPM approaches that have been developed with a strategic chemical application in the programme, only to be implemented when scouted thrips numbers per fruit exceeded the threshold of 4 per fruit on average per week.

Statistical analyses

All statistical analyses were performed in R (v. 3.5.2, R Foundation for Statistical Computing, Vienna, Austria).

Correlation statistics were done applying Pearson's product-moment correlation test on large sample sizes. Mixed effects models accounted for continuous predictors such as sampling date through Type III Analyses of Variance summarised in an ANOVA Table with Satterthwaite's method. Dependent variable results were subjected to a Shapiro-Wilk test of normality, and data transformation were done where necessary to ensure homoscedasticity. Type II Analyses of Variance (ANOVA) using a Satterthwaite's method were applied to test for effects of interactions, treatments and other factors. Significance of effects were tested using multiple comparisons of least-square means after Tukey adjustment on a confidence level of 95% where data met the assumptions of normality and Kruskal-Wallis rank sum tests where the distribution of errors were not normal. Where outcomes of the thrips control combinations were tested (treatment *vs*. control), t-tests or non-parametric Kruskal-Wallis rank sum tests were applied.

RESULTS

Thrips correlations

Pearson's product-moment correlation showed no significant correlations between the number of thrips stages counted ($t_{(823)} = 4.59$, p-value = < 0.001, $R^2 = 0.16$) or the number of thrips adults and larvae on the avocado fruit and percentage fruit damage observed on 'Hass' ($t_{(823)} = 4.59$, p-value = < 0.001, $R^2 = 0.16$).

On 'Fuerte', the number of thrips adults and larvae counted per fruit did not correlate ($t_{(676)} = -0.96$, p-value = 0.34). There was a significant correlation between the number of adult thrips counted and percentage damage on the avocado fruit ($t_{(676)} = 5.09$, p-value = < 0.0001, $R^2 = 0.04$) and the number of thrips larvae counted and percentage damage on the avocado fruit ($t_{(676)} = 3.76$, p-value = < 0.001, $R^2 = 0.02$). When we applied the regression to predict 10% damage, the threshold obtained for adult and larvae thrips were 2.52 and 3.12, respectively. The total number of thrips counted showed a significant relationship with percentage damage observed on the fruit on average than the respective life stages ($t_{(676)} = 6.53$, p-value = < 0.0001, $R^2 = 0.06$), so that 2.61 thrips in total correlated with 10% damage. The season did however show very low thrips counts and low thrips damage scores in general across all trial locations.

Thrips control

The results from three climate production regions showed a significant reduction in thrips numbers after IPM strategies on 'Fuerte' (Fig. 2 & Fig. 3). The results from the Limpopo trials are summarised in Table 2. The effect of Combo 1 on 'Fuerte' was significant (Kruskal-Wallis chi-squared = 23.15, df = 1, p-value < 0.001, Fig. 2A), so that the number of thrips was significantly reduced. The effect of Combo 1 on 'Hass' showed the direct opposite results (Kruskal-Wallis chi-squared = 5.35, df = 1, p-value = 0.02, Fig. 2B). Combo 2 resulted in a significantly reduced thrips number relative to the untreated control on 'Fuerte' (Kruskal-Wallis chi-squared = 10.28, df = 1, p-value < 0.01, Fig. 3B) while the effect on 'Hass' was not significant (Kruskal-Wallis chi-squared = 0.83, df = 1, p-value = 0.36,

Table 1: Treatment combinations (Combos). Combos 1 and 2 are IPM approaches that has been developed with a strategic chemical application in the programme

Treatment combinations (Combo's)		
Combo 1	**Combo 2**	**Combo 3**
"IPM PREDATOR & EPN"	"IPM EPF"	"CHEMICAL"
Mite release *(Amblyseius swirskii)* 500 mites [2 sachets] (Ulti-Mite) /tree.	***Beauveria bassiana*** Minimum of 50 x10^8 viable conidia (Boveril) + 2.5 L wetting agent (Addit) /ha.	**Formetanate** 500 g (Dicarzol) + 4 kg white sugar/ha
Endopathogenic nematode release *(Steinernema feltiae)* 86 million EPNs [2 sachets] (Entonem) /ha.	***Metarhizium anisopliae*** Minimum of 1390 x 10^8 viable conidia (Metarril) /ha.	**Spinetoram** 200 g/ha (Delegate)
Formetanate 500 g (Dicarzol) + 4 kg white sugar /ha.	**Formetanate** 500 g (Dicarzol) + 4 kg white sugar/ha.	
Mite release (*Amblyseius swirskii*) 500 mites [2 sachets] (Ulti-Mite) /tree.	***Metarhizium anisopliae*** Minimum of 1390 x 10^8 viable conidia (Metarril) /ha.	

ALYFOS 800 WDG

Your answer against Phytophthora root rot

Phytophthora root rot is the most serious and important avocado disease worldwide, potentially causing massive losses to the industry. Furthermore, the causal agent, *Phytophthora cinnamomi*, has over 1 000 hosts, so can affect many species of annual flower crops, berries, deciduous fruit trees, ornamentals, and vegetables.

Disease management is only possible when you understand the causes and ideal conditions causing it to take root and thrive. Root rot thrives in areas of excess soil moisture and poor drainage - trees of any size and age may be affected. The pathogen spreads through movement of contaminated nursery stock of avocado and other plants. Equipment and shoes, seed from fruit lying on infected soil, and people and animals moving moist soil from one place to another can also spread the pathogen. Furthermore, spores spread easily and rapidly in water running over or through the soil. Entire areas can readily become infected.

There are several things to look out for to determine whether your crop is infected. Foliar symptoms of Phytophthora root rot include small, pale green or yellowish leaves. Leaves often wilt and have brown, necrotic tips. Foliage is sparse, and new growth is rare. There may be little leaf litter under infected trees. Small branches die back in the treetop, exposing other branches and fruit to sunburn because of the lack of shading foliage. Fruit production declines, but diseased trees frequently set a heavy crop of small fruit.

Small, fibrous feeder roots are scarce at the advanced stages of this disease. Where present, small roots are black, brittle, and dead from infection. Foliage is wilted even when the soil under diseased trees is wet. Affected trees will decline and often die either rapidly or slowly.

There are two methods to control Phytophthora root rot – culturally or chemically.

CULTURAL CONTROL:

- Purchase certified disease-free nursery stock and root rot-resistant cultivars.
- Inspect roots before planting and if their health is questionable, seek advice from a farm advisor or private consultant before planting trees.
- Employ stringent sanitation measures, good cultural practices, and appropriate chemical control. The most important disease control method is good irrigation management. For example, where new trees are planted among older trees, install separate irrigation lines to ensure appropriate irrigation timing and amounts for the different aged trees.
- In new plantings, avoid soils and soil conditions favourable to root rot development, including poorly drained, saline, or pathogen-infested soils.
- Appropriate irrigation is the single most critical practice for improving tree health and managing root rot. Irrigation water with high overall salinity or an excess of boron, chloride, or sodium promotes infection of roots by *Phytophthora*. *Phytophthora* can contaminate irrigation water, such as surface water that is runoff from infested soil.

CHEMICAL CONTROL:

- **ALYFOS 800 WDG** is a water dispersible granule, systemic fungicide for the control of Phytophthora. The active ingredient in **ALYFOS 800 WDG** is fosetyl aluminium. It can markedly improve trees' ability to tolerate, resist, or recover from *Phytophthora cinnamomi* infection.
- It is a systemic protective, curative, and broad-spectrum fungicide that inhibits the germination of spores or by blocking sporulation and mycelium development. It also has limited antibiotic and bactericidal activity.
- The active ingredient enhances the plant's own natural defence system against fungal diseases.
- Good control requires using this chemical in combination with other recommended practices, such as careful irrigation practices and applying wood chip mulch. Fungicides cannot eradicate *Phytophthora* from the grove, and Phytophthora root rot requires ongoing management throughout the life of the trees.

Fig. 3B). The chemical treatments resulted in a significant reduction in thrips numbers in 'Fuerte' (Kruskal-Wallis chi-squared = 27.53, df = 1, p-value < 0.0001, Fig. 2C), while the opposite was true on 'Hass' (Kruskal-Wallis chi-squared = 45.29, df = 1, p-value < 0.0001, Fig. 2C).

A treatment with predatory thrips only showed significantly less thrips as a result, compared to a combined treatment with formetanate + sugar (Kruskal-Wallis chi-squared = 4.90, df = 1, p-value = 0.03) and the result of the treatment showed a slight increase in fruit damage, however not significant (Welch Two Sample t-test: $t_{(15.54)}$ = -0.77, p-value = 0.46).

CONCLUSION

There was no significant correlation between adult and larvae thrips counted. The percentage damage observed on 'Fuerte' avocado fruit correlated well with both stages present. It is advised to scout for larvae and adults as a collective on young 'Fuerte' fruit and start with biological interventions when 2.6 thrips are observed per fruit on average, while scouting at least 100 fruit per block. No significant correlations were found on 'Hass' fruit with thrips numbers.

On 'Fuerte', all the treatment combinations significantly reduced the thrips numbers. The second season of IPM strategies against thrips should shed more light on the questions that arose from the first seasons' results.

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- Delegate: Corteva Agriscience.

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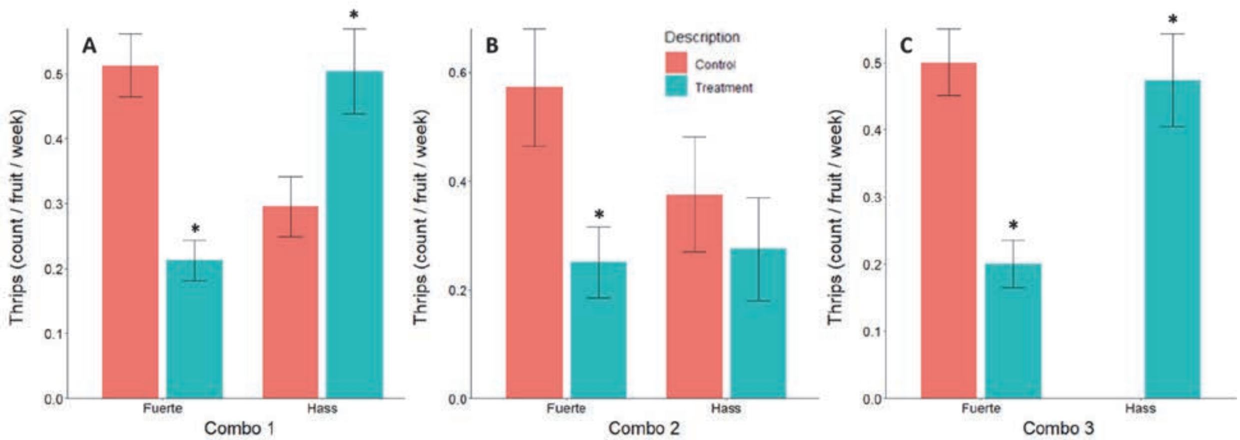

Figure 2: Summary of the results of average weekly thrips numbers resulting from monitoring on avocado fruit and the implementation of the integrated pest management approach based on thrips numbers that exceeded 4 larvae per fruit on average across 120 fruit per treatment and combo. Asterisks indicate significant differences between treatment descriptions in total thrips numbers.

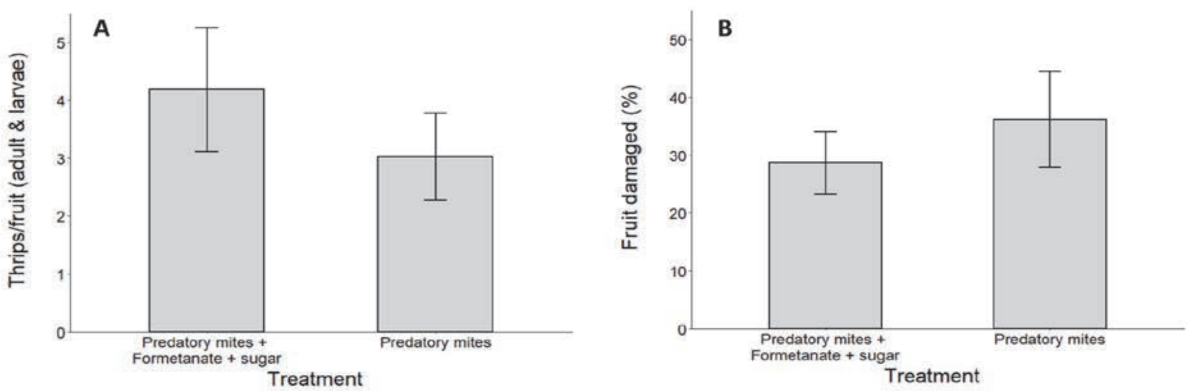

Figure 3: Summary of the results of average weekly thrips numbers resulting from monitoring on avocado fruit after application with a combination of predatory mites and formetanate + sugar or only mites, and the percentage fruit with thrips damage per treatment. Asterisks indicate significant differences between treatment descriptions.

Table 2: Summary statistical results per combo, cultivar and treatment description

Combo	Cultivar	Description	N	Thrips count (average/ fruit/week)	std. dev.	std. error	95% conf. int.
1	Fuerte	Control	359	0,51	0,91	0,05	0,09
	Fuerte	Treatment	324	0,21	0,55	0,03	0,06
	Hass	Control	240	0,30	0,71	0,05	0,09
	Hass	Treatment	240	0,50	1,01	0,06	0,13
2	Fuerte	Control	63	0,57	0,86	0,11	0,22
	Fuerte	Treatment	80	0,25	0,58	0,07	0,13
	Hass	Control	40	0,38	0,67	0,11	0,21
	Hass	Treatment	40	0,28	0,60	0,09	0,19
3	Fuerte	Control	200	0,50	0,70	0,05	0,10
	Fuerte	Treatment	200	0,20	0,50	0,04	0,07
	Hass	Control	160	0,00	0,00	0,00	0,00
	Hass	Treatment	203	0,47	0,98	0,07	0,14

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