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

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**INTRODUCTION**

Thrips (Order: Thysanoptera, Family: Thripidae) are tiny, slender insects with "grater-like" mouthparts and a stylet that sucks plant juice from soft plant tissue (Palmer *et al*., 1989). Thrips larvae emerge from eggs laid under the epidermal layer of soft plant tissue. Two larval instars, that are soft-bodied and wingless, are notorious for feeding on the plant tissue and causing scarring and damage to food crops (Grout, 2019; Lewis, 1973; Loomans *et al*., 1995). The third thrips larval instar pupates and completes this stage in organic matter, tree cracks or crevices from where adult thrips emerge.

On avocado, Bara & Laing (2019a) reported that citrus thrips, *Scirtothrips aurantii* (Faure, 1929), emerged from avocado fruitlets, highlighting the economic damage of concern in avocado orchards. Integrated pest management (IPM) is the recommended approach to controlling pest populations in avocado orchards. The IPM concept relies on three fundamentals: prevention, monitoring, and intervention. Preventative measures include an understanding of the pest, resistant cultivars, natural plant resistance, and pest suppression. Monitoring methods were evaluated and the method proven most accurate was visual observation on the fruitlets. Intervention strategies in the IPM framework follow the order 1) mechanical, 2) biological and then 3) chemical control methods. Mechanical control is where a pest is physically killed. Biological control methods include natural predators and pathogens. Chemical interventions are part of the IPM strategy when monitoring shows the mechanical and biological efforts are not feasible and the pest population exceeds a threshold level that results in numbers causing damage leading to economic losses.

The implementation of mechanical and biological methods is advised before monitored pest numbers reach economic damaging levels. The timing of product application is informed by the susceptible phenological stage during monitoring. Less chemicals could help maintain populations of natural enemies (Jones, 2002; O'Hare *et al*., 2004; Grass *et al*., 2018). The development of an IPM approach therefore requires knowledge of the susceptible cultivars, susceptible phenological stages, and pest biology (after 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 need to be studied.

Chemical actives like spinetoram (spinosyn), formetanate (carbamate), tartar-emetic, abamectin (avermectin), and many more have proven successful in controlling thrips on food crops. Due to the fast turnover of the thrips life stages, thrips can develop resistance to chemical compounds rapidly. Citrus thrips resistance has been reported after repeated applications with organophosphates, carbamates, pyrethroids, 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 thriphoborus*, and *O. naivashae*), predatory thrips (e.g. *Haplothrips* spp.), entomopathogenic nematodes (e.g. *Steinernema feltiae*), entomopathogenic fungi (e.g., *Bacillus subtillis*, *Beauveria bassiana,* and *Metarhizium anisopliae*), lacewings, spiders, and parasitoids e.g. *Goetheana incerta*.

Depending on predator and insect pathogen presence, natural means of control have proven successful in controlling thrips. 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* parasitized 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). Furthermore, incorporating entomopathogenic fungi like *B. bassiana* into an IPM programme can mitigate resistance build-up and perhaps reduce the number of chemical sprays (Bara & Laing, 2019b).

There is a need for integration of the biological pest understanding and control strategies in the context of the plant part damaged by thrips. Here we studied the pest associations with the sensitive phenological stage of avocado and related the outcomes of repeated insect monitoring with damage profiles and IPM programme efficacy.

## AIMS AND OBJECTIVES

In this study we first aimed to understand the interaction between the thrips species that cause damage and fruit character better. We secondly aimed to establish if thrips presence significantly impacted fruit quality and understand the pest density at which intervention is needed to prevent economic injury (i.e. economic threshold). Finally, we aimed to control thrips and reduce thrips damage by means of statistical experimentation of IPM control programmes that can be implemented in commercial avocado orchards.

The work was repeated according to statistical trial designs in 'Hass' and 'Fuerte' avocado orchards over several seasons (seasons given in methods section) in three Köppen-Geiger climate zones (Picture 1):

1. Bsh: a hot semi-arid climate which sometimes has extremely hot summers and warm to cool winters, with some to minimal precipitation (for example: Letsitele, Beaufort, Hoedspruit, Malelane, Komatipoort);
2. Cwa: monsoonal influenced dry-winter humid subtropical climate, with a dry winter – wet summer pattern associated with tropical monsoonal climates (for example: Modjajiskloof, Levubu, White River, Ladysmith) and;
3. Cwb: dry-winter subtropical highland climate where winters are noticeable and dry, and summers can be very rainy (for example: Magoebaskloof, Witvlag, Haenertsburg, Elandshoek, Brondal, Howick).

## METHODS AND RESULTS

For each season, the specific outcomes tested are described and the results given. Here is a summary of the work conducted -

| | |
|---|---|
| 2013-2014: | sticky traps as a method of thrips monitoring. |
| 2017-2018: | thrips visual counts, fruit character, and damage correlations. |
| 2020-2023: | IPM programme evaluation for thrips damage control and correlations with thrips counts. |

### Statistical analysis

Data were analysed in RStudio: R Core Team (2015), v 4.2.1. Dependent variable data were subjected to Shapiro-Wilk tests of normality of model residuals and Levene's Test for Homogeneity of Variance prior to statistical analyses and plotting with the packages ggisgnif (Ahlmann-Eltze, 2021), ggstatsplot (Patil, 2021), and ggplot (Wickham, 2016).


**Picture 1:** Köppen-Geiger climate zones and approximate locations of field trials.

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Outliers were removed from the dataset using the Interquartile Range (IQR) method. The IQR is the central 50% of the dataset, between the 75th and 25th percentile of the data distribution. Outliers were identified as points 1.5 times smaller or larger than the IQR. Data were plotted per treatment with significant differences indicated above the error bars in different letters, unless specified otherwise, based on post-hoc tests.

Statistical results of each predictor variable were summarized in text or in a table format from the summary results obtained by applying the R package Rmisc (Hope, 2022) showing the sample size (N), average (mean), standard deviation (sd), standard error (se), and 95% confidence intervals (ci). Significant predictor factor effects were evaluated using appropriate post-hoc tests for pairwise multiple comparisons of the ranked data in the package rstatix (Kassambara, 2021). All statistical significance were determined on the alpha level = 0.05 (95% confidence limit). Intervention strategy outcomes were analyzed after percentage damage data were subjected to Henderson-Tilton data corrections to provide the corrected efficacy percentage (%) per strategy applied, relative to the untreated control (Gama, 2015).

**Thrips monitoring with sticky traps**

During the 2013-2014 season, sticky traps were deployed, and 658 thrips individuals were identified to one of four functional groups by Dr Michael Stiller (ARC-PPRI). The black thrips that were found on the sticky traps were characterized as *Haplothrips* spp. that are pollen or fungal spore feeders. Brown thrips included *Thrips gowdeyi* and other rare species not of economic concern. A few brown specimens were relatively large and were probably *Megalurothrips sjostedti. Frankliniella occidentalis* (Pergande) (western flower thrips) is generally two-toned, light, and dark brown, and even grey in some parts. None of the thrips on the sticky traps matched this description. Not many leaf feeders (*Panchaetothripinae*) were caught, and each specimen differed from the other of this group. Yellow thrips, which classify as crop pests, were classified as either *Scirtothrips aurantii* or *T. tenellus* in the ARC-PPRI reports received in 2014 (Fig. 1).

Many parasitic wasps were noticed in the sticky traps, probably more than 10 morphospecies that could kill thrips larvae and adults. Egg parasitoids were also seen. Some traps were in poor condition, with plastic folds obscuring specimens. Some specimens were covered with secondary fungi. It was recommended that thrips be collected and observed on the plant parts where damage is suspected and pan traps or a similar method be used that could preserve the specimens better for identification purposes.

The sticky trap results showed that there were significantly more yellow thrips in general than the other groups (black thrips, brown thrips, leaf feeders), and significantly more yellow thrips on the yellow sticky traps compared to the blue sticky traps (Fig. 2, *P* = 0.02). The yellow sticky trap results did not show significant differences between the locations of the traps (avocado, macadamia, banana orchards, or adjacent to natural bush) ($\chi^2_{Kruskal\text{-}Wallis}(5) = 2.97$, *P* = 0.70, N = 346).

**Visual thrips monitoring**

Thrips counts and damage data were collected across a range of 'Fuerte' and 'Hass' fruit sizes from four wind directions per replicated data trees (N = 280) by tapping fruitlets 5 times on an A4 surface during the 2017-2018 season. Damage results were scored per fruitlet as a percentage of the whole fruit covered in thrips feeding-related scarring. Data were collected from two farms, one in the Cwa climate zone and one in the Bsh climate zone.

Outliers were removed from the damage dataset after grouping by farm, and the results showed that there was significantly more thrips damage (% of fruit surface damaged) in the Bsh climate zone (22.92 ± 1.13% thrips damage) compared to the Cwa climate zone (14.23 ± 0.92% thrips damage) ($W_{Mann\text{-}Whitney}$ = 12250, *P* = 6.19e-08, N = 269) (Fig. 3A). Thrips larvae count averages per fruitlet were significantly higher in the Bsh climate zone (3.33 ± 0.18) compared to the Cwa climate zone (1.38 ± 0.15) ($W_{Mann\text{-}Whitney}$ = 13314, *P* = 7.87e-14, N = 267) (Fig. 3B). Thrips adult count averages were significantly higher

**Figure 1:** *Scirtothrips aurantii* (left) and *Thrips tenellus* (right) adults. Photo credits: E Joubert.

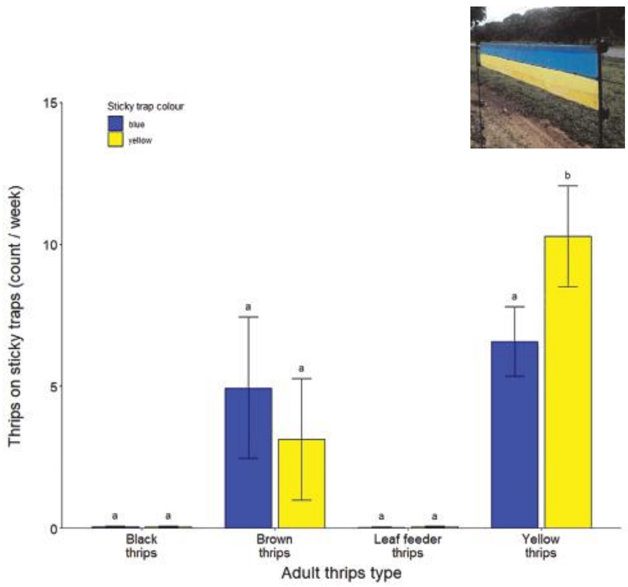


**Figure 2:** Sticky trap results showing the different thrips types observed on blue and yellow sticky traps.

in the Bsh climate zone (1.25 ± 0.08) compared to the Cwa climate zone (0.66 ± 0.07) ($W_{Mann\text{-}Whitney}$ = 11683.50, $P$ = 4.62e-07, N = 267) (Fig. 3C). The total number of thrips (larvae plus adults, N = 1 113) counted were significantly higher in the Bsh climate zone (3.33 ± 0.18) compared to the Cwa climate zone (1.38 ± 0.15) ($W_{Mann\text{-}Whitney}$ = 13314, $P$ = 7.87e-14, N = 267).

Outliers were removed from the dataset after grouping by cultivar, and the results showed that there was significantly more thrips damage (% of fruit surface damaged) on 'Fuerte' (20.94 ± 0.90% thrips damage) compared to 'Hass' (10.82 ± 1.20% thrips damage) ($W_{Mann\text{-}Whitney}$ = 6815, $P$ = 1.39e-06, N = 271) (Fig. 4A). Thrips larval count averages were significantly higher on 'Fuerte' (3.09 ± 0.16) compared to 'Hass' (0.53 ± 0.12) ($W_{Mann\text{-}Whitney}$ = 7130.50, $P$ = 7.38e-11, N = 274) (Fig. 4B). Thrips adult counts were significantly higher on 'Fuerte' (1.20 ± 0.07) compared to 'Hass' (0.64 ± 0.12) ($W_{Mann\text{-}Whitney}$ = 5967.50, $P$ = 3.29e-03, N = 278) (Fig. 4C).

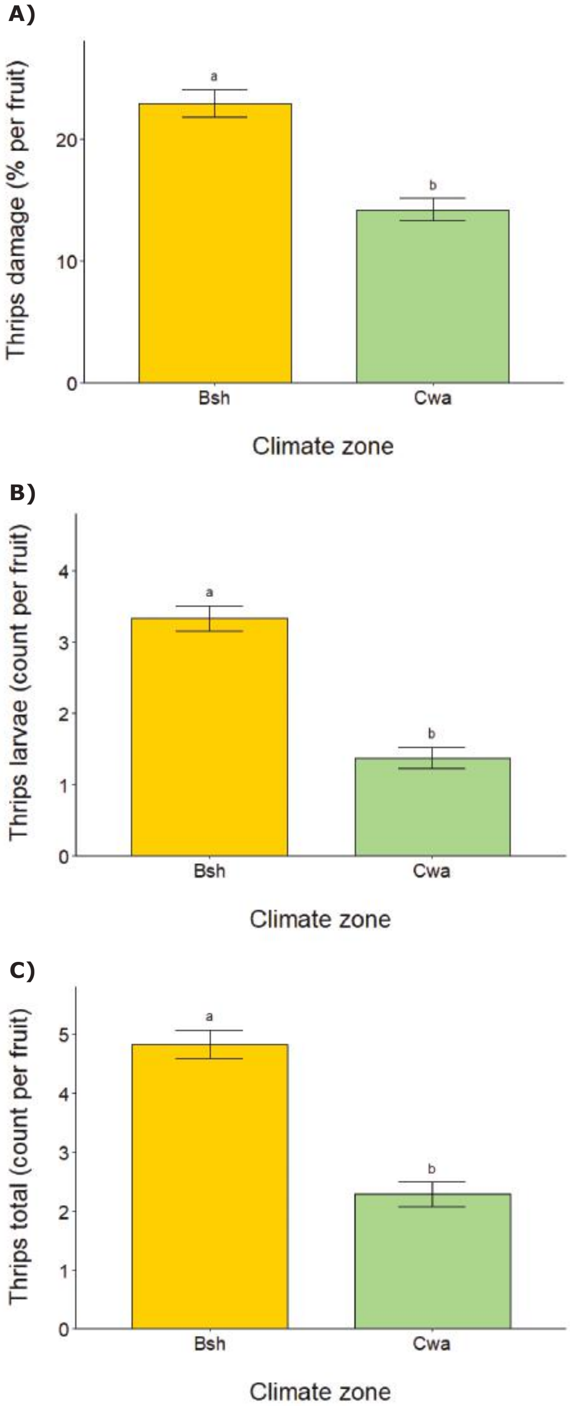


**Figure 3:** Two Köppen-Geiger climate zones and observed (A) thrips damages, (B) average larval counts, and (C) average adult counts per fruitlet (observations on 'Fuerte' and 'Hass' combined to see the significant climate effect).

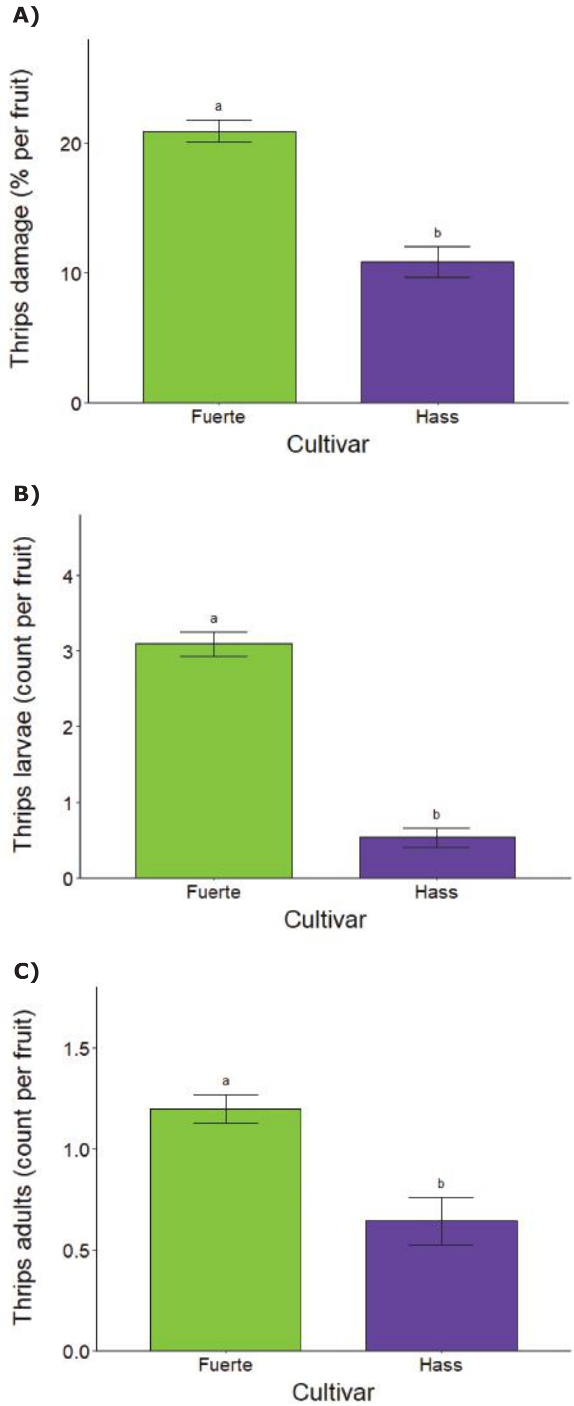


**Figure 4:** Two cultivars and observed (A) thrips damages, (B) average larval counts, and (C) average adult counts per fruitlet (observations from Cwa and Bsh climate zones combined to see the significant cultivar effect).

Thrips total counts were significantly higher on 'Fuerte' (2.69 ± 0.29) compared to 'Hass' (1.50 ± 0.25) ($W_{Mann-Whitney}$ = 5967.50, *P* = 3.29e-03, N = 278).

Calyx refers to the remaining small brown leaves (sepals that initially surrounded and protected the flower) on top of the fruitlet like a 'cap' after fruit set, during fruit expansion. Fruit with and without a calyx present were monitored in the four wind-directions of each data tree. Outliers were removed from the dataset after grouping by calyx presence or absence, and then by wind direction.

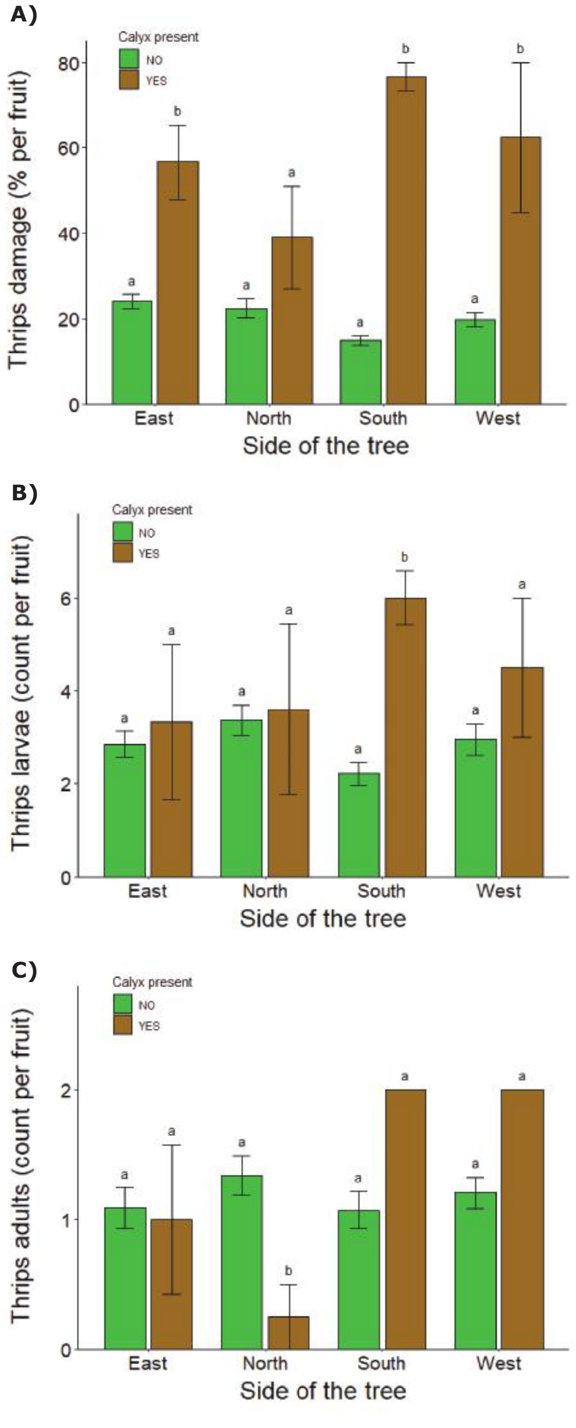


**Figure 5**: 'Fuerte' results of observed (A) thrips damages, (B) average larval counts, and (C) average adult counts per fruitlet (observations from Cwa and Bsh climate zones combined to see the significant side and calyx effect).

'Fuerte' fruit with a calyx had significantly more thrips damage (55.39 ± 6.63% thrips damage) compared to 'Fuerte' fruit without a calyx (20.44 ± 0.88% thrips damage) ($W_{Mann-Whitney}$ = 331, *P* = 2.53e-06, N = 237). Percentage thrips damage was significantly greater on the eastern side of the trees compared to the southern side of the trees (Fig. 5A), while significantly more larvae occurred on southern facing fruit with a calyx (6.00 ± 0.58) than on fruit without a calyx (2.2.1 ± 0.24) (Fig. 5B). When effects from the calyx were grouped, average thrips larval counts did not differ among the directions ($\chi^2_{Kruskal-Wallis}(3)$ = 4.17, *P* = 0.24, N = 232). Adult thrips counts did not differ between 'Fuerte' fruit with and without a calyx ($W_{Mann-Whitney}$ = 1323, *P* = 0.53, N = 239) grouped across all four sides of the trees, and no significant differences occurred between the four sides of trees ($\chi^2_{Kruskal-Wallis}(3)$ = 2.25, *P* = 0.52, N = 237) whether a calyx was present or not. Slightly more thrips occurred on fruit without a calyx on the northern side of the tree (Fig. 5C). Total thrips counts were higher (5.54 ± 0.19 *vs*. 3.91 ± 0.19), but not significantly influenced by the presence of a calyx on 'Fuerte' fruitlets generally ($W_{Mann-Whitney}$ = 1008.50, *P* = 0.08, N = 231). However, there were significantly more thrips in total on the southern side of trees where a calyx was present (8.00 ± 0.58) compared to the fruit without a calyx (3.28 ± 0.32).

'Hass' fruit with a calyx did not have significantly more thrips damage (17.50 ± 4.79% thrips damage) compared to fruit without a calyx (10.08 ± 1.19% thrips damage) ($W_{Mann-Whitney}$ = 36, *P* = 0.10, N = 40). There was no significant difference in average thrips larval counts between fruit with and without a calyx ($W_{Mann-Whitney}$ = 38.50, *P* = 0.15, N = 36), nor between the sides of trees ($W_{Mann-Whitney}$ = 44.50, *P* = 0.68, N = 20). Thrips damage percentages were also not significantly different among the wind direction sides of 'Hass' trees ($W_{Mann-Whitney}$ = 49.50, *P* = 1, N = 20). Adult thrips counts were not significantly different between fruit with and without a calyx ($W_{Mann-Whitney}$ = 108.00, *P* = 0.06, N = 39), or fruit on the different sides of the tree ($W_{Mann-Whitney}$ = 50.00, *P* = 1.00, N = 20). Total thrips counts were not significantly different between fruit with and without a calyx ($W_{Mann-Whitney}$ = 80.00, *P* = 0.73, N = 40), or on fruit on the different sides of trees ($W_{Mann-Whitney}$ = 46.50, *P* = 0.82, N = 20).

The pest density at which intervention is required to prevent numbers from reaching economic threshold densities that cause economic injury levels on fruit is important. The economic injury level of avocado fruit remains consistent across seasons; 10% of the fruit that may be damaged by insects according to Standard No. C-3 of the Agricultural Product Standards Act [Act No. 119 of 1990]: Standards and Requirements Regarding Control of the Export of Avocados. When more than 10% of the fruit is scarred, fruit will be downgraded from Class 1 (A04 'Fuerte' carton) to Class 2 (D04 'Fuerte' carton). The difference amounts to an average 12.82% price reduction for 'Fuerte' and 26.10% price reduction for 'Hass'

based on average prices achieved per 4 kg carton (calculated with industry benchmark figures, over 5 seasons: 2018-2022, SourceB.I.). Spearman's correlation statistics showed no significant relationship between 'Fuerte' (R = 0.046, *P* = 0.48) or 'Hass' (R = 0.028, *P* = 0.86) fruit diameters and thrips damage observed (Fig. 6).

The relationship between thrips larval counts and observed damage were significant for 'Fuerte' (R = 0.45, *P* = 6.4e-13) and 'Hass' (R = 0.43, *P* = 6.3e-3) (Fig. 7A). The relationship between thrips adult counts and damage was significant for 'Fuerte' (R = 0.29, *P* = 6.4e-6) and 'Hass' (R = 0.36, *P* = 0.02) (Fig. 7B). The relationship between thrips total counts and damage was significant for 'Fuerte' (R = 0.44, *P* = 1.9e-12) and 'Hass' (R = 0.48, *P* = 1.5e-3) (Fig. 7C).

**Thrips control**

The effects of different intervention strategies were evaluated on avocado against thrips across Köppen-Geiger climate zones. Two different IPM strategies were evaluated. The IPM programmes (IPM 1 and IPM 2) were developed with a strategic chemical application in the programme, with the strategy implemented when scouted thrips numbers per fruit exceeded a threshold of 3-4 thrips per fruitlet on average. Interventions were applied only when thrips were present leading to many trial sites not yielding data, as thrips were not observed during above average rainfall seasons. Thrips control trials were conducted during the 2020-2023 avocado production seasons (three consecutive seasons) following randomized block experimental designs or parallel applications in dedicated areas demarcated per treatment in a block, to keep all variables other than the intervention constant. The IPM 1 programme included predatory mite releases (500 *Amblyseius swirskii* / ha) and entomopathogenic nematode releases (86 million nematodes / ha) applied through irrigation. The first release was done preventatively (no thrips observed yet, but the fruit set had started). The IPM 2 programme consisted of applications only based on scouting and thrips presence. These applications were *Beauveria bassiana* (50 x $10^8$ viable conidia + a wetting agent per hectare, followed by *Metarhizium anisopliae* at a rate of 1 390 x $10^8$ viable conidia per hectare).

Spray cart calibrations were done to ensure full cover applications. Treatment applications are summarized in Table 1 and all treatments outcomes were compared to an untreated control using Henderson-Tilton data corrections. Thrips count data were collected weekly for thrips adults and larvae seperately

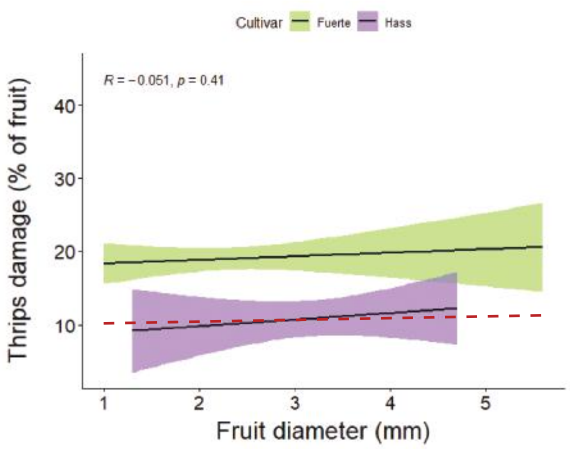


**Figure 6**: Relationships observed between thrips damage observed on 'Hass' and 'Fuerte' across fruit diameters. The economic injury level of 10% of the fruit surface damaged is indicated with a dotted red line.

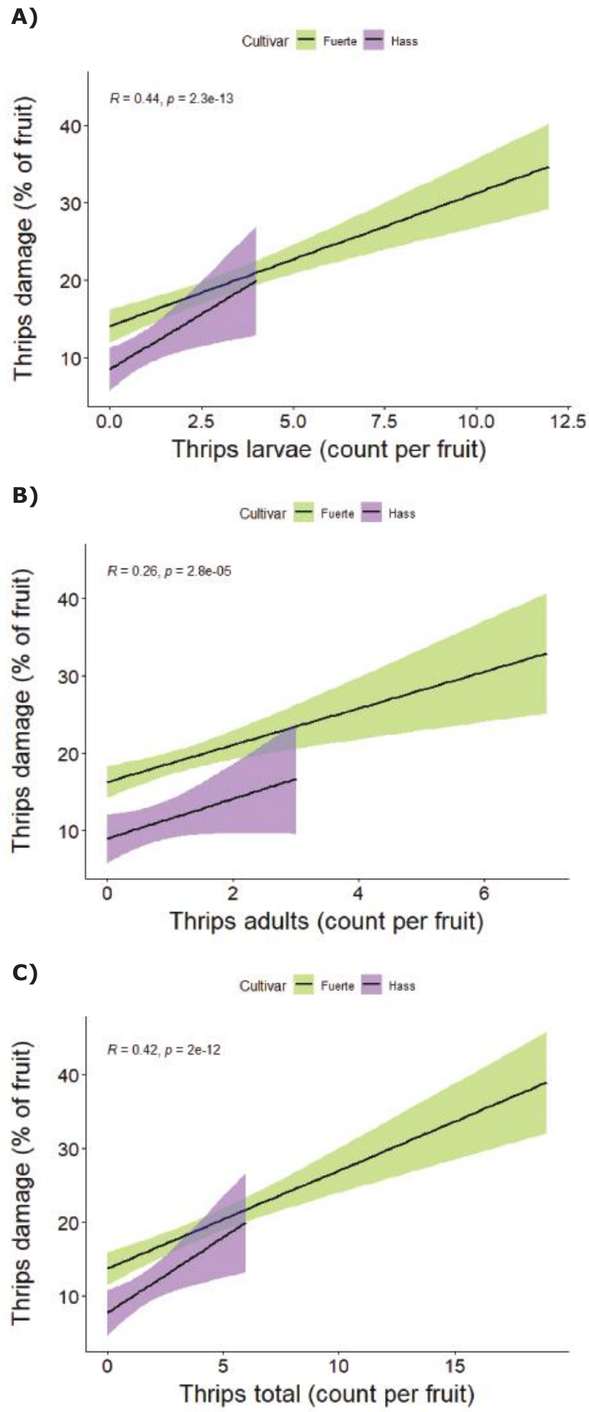


**Figure 7:** Thrips damage observed and correlated with (A) thrips larval counts, (B) thrips adult counts, and (C) thrips adult counts per fruitlet (observations from Cwa and Bsh climate zones combined to see the effects).

by tapping fruit 5 times on an A4 surface and counting the individuals. Damage results were scored per fruitlet as a percentage of the whole fruit covered in thrips feeding-related scarring. Damage results were statistically analysed here and interpreted between treatments.

2020-2021 season results

'Hass' in the Cwa climate zone results showed a significant difference between the IPM strategy and the untreated control ($W_{Mann\text{-}Whitney}$ = 20700, *P* = 7.72e-03). The strategy where the IPM 1 programme were followed were 11.5 ± 5.17% more effective than the control (Tables 2 and 3).

'Fuerte' in the Bsh climate zone was treated with a chemical or an integrated pest management strategy, and the results showed significant difference between the two strategies ($W_{Mann\text{-}Whitney}$ = 6.76e05, *P* = 1.60e-07). The strategy where the IPM 1 programme was followed was more effective than the chemical intervention (Tables 2 and 3).

2021-2022 season results

Fruit bags, usually used on mango to prevent sunburn, were placed onto 882 random individual 'Fuerte' fruit from 34 trees during December 2021 in the Cwa climate zone to verify the hypothesis that thrips damage can be prevented by early intervention,

**Table 1:** Summary results showing the Henderson-Tilton corrected percentage efficacy scores on thrips damage observed for different intervention strategies. Sample sizes (N) and averages (mean percentages), standard deviation of the mean (sd), standard error of the mean (se), and 95% confidence intervals (ci).

| Season | Climate zone | Cultivar | Strategy | N | Efficacy % | sd | se | ci |
|---|---|---|---|---|---|---|---|---|
| 2020-2021 | Cwa | 'Hass' | IPM 1 | 200 | 11.50 | 73.11 | 5.17 | 10.19 |
| | Bsh | 'Fuerte' | IPM 1 | 630 | 189.52 | 327.61 | 13.05 | 25.63 |
| | | | Chemical | 610 | -11.64 | 291.95 | 11.82 | 23.21 |
| 2021-2022 | Cwb | 'Fuerte' | IPM 2a | 61 | 86.89 | 167.80 | 21.49 | 42.98 |
| | | | IPM 2b | 60 | 102.22 | 48.66 | 6.28 | 12.57 |
| | | | Chemical | 60 | 101.11 | 55.90 | 7.22 | 14.44 |
| | Cwa | 'Hass' | IPM 2 1x | 48 | 62.50 | 107.28 | 15.48 | 31.15 |
| | | | IPM 2 2x | 48 | 50.93 | 116.78 | 16.86 | 33.91 |
| | | | Chemical | 48 | 583.33 | 1007.07 | 145.36 | 292.42 |
| | Bsh | 'Hass' | IPM 2 1x | 492 | 33.54 | 73.25 | 3.30 | 6.49 |
| | | | IPM 2 2x | 492 | 48.78 | 72.48 | 3.27 | 6.42 |
| | | | Chemical | 564 | -34.57 | 164.65 | 6.93 | 13.62 |
| 2022-2023 | Bsh | 'Fuerte' | IPM 1 | 35 | 46.43 | 80.70 | 13.64 | 27.72 |
| | | | IPM 2 | 32 | 39.06 | 58.87 | 10.41 | 21.22 |
| | | | Chemical | 37 | 45.05 | 71.53 | 11.76 | 23.85 |

**Table 2:** Pairwise comparison results between intervention strategies after Henderson-Tilton correction of the fruit damage data showing sample sizes for the implemented strategies, Dunns' statistic, and adjusted *P*-values indicating significance.

| Season | Climate zone | Cultivar | Strategy 1 | Strategy 2 | n1 | n2 | statistic | *P*-value | Significance |
|---|---|---|---|---|---|---|---|---|---|
| 2020-2021 | Bsh | 'Fuerte' | IPM 1 | Chemical | 630 | 610 | -3.28 | 0.001 | Significant |
| 2021-2022 | Cwb | 'Fuerte' | IPM 2a | IPM 2b | 61 | 60 | -3.01 | < 0.05 | Significant |
| | | | IPM 2a | Chemical | 61 | 60 | -2.80 | 0.01 | Significant |
| | | | IPM 2b | Chemical | 60 | 60 | 0.21 | 0.84 | Not significant |
| | Cwa | 'Hass' | IPM 2 1x | IPM 2 2x | 48 | 48 | -0.42 | 0.68 | Not significant |
| | | | IPM 2 1x | Chemical | 48 | 48 | -0.60 | 0.55 | Not significant |
| | | | IPM 2 2x | Chemical | 48 | 48 | -0.18 | 0.86 | Not significant |
| | Bsh | 'Hass' | IPM 2 1x | IPM 2 2x | 492 | 492 | 2.76 | 0.01 | Significant |
| | | | IPM 2 1x | Chemical | 492 | 564 | -4.74 | < 0.01 | Significant |
| | | | IPM 2 2x | Chemical | 492 | 564 | -7.60 | < 0.01 | Significant |
| 2022-2023 | Bsh | 'Fuerte' | IPM 1 | IPM 2 | 35 | 32 | -0.88 | 0.99 | Not significant |
| | | | IPM 1 | Chemical | 35 | 37 | -0.98 | 0.99 | Not significant |
| | | | IPM 2 | Chemical | 32 | 37 | -0.06 | 0.99 | Not significant |

after fruit set. There was no significant difference between thrips damage on bagged fruit (4.25 ± 0.24% thrips damage) and those left open (5.26 ± 0.36% thrips damage) after December, supporting the hypothesis that early intervention is key for thrips damage control (Wilcoxon rank sum test with continuity correction: W = 72728, *P*-value = 0.05).

A complete randomized block design trial commenced in three climate zones, to test the efficacy of integrated pest management strategies, and specifically if these strategies are comparable to the chemical results. The geographic locations of the trials were: JC Nel Boerdery: -22.979774, 29.949278 (Cwb climate zone), Springfield Farms: -23.074902, 30.183889 (Cwa climate zone) and HP de la Rey Boerdery: -23.107122, 30.252021 (Bsh climate zone).

In the Cwb climate zone, the results on 'Fuerte' showed effective integrated pest management intervention (Table 2) that was not significantly different from the standard chemical intervention (Table 3). In the Cwa climate zone, results on 'Hass' showed no significant differences in efficacy on thrips damage percentages ($\chi^2_{Kruskal\text{-}Wallis}(2) = 0.38$, $P = 0.83$, N = 144) after Henderson-Tilton data correction. The data therefore support the hypothesis of equal efficacy on 'Hass' (Tables 2 and 3).

In the Bsh climate zone, the results on 'Hass' showed that there were significant differences in

**Table 3:** Correlation test results between thrips counts (adult, larvae and total) and observed fruit damage.

| Climate zone | Cultivar | Variable 1 | Variable 2 | Correlation | Statistic | *P*-value |
|---|---|---|---|---|---|---|
| Cwa | 'Fuerte' | adults | total | 0.84 | 2.05E+05 | < 0.001 |
| Bsh | 'Fuerte' | adults | total | 0.82 | 7.07E+08 | < 0.001 |
| Cwb | 'Fuerte' | adults | total | 0.80 | 2.03E+08 | < 0.001 |
| Bsh | 'Hass' | larvae | total | 0.77 | 1.74E+08 | < 0.001 |
| Bsh | 'Hass' | adults | total | 0.72 | 2.16E+08 | < 0.001 |
| Cwa | 'Hass' | larvae | total | 0.68 | 2.51E+05 | < 0.001 |
| Cwa | 'Hass' | adults | total | 0.67 | 2.63E+05 | < 0.001 |
| Cwb | 'Fuerte' | larvae | total | 0.65 | 3.56E+08 | < 0.001 |
| Bsh | 'Fuerte' | larvae | total | 0.56 | 1.75E+09 | < 0.001 |
| Cwa | 'Fuerte' | larvae | total | 0.41 | 7.76E+05 | < 0.001 |
| Cwa | 'Hass' | damage | total | 0.21 | 6.24E+05 | < 0.05 |
| Bsh | 'Hass' | adults | larvae | 0.19 | 6.09E+08 | < 0.001 |
| Cwa | 'Hass' | damage | adults | 0.18 | 6.48E+05 | < 0.05 |
| Cwa | 'Fuerte' | larvae | damage | 0.14 | 1.13E+06 | < 0.05 |
| Cwb | 'Fuerte' | adults | larvae | 0.12 | 8.84E+08 | < 0.001 |
| Bsh | 'Fuerte' | damage | total | 0.12 | 3.48E+09 | < 0.001 |
| Cwa | 'Hass' | larvae | damage | 0.11 | 7.04E+05 | 0.16 |
| Bsh | 'Fuerte' | damage | larvae | 0.10 | 3.55E+09 | < 0.001 |
| Bsh | 'Fuerte' | larvae | damage | 0.10 | 3.55E+09 | < 0.001 |
| Cwa | 'Fuerte' | damage | total | 0.09 | 1.19E+06 | 0.20 |
| Bsh | 'Fuerte' | damage | adults | 0.08 | 3.65E+09 | < 0.001 |
| Bsh | 'Hass' | damage | adults | 0.04 | 7.24E+08 | 0.07 |
| Bsh | 'Fuerte' | larvae | adults | 0.04 | 3.78E+09 | < 0.05 |
| Cwb | 'Fuerte' | damage | total | 0.02 | 9.86E+08 | 0.35 |
| Cwb | 'Fuerte' | damage | larvae | 0.02 | 9.91E+08 | 0.48 |
| Cwa | 'Fuerte' | damage | adults | 0.02 | 1.29E+06 | 0.83 |
| Cwb | 'Fuerte' | adults | damage | 0.01 | 9.95E+08 | 0.57 |
| Cwb | 'Hass' | adults | damage | -0.01 | 2.94E+07 | 0.74 |
| Cwb | 'Hass' | damage | total | -0.01 | 2.94E+07 | 0.74 |
| Bsh | 'Hass' | damage | total | -0.02 | 7.68E+08 | 0.54 |
| Bsh | 'Hass' | larvae | damage | -0.07 | 8.07E+08 | < 0.05 |
| Cwa | 'Hass' | larvae | adults | -0.09 | 8.59E+05 | 0.26 |
| Cwa | 'Fuerte' | adults | larvae | -0.13 | 1.48E+06 | 0.07 |

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efficacy on thrips damage percentages ($\chi^2_{Kruskal-Wallis}(2) = 59.54$, *P* = 1.18e-13, N = 1548) after Henderson-Tilton data correction. The data therefore refute the hypothesis of equal efficacy and support the null hypothesis that the interventions perform unequally on 'Hass' (Tables 2 and 3).

2022-2023 season results
Data were collected in the Bsh climate zone on 'Fuerte' to test the hypothesis that integrated pest management strategies performs better or just as well as chemical intervention in a high-pressure climate zone on a susceptible cultivar. Outliers were removed from the dataset after grouping by treatment (intervention strategy), and the results showed that there were no significant differences in thrips damage (% of fruit surface damaged) between treatments ($\chi^2_{Kruskal-Wallis}(2) = 1.16$, *P* = 0.56, N = 104) after Henderson-Tilton data correction. The data did not show evidence for the null hypothesis, and hence, did not prove that integrated pest management strategies perform equally as well as chemical intervention in a high-pressure climate zone on a susceptible cultivar (Tables 2 and 3).

**Thrips damage trends and correlations with counts**

The untreated control groups of the blocks where intervention strategies were applied, were used to draw long-term trends of thrips numbers across climate zones and cultivars. The untreated control data were also used to establish a better understanding of the relationship between thrips numbers and observed damage on avocado fruit. Data were used where the observed damage exceeded zero (not including zeros) and the intercept of the relationship was set to zero accordingly. The grouped dataset showed a correlation coefficient ($R^2$) of 0.45 and slope of 4.29 on the total number of thrips. This applied in the formula y = mx, resulted in 2.33 thrips (x) causing 10% (y) damage. Spearman's correlation tests were applied for thrips larvae, thrips adults, thrips total counts, and damage per cultivar and climate zone. The results are summarized in Table 4. The strongest correlations were observed between adult thrips counts and total thrips numbers on 'Fuerte'. Damage was significantly related to total thrips counts on 'Fuerte' in the Bsh climate zone (Fig. 8A) and 'Hass' in the

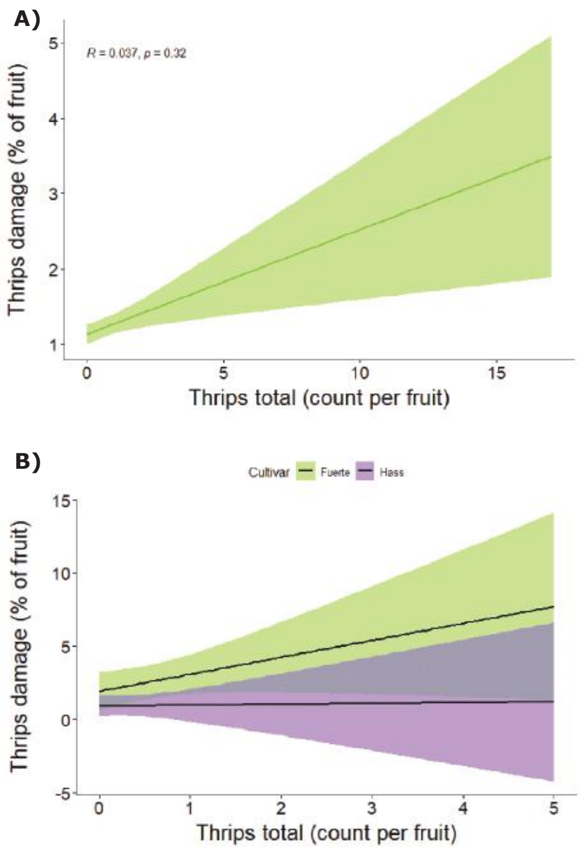


**Figure 8:** Thrips damage correlations with thrips total counts in the (A) Bsh climate zone observed on 'Fuerte' and in the (B) Cwa climate zone observed on 'Hass'.

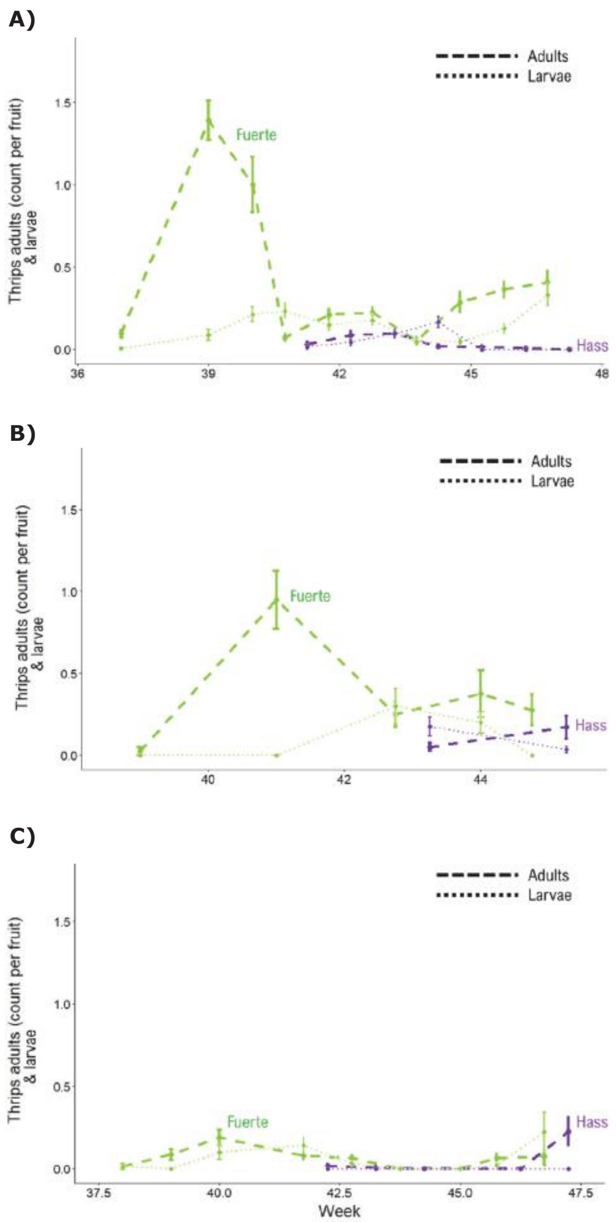


**Figure 9:** Thrips count data observed over time (calculated as an average across three seasons) in the (A) Bsh, (B) Cwa and (C) Cwb climate zones on 'Hass' and 'Fuerte'.

Cwa climate zone (Fig. 8B). Thrips larval counts correlated significantly and strongest with damage on 'Fuerte' in the Cwa climate zone and correlated significantly with 'Hass' damage in the Bsh climate zone. None of the damage correlations were significant in the Cwb climate zone.

## DISCUSSION

Thrips cause economic losses on many food crops throughout the world (Kirk & Terry, 2003). In mango orchards *Scirtothrips aurantii* (citrus thrips) and *Thrips tenellus* (Trybom) were found in high numbers on the flowers, however far more citrus thrips were identified on the fruit set beyond 9 mm diameter, and economic damage was ascribed to citrus thrips presence on the fruitlets (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 & Giliomee, 2001; Gilbert, 1990).

Citrus thrips control poses various challenges in the avocado industry of South Africa. Despite limited insecticide registrations and the vast development of resistance, spray programmes are costly and are not always effective. Pest monitoring is advised to time applications of products better, and to test the efficacy of the intervention. An effective way to scout for thrips in avocado orchards is a visual method or by beating the fruitlets softly. The sticky trap approach was evaluated and not considered the most effective, as the damaging life stage (thrips larvae) was not caught, but only adults and many other thrips too. 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. Where the fruitlets have a calyx present, it is advised to do visual counting under the calyx by lifting the calyx.

Much of the pest problems arising in avocado orchards result from repeated sprays, and hence, reduced natural enemy populations. 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. However, due to the fast turnover of stages, thrips develop resistance to chemical compounds rapidly and repeated sprays should be avoided. Indeed, citrus thrips resistance has been reported after applications with organophosphates, carbamates, pyrethroids, 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.),

**Table 4:** Summary of intervention strategies applied to test thrips control efficacy.

| Season | Climate zone | Cultivar | Intervention strategies compared to untreated control | Actives applied and compared to the untreated control | Application date(s) |
|---|---|---|---|---|---|
| 2020-2021 | Cwa | 'Hass' | IPM 1 | Predatory mites & entomopathogenic nematodes (EPNs) (IPM 1) | 7 September 2020 (mites) & 13 October 2020 (EPNs) (IPM 1) |
| | Bsh | 'Fuerte' | IPM 1; chemical | Predatory mites & EPNs (IPM 1); Spinetoram (chemical) | 29 August 2020 (mites) & 13 October 2020 (EPNs) (IPM 1); 13 October 2020 & 29 October 2020 (chemical). |
| 2021-2022 | Cwa | 'Hass' | IPM 1; IPM 2 | Predatory mites & EPNs (IPM 1); *B. bassiana* & *M. anisopliae* (IPM 2) | 7 September 2021 (mites) & 13 October 2021 (EPNs) (IPM 1); 11 November 2021 (*B. bassiana*) & 14 November 2021 (*M. anisopliae*) (IPM 2). |
| | Bsh | 'Fuerte' | IPM 1; chemical | Predatory mites & EPNs (IPM 1); Spinetoram (chemical) | 29 August 2021 (mites) & 13 October 2021 (EPNs) (IPM 1); 13 October 2021 & 29 October 2021 (chemical). |
| | Bsh | 'Hass' | IPM 2; chemical | *B. bassiana* (1x); *B. bassiana* (2x); Spinetoram (chemical) | 18 August 2021, 16 September 2021, 21 October 2021, & 18 November 2021 for all three treatments. |
| 2022-2023 | Bsh | 'Fuerte' | IPM 1; IPM 2; chemical | EPNs, predatory mites & strategic chemical (IPM 1); *M. anisopliae* & *B. bassiana* (IPM 2); Spinetoram (chemical) | 12 June 2022 (EPNs), 3 August 2022 (mites), 13 September 2022 (formetanate + sugar) (chemical), 15 September 2022 (mites), & 15 November 2022 (EPNs) (IPM 1); 13 September 2022 (*M. anisopliae*), & 27 September 2022 (*B. bassiana*) (IPM 2); 27 September 2022 (chemical) |

entomopathogenic nematodes (e.g. *Steinernema feltiae*), entomopathogenic fungi (e.g., *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* parasitized 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). Entomopathogenic fungi like *B. bassiana* can be incorporated into an IPM programme to mitigate resistance build-up and reduce the number of chemical sprays (Bara & Laing, 2019b).

## CONCLUSION

The results from the novel work on thrips in the avocado industry showed that thrips damage and numbers were higher in the drier climate zones compared to the wetter zones. This was true for dry and wet seasons too. 'Fuerte' fruit with characteristic calyx were more susceptible to thrips damage in general. Thrips total counts correlated significantly with the observed damage on 'Hass' and 'Fuerte' however, no relationship could be confirmed between the size of the fruitlets and thrips counts or damage. This early dataset was, however, very limited. IPM intervention strategies that showed results that could be compared to the untreated control through Henderson-Tilton data transformation, have proven successful and comparable in chemical intervention strategy outcomes. Very low numbers of thrips (2.33 thrips on average per fruit) resulted in 10% fruit damage, suggesting that thrips numbers should be managed in the field using IPM strategies that prevent, continuously monitor for, and successfully control thrips.


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