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Identity and Population Density of *Thrips hawaiiensis* (Insecta: Thysanoptera) in Conventional "Magallanes" Pummelo Orchard in Carmen, Davao del Norte, Philippines

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A conventional "Magallanes" Pummelo orchard in Brgy. Minda, Carmen, Davao del Norte, Philippines was selected to assess thrips species composition, population density, and associated natural enemies. The insecticide treated pummelo orchard was situated adjacent to vast Cavendish banana plantations. Thrips were collected weekly from September 2017 to July 2018 from five different randomly selected flowering pummelo trees by destructive sampling and yellow sticky trap methods. Thrips were sorted and examined under the microscope. Findings of the study showed that *Thrips hawaiiensis* (Morgan), (Thripidae: Thripinae) was the only species of thrips infesting "Magallanes" pummelo. This constitutes the first report in this host variety. *Thrips hawaiiensis* population fluctuated within the six phenological stages of pummelo fruiting cycle but was significantly high at the peak of flowering stage. Population started to decline at petal fall and fruit development stages although the pummelos still produced small numbers of new terminal shoots. These shoots provided stable food source for remaining thrips larvae. Population was significantly low when the fruits are at harvestable stage ($p < 0.01$). Among the weather variables monitored temperature had very low coefficient value ($r = 0.09$) with a positive relationship to thrips population; however, together with rainfall and relative humidity, statistical significance value did not significantly ($p > 0.05$) influence thrips population. Furthermore, absence of parasitoids during the whole duration of the study may have been affected by the conventional pest management continuously being practiced by plantation owners of using broad spectrum insecticides that may have affected the non-target species in the area.

Keywords: destructive sampling, insects, Thripidae, *Thrips hawaiiensis*

INTRODUCTION

Thrips are tiny phytophagous, mycophagous, or predatory insects with an adult body size ranging from 0.5 to 15 mm (Reynaud et al. 2008; Morse and Hoddle 2006; Reynaud 2010; Goldarazena 2011). There are over six thousand (6,000) species of thrips (Insecta: Thysanoptera) known worldwide (Buckman et al. 2013). Several species of thrips are well known for causing plant damage and reduction in crop yield (Morse and Hoddle 2006). In addition to direct or cosmetic plant damage, thrips vector a number of microbial pathogens through mechanical transmission (Ullman et al. 1997). Bagaoisan et al. (2019) provided the first available literature on thrips, *Thrips hawaiiensis* (Morgan), infesting "Magallanes" pummelo in Ato Belen Farms, Laguna, Philippines. The studies conducted on thrips in other countries are on lemon, orange, and grapefruit. There are several species of thrips that cause flower injuries and fruit blemishes reported on citrus. Some of the reported thrips species are *Scirtothrips citri* Moulton, *S. aurantii* Faure, *S. dorsalis* Hood, *Pezothrips kellyanus* Bagnall, *Frankliniella bispinosa* Morgan, *Chaetanaphothrips orchidii* Moulton, *Danothrips trifasciatus* Sakimura, and *Heliothrips haemorrhoidalis* Bouché were considered economically important insect pests of citrus (Reyes 1994; Chiu et al. 1991; Chen et al. 2018). Chang (1995) mentioned that *S. dorsalis* and *T. hawaiiensis* frequently occur in Citrus orchards in Taiwan. Moreover, Chiu et al. (1991) found out that *T. hawaiiensis, S. dorsalis, F. intonsa* and *Megalurothrips usitatus* occur in Citrus orchards in southern Taiwan, with high population densities during flowering. *T. hawaiiensis* aggregated in the flowers, and damaged flowers and young fruits by feeding and ovipositing on them. *S. dorsalis* fed on leaflets, producing brown spots.

Specific hymenopteran parasitoids attack thrips eggs (Mymaridae: *Megaphragma* spp.) and larvae (Eulophidae: *Ceranisus* spp.) however, these parasitoids do not appear to be major regulators of thrips population growth. The study of Hirose et al. (1993) indicated that the eulophid larval parasitoid *Ceranisus menes* Walker was the most effective parasitoid of *Thrips palmi* Karny but was only limited to home gardens in Thailand. Van Lenteren and Loomans (1999) indicated that several promising natural enemies of thrips were identified, however, they are effective only under specific environmental conditions. Research on the biological control of thrips is more common in vegetables than in ornamentals. Predatory thrips and parasitoids, though the only very specific natural enemies of thrips, have not shown much potential for control.

Pummelo (*Citrus maxima* Burm.) has grown as an essential commodity in international markets. In terms of land area, China is the top producing country in 2011 followed by Thailand, USA, Mexico, South Africa, Cuba, India, Argentina, Bangladesh, and last is the Philippines. China remained at the top in terms of production volume for 2012, however, Philippines is ranked 20 since the country's production is only for local consumption (ITFNET 2013). Pummelo production averaged 30,158 metric tons from 2012 to 2014. It was 30,506 metric tons in 2012 and decreased to 29,973 and 29,994 metric tons in 2013 and 2014, respectively. No imports were noted during the reference years. The country exported less than 1 metric ton of pummelo in 2012 and 2013, and increased to 26 metric tons in 2014 (PSA 2015). Davao City is the top producer in the country, contributed to 34.5 percent to the Philippine pummelo production and followed by Isabela, Cagayan, Nueva Vizcaya, and Davao Oriental. The expansion of area planted accompanied by decreasing volume of production have greatly affected the productivity of pummelo. This is reflected on the declining trend of its yield with value of production from 1998 to 2008 is decreasing at an average of two percent (Luistria et al. 2009).

Proper identification of the pest is a prerequisite to a successful pest control program. Effective pest control is often dependent on basic knowledge of the pest, including the life cycle stage where the pest is most likely to be controlled by the method chosen (Gaver and Futch 2012). The knowledge of different pests and their density in a crop and in moments of their development and population increase is very important when an Integrated Pest Management (IPM) is chosen to control a specific pest (Elimem and Chermiti 2013). Monitoring is one of the key elements in integrated pest management which determines what is happening in the crop such as pests present, pest abundance, and crop stage (Johnson 2001; Kindlmann and Dixon 2010; Aliakbarpour et al. 2010).

The population density of thrips on pummelo in the Philippines seems poorly studied. Ideally, intensive surveillance of thrips population is necessary to understand temporal dynamics and distribution in pummelo plantations where no pesticide applications are done. However, almost all the pummelo plantations in the Davao area are continuously bombarded with commercial pesticides, a management decision of plantation owners. No site in the plantation that has not been exposed to pesticides nor been assured that no pesticides will be applied within the fruiting season. The study aimed to identify species of thrips infesting pummelo, determine population density, and their natural enemies in a conventional orchard in Brgy. Minda, Carmen, Davao del Norte, Philippines.

MATERIALS AND METHODS

Study Site

This study was conducted in conventional 'Magallanes' pummelo orchard in barangay Minda, Carmen, Davao del Norte. The study site has a latitude of 7°22'57.72" N and longitude of 125°34'40.95" E at an altitude of 90 feet. The 'Magallanes' pummelo trees were planted in a total of 26.90 ha with a planting distance of 8x8 m, and trees were about 15 - 20 years old. A portion of the orchard about 4.0 ha was used as study plot. The orchard is situated adjacent to "Cavendish" banana plantation.

Thrips Population Density

Survey of thrips on pummelos was conducted weekly from September 2017 to July 2018, or a total of 38 weeks. Additionally, two sampling methods were assessed to determine which method will record, capture, and collect the most number of thrips.

There were five different pummelo trees sampled randomly each week. Sampling was done during the flowering stage (flushing, flowering, petal fall), at early stages of fruit development, and up to harvest where samples composed of terminal shoots (growing terminal with new shoots, flowers, fruitlets). Four yellow sticky traps were installed a week before the destructive sampling. The yellow sticky traps (10 x 15 cm) were modified from (Aliakbarpour et al. 2010) using yellow plastic cards coated with unscented petroleum jelly. Yellow sticky traps were arranged in four cardinal directions (North, South, East, West) within the canopy at a height of 180 cm from the ground. On the 6th day, all sticky traps were collected, labelled appropriately with the date and tree number, and were brought to the laboratory for processing. All unwanted or contaminants were discarded and all the thrips were sorted out according to stage, sex and were counted and recorded using a stereomicroscope (Euromex StereoBlue). A set of newly prepared sticky trap was again installed and due for collection for the next six days.

Destructive sampling was done in the same tree sampled for the modified sticky trapping. Six terminal shoots were taken within the canopy, two twigs each from the upper, middle, and lower portions of pummelo tree. All thrips samples were carefully collected and placed into a vial with 70% ethanol. Specimens in the vial were examined and counted for various thrips life stages such as larva 1, larva 2, pro-pupa, pupa, and adults (female/male). Counting was done under stereomicroscope (Euromex StereoBlue).

Identification of Thrips

Adult thrips were counted and representative samples were mounted on slide to determine the identity of thrips. The method for mounting specimens was modified from the protocol of Bisevac (1997), Mirab-Balou and Chen (2010), and Silveira and Haro (2016). Thrips specimens were macerated in 10% KOH solution for five minutes. Then, specimens were dehydrated in 60% and 95% ethanol. Specimens were cleared in clove bud oil for 10 - 15 minutes. Cleared thrips were then fixed with ventral side upward in Canada balsam before being mounted onto glass slides, and covered with a coverslip.

The mounted thrips specimens were examined, and identified under a compound microscope (Motic Panthera L) using the published keys of Reyes (1994), Mound and Masumoto (2005), and Mound and Azidah (2009). Photomicrographs were taken using the imaging system of Motic Panthera L under 40x magnification.

Natural Enemies Sampling

Sampling for insect parasitoids was done in the same 'Magallanes' pummelo trees sampled for sticky trap and destructive sampling. Six terminal shoots were taken within the canopy, two twigs each from the upper, middle, and lower portions of pummelo tree (Ceballo et al. 1998). Terminal shoots were placed in modified emergence cage made up of rectangular microwavable plastic containers measuring 26 x 15 x 8 cm with snap-on lids. The lid had a hole made up of silk organza for proofing and ventilation. Modified emergence cages were kept for one month inside the isolation room and checked weekly for emergence of natural enemies. The isolation room had 25°C ± 3°C temperature, 70 ± 10% relative humidity, and 16:08 h light: dark photoperiod.

Abiotic Factors

The number of thrips was recorded from both destructive and yellow trap samplings at weekly intervals. Average daily temperature, relative humidity, and rainfall during the conduct of the study were gathered from Davis climatic station.

Statistical Analyses

The population of thrips collected from destructive sampling and modified sticky traps was compared using Student t-test analysis. Thrips abundance was plotted against pummelo phenological stages.

RESULTS AND DISCUSSION

Identity of Pummelo Thrips

Findings showed that *Thrips hawaiiensis* (Morgan) was the only species of thrips infesting "Magallanes" pummelo. This species was also in congruence from the study of Bagaoisan et al. (2019) where *T. hawaiiensis* was the first reported thrips species infesting pomelo in the Philippines. Thrips samples were compared with the voucher of *T. hawaiiensis* specimens previously identified by Cecilia P. Reyes collected from Cavendish banana and deposited in Entomology and Nematology Research and Development Department of Tagum Agricultural Development Co., Inc (TADECO) at Panabo City. The specimens corresponded to the bicolored form with lighter yellow or yellowish-beige head and thorax regions and distinctly dark brown abdomen (Figure 1A). Reyes (1994) stated that *T. hawaiiensis* has a bicolored body, with yellow to yellowish orange head and thorax, and with brown abdomen. Using the keys from Mound and Masumoto (2005) and Mound and Azidah (2009), all the distinguishing characters of the thrips samples positively showed to be all *T. hawaiiensis*. All samples had 7-segmented antennae with the antennal segment III having yellow or lighter color than the rest of the segments (Figure 1B). Samples possessed *T. hawaiiensis* characters listed as follows: forewing first vein with 3 setae on distal half (Figure 1C); pronotum with 2 pairs of long posteroangular setae (Figure 1D); and head wider than long; mesonotum with lines of sculpture, metanotum with lines of sculpture longitudinal medially and median setae arising at anterior margin (Figure 1E) with campaniform sensilla present (Figure1F); abdominal sternite VII with discal setae (Figure 2A); and, tergite VIII marginal comb complete (Figure 2B).

Thrips hawaiiensis Morgan as reported by Murai (2001) is a common flower-inhabiting thrips distributed in the Asian and Pacific regions. Mound and Masumoto (2005) pointed out that *T. hawaiiensis* is a highly polyphagous

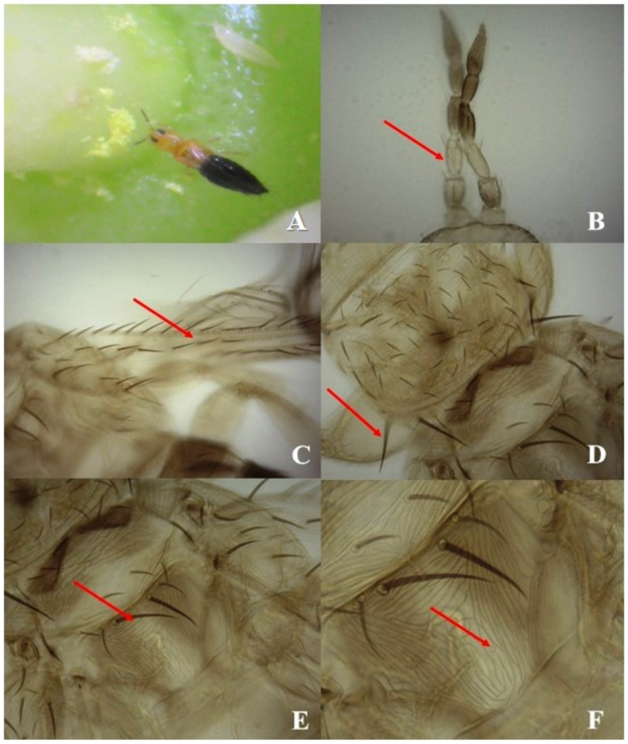

Fig. 1. Morphological characters of *Thrips hawaiiensis*. (A) female on the pollen tube of pummelo flower; (B) antennae; (C) forewing; (D) posteroangular setae; (E) median setae; and, (F) campaniform sensillum. Sample A was viewed at 4x and Samples B to F were viewed at 40x. Photos taken from mounted thrips specimen last August 19, 2018.

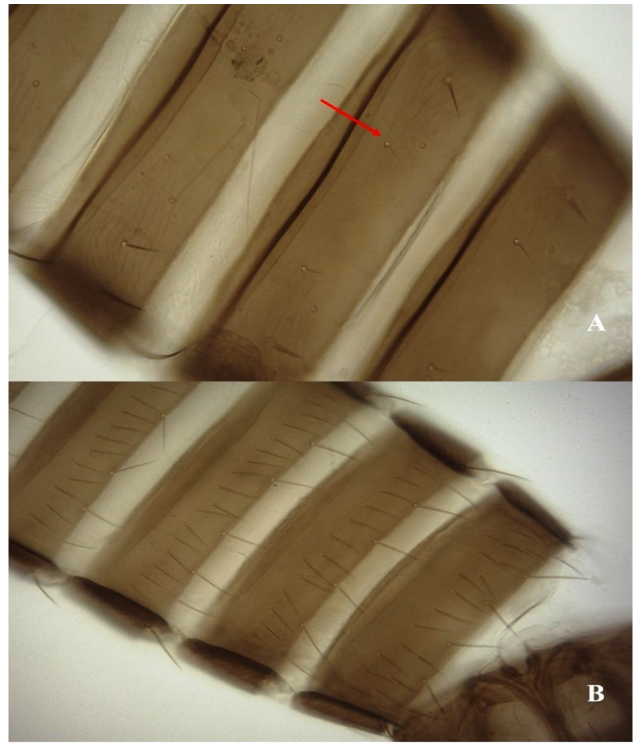

Fig. 2. Abdominal characters of *Thrips hawaiiensis*. (A) discal setae on sternite VII; and, (B) complete marginal comb on tergite VIII. Samples B-F were viewed at 40x. Photos taken from mounted thrips specimen last August 19, 2018.

species which has been recorded from the flowers of many plants. It was also pointed out by Marullo and De Grazia (2017) that *T. hawaiiensis* is a species of thrips showing invasive capacities.

The result of this identification is supplemental to what was reported by Bagaoisan et al. (2019) that *T. hawaiiensis* is the sole species associated with pummelo. The host range of *T. hawaiiensis* as pest now includes pummelo that can be possibly linked to the monoculture production of Cavendish banana and pummelo in Davao Del Norte. Thrips population are likely to increase when flowers, flushes and terminal shoots are abundant and favors pest species with short developmental period and with overlapping generations like the *T. hawaiiensis*.

This thrips species belongs to family Thripidae and subfamily Thripinae. *T. hawaiiensis* has been found to be the primary pest infesting Cavendish banana where the pummelo orchard is surrounded with vast plantation of Cavendish banana.

Thrips Population Density

The population density is considered as the mean number of respective life stages of thrips (larva, propupa, pupa, and adult) per terminal shoot on all pummelo phenology stages is shown in Table 1. *T. hawaiiensis* was encountered throughout the pummelo growing season however, population peak was observed within the flowering period with a total population of 1,335 individuals per terminal shoot. On the other hand, low populations were recorded during flushing and fruit development stages with means of 148 ± 40.9 and 143 ± 26.2 individuals, respectively. The lowest populations were recorded during petal fall and harvestable stages of pummelo with only 17 ± 13.2 and 7 ± 3.9 individuals, respectively.

Majority of the thrips population data were collected using destructive sampling and some from the yellow sticky traps. Destructive sampling provided more accurate estimate and counted a greater number of thrips for the whole season.

It was also observed that all the adults monitored throughout the duration of the experiment were females and no male thrips were encountered. Reyes (1994) mentioned that female thrips predominate in the population because they outlive males. The absence of male thrips was similar to the study of Aliakbarpour and Rawi (2011) where no male thrips was observed on *T.*

Table 1. Mean number ± SE of *Thrips hawaiiensis* (Morgan)[1] sampled per terminal shoot (n = 228) (September 2017 to July 2018; Minda, Carmen, Davao del Norte, Philippines).

Pummelo Phenology	Larva 1	Larva 2	Pne-Pupa	Pupa	Adult	Mean Thrips Population
Flushing	28 ±22.9	49 ±13.4	9 ±7.6	22 ±12.0	40 ±20.1	148 ±40.9
Flowering	360±300.9	794 ±469.6	66 ±57.8	12 ±6.4	103 ±82.3	1,335 ±780.2
Petal Fall	2 ±1.9	9 ±1.9	1 ±1.3	-	4 ±1.8	17 ±13.2
Fruit Development	18 ±4.9	65 ±16.7	14 ±6.1	3 ±1.1	42 ±10.8	143 ±26.2
Harvestable	-	5 ±2.8	1 ±0.7	0 ±0.2	0 ±0.4	7 ±3.9

[1]Sampling was conducted to coincide with the flushing until the harvestable stage.

hawaiiensis and *S. dorsalis* in pesticide-treated mango orchard in Malaysia, however, the authors did not elaborate the findings. Lewis (1973) also mentioned that under equal sex ratio the females apparently predominate because they often live longer than the males.

The population fluctuation of *T. hawaiiensis* from flushing to pummelo harvesting is shown in Figure 3. At flushing stage, *T. hawaiiensis* population ranged from 89 to 227 thrips per week. The population abruptly increased during the flowering stage with 2,878 individuals per terminal shoot per week. Thereafter, thrips population drastically dropped during the petal fall with 0-23 individuals. After petal fall, the population slightly increased during fruit development from 3 to 469 individuals per terminal shoot. Thereafter, negligible population was observed at harvestable stage.

It is evident from the results that the highest thrips population was recorded during the flowering stage. On the other hand, negligible populations were recorded during flushing, petal fall, and fruit development stages. As cited from Affandi and Emilda (2009) the population fluctuation of flower thrips would be a function of flower density. Varatharajan and Chochong (2004) also pointed that in the case of flower inhabiting thrips, their distribution and abundance were found to be in tune with flowering stage. Funderburk (2002) indicated that young leaves are exploited by adult thrips when flowers are scarce as the leaves are preferred as a more stable source of food for developing larvae. Negligible population of thrips was observed during harvestable stage due to scarcity of new leaves.

The experimental site is a commercial production area where insecticide sprays are regularly applied against thrips. As shown in Figure 3, the red arrows indicate application of dimethoate while the blue arrow indicates the application of deltamethrin. Throughout the pummelo growing season, dimethoate was applied five times while only once for deltamethrin. Based on thrips population fluctuation, insecticide applications in pummelo being directed against thrips are improperly timed: aside from being laborious and expensive,

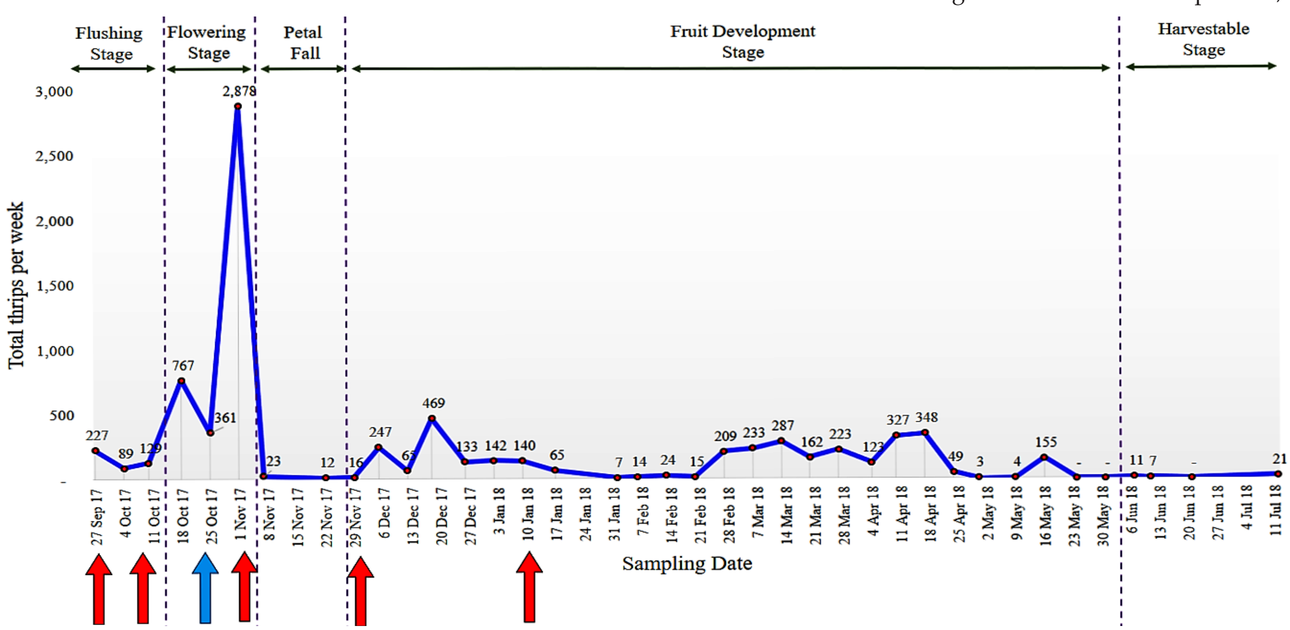

Fig. 3. Population fluctuations of the flower thrips, *Thrips hawaiiensis* from onset of flushing until the fruits are at harvestable stage, with weekly population significant at *p*- value of 0.0152 (September 2017 to July 2018; Minda, Carmen, Davao del Norte, Philippines). The red arrows indicate application of dimethoate while the blue arrow for deltamethrin.

excessive insecticide application will be deleterious to non -target pests and may contribute to pests developing resistance to insecticides. Morse et al. (2014) indicated that citrus thrips, together with red scale and red mite, have a history of developing resistance to pesticides. Moreover, citrus thrips had developed resistance to any chemical used repeatedly for its control.

In addition, the pummelo thrips puncture the epidermal cells, damaging the fruit by scarring the peel. Scars appear as water-soaked marks in the rind. The marks stay as the fruit grows creating permanent blemishes on the rind which affects cosmetic marketability of the fruit. Figure 4 shows thrips damage of the entire rind surface (right photo). According to Vassiliou (2011) thrips prefers to feed in sheltered areas such as under the calyx, between touching fruits, and where a leaf or a twig touches the fruit. The damage possibly caused by the sporadic flowering and new terminal shoots emerging throughout the early fruit development stages of pummelo where it provided food source for thrips.

Correlation Between Population of Thrips hawaiiensis (Morgan) and Abiotic Factors

Weather parameters were plotted against *T. hawaiiensis* population to determine the influence of temperature, relative humidity and rainfall on the pest population. The amount of rainfall per week that prevailed during the sampling period ranged from 0.076 – 33.884 mm (Figure 5). The highest amount of rainfall was recorded on December 20, 2017 while the lowest on April 3, 2018. Mean temperature ranged from 24°C to 28°C whereas, relative humidity varied between 81.9% and 90.5% (Figure 6).

Fig. 4. Samples of harvested pummelo fruits without thrips damage (left) and with thrips damage (right).

The results of correlation analysis suggest that the number of flower thrips, *T. hawaiiensis* in the orchard is not dependent on the weekly changes on rainfall, temperature, and relative humidity. This result is similar to Pearsall and Myers (2000) as cited from Merene (2015) that seasonal changes in temperature did not appear to result in any consistent effect on the population density of western flower thrips. However, the present results do not conform to the report in Queensland citrus orchard where subtle change in any of the weather variables have significant effect on the field populations of citrus

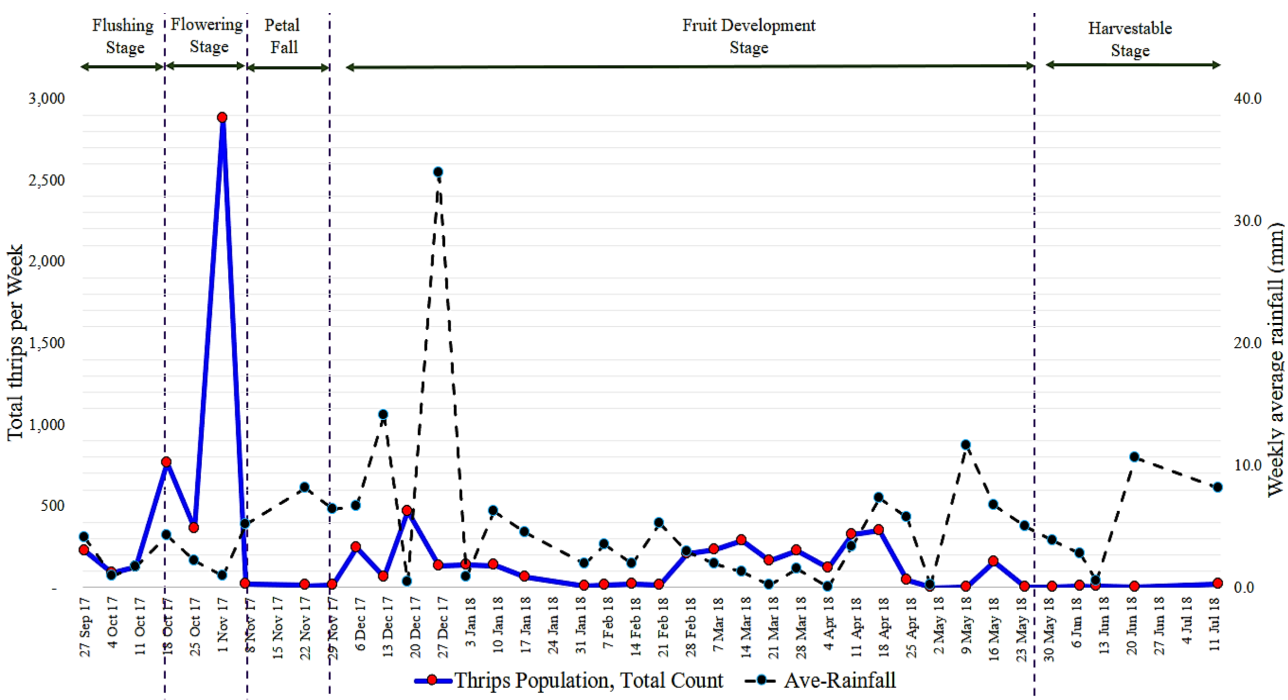

Fig. 5. Influence of rainfall on the population of *Thrips hawaiiensis* in pummelo (September 2017 to July 2018; Minda, Carmen, Davao del Norte, Philippines).

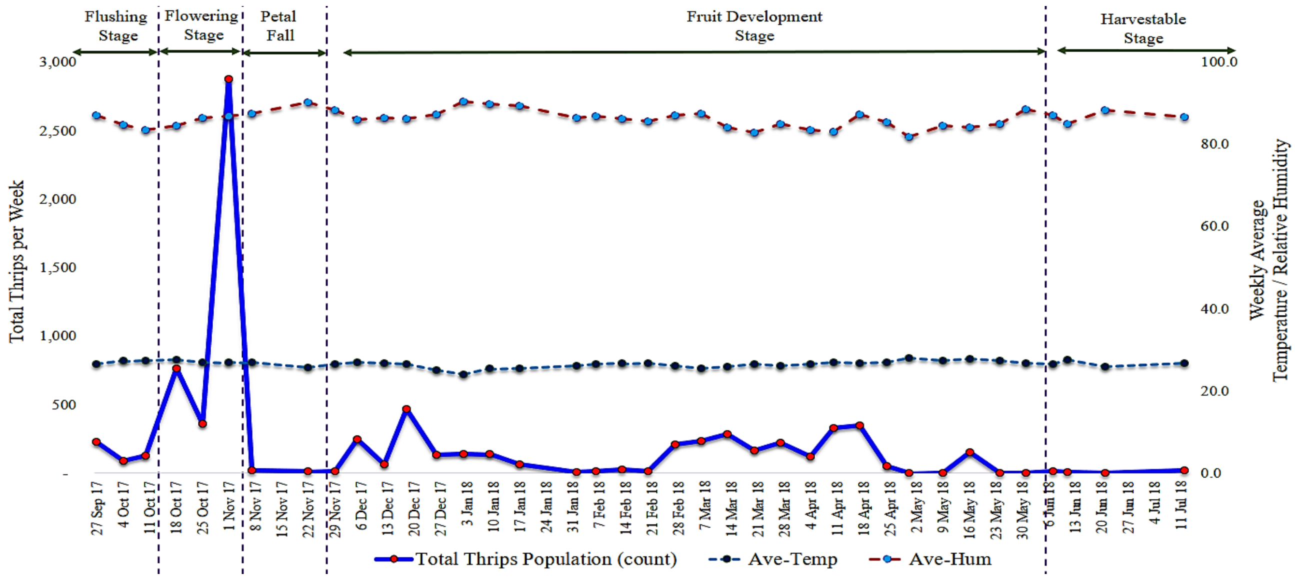

Fig. 6. Influence of temperature and humidity on the population of *Thrips hawaiiensis* in pummelo (September 2017 to July 2018; Minda, Carmen, Davao del Norte, Philippines).

mealybugs and its associated parasitoid (Davies et al. 2004; Ceballo and Walter 2005; Ceballo et al. 2010). Our result is based on one fruiting season only, thus there is a need to verify the present findings for another season using more samples of untreated and observe if similar results will be obtained and a more conclusive statement can be made.

Natural Enemies Monitored

No insect parasitoid emerged from thrips in all the dates collected in the experimental area and allowed to emerge in the laboratory (Table 3). It should be noted that dimethoate and deltamethrin were regularly applied in the orchard at 15- to 30- day interval. The spraying of dimethoate and deltamethrin proved to be deleterious to the natural enemies of thrips (Rocha et al. 2015). They further pointed out that orchard regularly sprayed with broad spectrum insecticides had fewer species and lower population of natural enemies than orchard that did not use insecticides. Moreover, insecticide applications that suppress generalist predators frequently increase the population of *Frankliniella* thrips (Funderburk 2009).

The pest management being practiced by plantation owners of using broad spectrum insecticides continuously may have affected the non-target species in the area. Predators and parasitoids are among the non-target species that may have been negatively affected by the pesticides and were not able to re-establish due to the continuous exposure to the toxicant. Other non-target species are the bees and other pollinators whose presence

Table 2. Correlation coefficients (r) for weather factors affecting thrips populations.

Weather Variable	Pearson's Correlation	*P*-value
Rainfall (mm)	-0.168	0.313
Temperature	0.089	0.834
Relative Humidity	-0.015	0.929

Table 3. Thrips emergence and percentage parasitism from parasitoid emergence monitoring (September 2017 to May 2018; Minda, Carmen, Davao del Norte).

Date Collected	Number of Thrips Larvae Emerged	% Parasitized
07-Sep-17	16	0
04-Oct-17	0	0
10-Oct-17	18	0
26-Oct-17	0	0
25-Oct-17	17	0
27-Sep-17	0	0
07-Nov-17	11	0
22-Nov-17	0	0
29-Nov-17	0	0
05-Dec-17	0	0
04-Mar-18	0	0
26-Dec-18	0	0
02-Jan-18	15	0
17-Jan-18	10	0
24-Jan-18	14	0
06-Feb-18	8	0
13-Feb-18	7	0
20-Feb-18	25	0
27-Feb-18	2	0
06-Mar-18	31	0
13-Mar-18	36	0
20-Mar-18	56	0
27-Mar-18	0	0
03-Apr-18	47	0
10-Apr-18	30	0
17-Apr-18	17	0
24-Apr-18	11	0
30-Apr-18	8	0
09-May-18	9	0
16-May-18	5	0
24-May-18	0	0
31-May-18	0	0

and numbers in the area may likewise be at risk if this practice will continue. Therefore, there is a need to find other management options that are effective against the thrips but safe to non-target species.

CONCLUSION

The flower thrips, *Thrips hawaiiensis* Morgan, was the only thrips species collected during the entire pummelo fruiting season from September 2017 to July 2018. Despite the continuous exposure of the pummelo trees to insecticides treatments, thrips are still present. Thrips population was initially low at the onset flowering which is during the early stages of flower initiation however, as flowering stage progresses, thrips population correspondingly increased. Population was highest prior to mid flowering stage, which indicates more numbers of flowers present are available for thrips to infest. The decline in thrips population was observed at petal fall and fruit development stages when pummelo trees produced limited numbers of new terminal shoots/ leaves. Negligible population of thrips was observed during harvestable stage due to scarcity of new leaves.

Destructive sampling of monitoring *T. hawaiiensis* is much better than installation of yellow sticky traps, as there is significantly more number of thrips counted thus providing a relatively accurate population estimate. Thrips captured on the yellow sticky traps were mostly adults indicating that it only capture flying adults which are more useful as an early warning system to detect impending increase in adult thrips population in the field.

No parasitoids were observed from the samples collected. The absence of natural enemies during the whole duration of the study may have been affected by the conventional pest management being practiced by plantation owners of using broad spectrum insecticides continuously may have affected the non-target species in the area. Weather parameters revealed that the density of *T. hawaiiensis* population had weak relationship to rainfall, temperature, and relative humidity. The seasonal changes in temperature did not appear to result in any consistent influence on thrips population.

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