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Solomon Danjuma
(a) Department of Crop Production, Faculty of Agriculture, Ibrahim Badamasi Babangida University, P.M.B 11, Lapai, Niger State, Nigeria.
(b) Department of Biology, Faculty of Science, Prince of Songkla University, Hat Yai, Thailand. 90112.

Singtoe Boonrotpong
Department of Biology, Faculty of Science, Prince of Songkla University, Hat Yai, Thailand. 90112.

Narit Thaochan
Department of Pest Management, Faculty of Natural Resources, Prince of Songkla University, Hat Yai, Thailand. 90112.

Surakrai Permkam
Department of Pest Management, Faculty of Natural Resources, Prince of Songkla University, Hat Yai, Thailand. 90112.

Chutamas Satasook
Department of Biology, Faculty of Science, Prince of Songkla University, Hat Yai, Thailand. 90112.

Correspondence:
Solomon Danjuma
(a) Department of Crop Production, Faculty of Agriculture, Ibrahim Badamasi Babangida University, P.M.B 11, Lapai, Niger State, Nigeria.
(b)Department of Biology, Faculty of Science, Prince of Songkla University, Hat Yai, Thailand. 90112.

Seasonality of the Asian papaya fruit fly *Bactrocera papayae* Drew and Hancock (Diptera: Tephritidae) on guava *Psidium guajava* in peninsular Thailand

Solomon Danjuma, Singtoe Boonrotpong, Narit Thaochan, Surakrai Permkam and Chutamas Satasook

Abstract
The seasonality of *Bactrocera papayae* (Drew and Hancock), a notorious pests of fruits, was studied for one year (August 2011 to August 2012) in guava orchards and their surrounding environments in peninsular Thailand. The fruit fly was collected using Steiner traps baited with methyl eugenol as an attractant. Guava fruits were sampled and categorised into three developmental stages—ripe, mature and immature—with the aid of a fruit firmness tester. The fly species was trapped in the field throughout the season and was found exhibit distinct patterns of seasonal occurrence with two population peaks, during August-September and May. The density of *B. papayae* was high at all study sites. Fly population density was correlated with the interaction of temperature, rainfall and relative humidity. The fruit sampling revealed that the fruit fly emerged in larger numbers from ripe guava fruits

Keywords: *Bactrocera papayae*, guava, methyl eugenol, Steiner trap.

1. Introduction
Guava *Psidium guajava* (L.) is one of the most common fruits in Thailand, appearing at all stalls and markets. It is an important source of income and also represents an important part of gastronomic culture for Thai people. The fruit is produced via small-scale farming and sometimes at the subsistence level. It is found intercropped among rubber plantations surrounded by little or no forest and sometimes grown side-by-side or intercropped with other major economic fruits such as rambutan (*Nephelium lappaceum* L.), durian (*Durio zibethinus* L.), jackfruit (*Artocarpus heterophyllus* Lam.), rose apple (*Syzygium samarangense* Merrill & Perry) and mangosteen (*Garcinia mangostana* L.).
Infestation by fruit flies (Diptera: Tephritidae) leads to economic losses for smallholder farmers as well as a reduced source of essential dietary components to the population [1]. Infestation leads to losses of up to 12–60% in mango, 40–90% in guava and 12–60% in papaya [2]. The preferred fruit developmental stage of female fly has been studied. [3] Reported the mature stage of the Sharwil avocado to be more heavily infested by the Oriental fruit fly, *Bactrocera dorsalis* (Hendel). Similarly, [4] reported that an increase in the population of *B. invadens* (Drew and Hancock) appeared to be directly linked to the ripening of different mango cultivars. In peninsular Thailand, the damage to fleshy fruits is caused primarily by a limited number of highly polyphagous species, mostly *Bactrocera dorsalis* (Hendel) complex members and few other *Bactrocera* species. Most prominent of these polyphagous species are *Bactrocera carambolae* (Drew and Hancock), *Bactrocera papayae* (Drew and Hancock) and the cucurbit feeders *Bactrocera cucurbitae* (Coquillet), *Bactrocera umbrosa* (Fabricius), *Bactrocera correcta* (Bezzi) and *Bactrocera tau* (Walker) [5]. Of these, *B. papayae* was classified as highly polyphagous species and are prevalent in peninsular Thailand and Malaysia [5, 6]. Its polyphagous status has been confirmed by the total number of hosts from which they were reared. In this region, 193 host species have been reported for *B. papayae*. Amongst the listed hosts, guava, which is one of the most-consumed fruits in this region, was found to have yielded a significantly higher population of these flies compared to any other sampled host [5, 7].

A recent study by [8] revealed that both local (temperature and rainfall) and global climate variations have been reported to be responsible for the detected differences among fruit fly species and locations. Similarly, [9] stated that temperature is the dominant abiotic factor that directly affects the development, survival, range and abundance of herbivorous insects. Tephritid distribution and abundance are notably dependent on several abiotic factors (e.g., temperature, relative humidity, and rainfall) and several biotic factors (e.g., host plants and natural enemies) [10].

There are few ecological studies on fruit fly in Thailand, and [5] covered seven species of *Bactrocera* in Thailand and peninsular Malaysia with no consideration of specific fruits and with little or no statistical application, hypothesis or experimental design in mind. The seasonality, distribution and abundance of other fruit fly species have been studied in other parts of the world [11, 12, 13, 14, 15, 16, 17]. In peninsular Thailand, guava is available in all seasons, highly consumed and suffers a high rate of infestation from fruit fly. Therefore, it is pertinent to study the ecology of this fruit fly on this important fruit. This paper presents the first results of trapping of this fly in guava orchards and surrounding areas in peninsular Thailand. The aim of this study was to elucidate the seasonal abundance and pattern of distribution of *B. papayae* in guava orchards and their surroundings and to determine the most suitable guava developmental stage for its development and survival. All of this was aimed towards generating specific information necessary for the development of suitable control measures to reduce the damage caused by this notorious pest.

2. Materials and methods

This study was carried out for 53 consecutive weeks (August 2011 – August 2012).

2.1 Study areas

This study was carried out in the Songkhla province of peninsular Thailand, which lies approximately at latitude 7° 2' 56.7779"N and longitude 100° 28' 11.8945"E. This province is situated in tropical rainforest. Its rainfall distribution pattern is unimodal, and rainfall occurs within 8 months (May-December). The relative humidity ranged from 63.75–89.00% and temperature ranged from 24.55–30.38 °C during the period of the study, respectively. Guava orchards were selected from two environments, specifically agro-forest and urban areas. The agro-forest study sites were the Ban Koyai (BK) and Ban Phru (BP) rural settlement areas. The urban study sites were Hat Yai Nai (HN) and Prince of Songkla University (PSU), Hat Yai campus, respectively.

The selected orchards measured approximately 0.2, 0.4, 0.5 and 0.8 hectares for PSU, BK, HN and BP, respectively. Apart from the PSU orchard, which was planted with a local cultivar of guava, the other sites were monocropped exclusively with the same type of improved cultivar. The number of guava trees per site was on the order of 147, 192, 244 and 245 plants for PSU, HN, BP and BK, respectively. To keep fruits devoid of chemical residues, neither pesticides nor herbicides were used at any of the sites to control fruit flies or weeds; instead, the guava fruits were protected by bagging the fruits at the onset of fruit formation. The bags were made from poly bags lined on the inside with newspaper. All healthy immature fruits were bagged until the fruits were matured for harvest, and the unhealthy fruits were detached and disposed accordingly. The bagging of fruits was only practiced at the HN, BP and BK guava orchards. A combination of slashing and hoeing were the cultural methods used for weed control at all orchards. The agro-forest sites were situated within extensive rubber (*Hevea brasiliensis* Arg.) plantations. Other fruit-bearing plants within a radius of 3 km of the orchards were observed. The urban orchards were also screened for other fruit-bearing plants to a distance of 200 m. Fruit-bearing plants common to the surrounding areas of all sites were *A. heterophyllus*, *S. samarangense*, banana (*Musa* spp. L.), bitter bean (*Parkia speciosa* Hassk.), santol (*Sandoricum koetjape* Merr.), mango (*Mangifera indica* L.) and papaya (*Carica papaya* L.). Other fruit plants common to the agro-forest sites were sapodilla (*Manilkara zapota* L.), orange (*Citrus sinensis* L.), starfruit (*Averrhoa carambola* L.), *N. lappaceum*, *D. zibethinus*, *G. mangostana* and langsat (*Lansium domesticum* Corrêa.). Malabar almond (*Terminalia catappa* L.) was only common near the urban orchards. With the exception of bitter bean, all of the listed plants are hosts of the studied flies.

2.2 Traps and trapping

Trapping was conducted for 53 consecutive weeks. The trapping targeted *B. papayae*, which was the major fruit-infesting species. Steiner traps (Thailand modification) were used for fly trapping. Chemical lure-based trapping has previously been used for assessing fly populations [18]. Field populations of fruit fly have an equal sex ratio of 1:1 as assumed for most diploid insects, so number of males captured can be used to estimate number of females present. Males of the studied species have been found to largely respond to a parapheromone, methyl eugenol (Benzene, 1, 2,-dimethoxy-4-(2-propenyl) [6]. Therefore, the combination of Steiner traps and methyl eugenol was a suitable trapping method for these species. The adult male flies were trapped and killed solely with a mixture of methyl eugenol and pyrethroid (Changzhou Kangmei Chemical Industry, China) at the rate of 62.5 ml pyrethroid/1000 ml methyl eugenol. One millilitre of the mixture was used to impregnate a lid of 4.5cm diameter packed with cotton wool.

Six and three traps were placed within each agro-forest and urban orchard, respectively. Additionally, six traps were placed 500–1,500 m from the guava orchards at the agro-forest sites. Within all orchards, traps were hung permanently on guava trees. In the areas surrounding the agro-forest orchards, traps were mounted on rubber trees, sapodilla trees, banana trunks, bamboo trunks and bitter bean trees. The Steiner traps were suspended between 1.3 and 1.5 m above the ground in the guava orchards and 1.5 - 2.3 m outside of the guava orchards depending on the height of the vegetation present at each trap location. Fruit fly samples were collected from the traps on a weekly (7 days) basis at all sites. The lure + insecticide were recharged every 21 days, and the cotton wools were replaced every 42 days (6 weeks).

Fruit fly specimens were identified on the basis of the morphological characters detailed by [6] [19] with the aid of a stereomicroscope. Voucher specimens were deposited at the Entomology Research Unit of the Department of Biology, PSU, Hat Yai.

2.3 Guava fruit sampling

Fruit sampling followed the method of [20]. Guava fruits were sampled systematically from the trees on a monthly basis at all study sites. Sites were divided into homogeneous subgroups, and simple random sampling method was used to sample fruits within each subgroup [21]. A total of 20–50 guava fruits per month were sampled directly from the guava trees at each site.

All sampled fruits were packed in a Styrofoam box according to site of collection and transported to the laboratory. Fruits were then washed, dried and weighed, and maturity stages (ripe, mature and immature) were determined immediately by observing the fruits' colour (greenish = immature, green – brown = mature, and brown – yellow = ripe), size in diameters (2-4 cm = immature, >4-7 cm = mature, and >7cm = ripe) and hardness, was ascertained by exerting pressure with the fingers (very hard = immature, relatively soft and not breakable under pressure from finger = mature, and soft, easily broken under finger pressure = ripe). Finally, the classification was standardized with a digital fruit firmness tester (Penetrometer, Agriculture Solution LLC, Strong ME, USA) with an 11.1 mm plunger tip, and the results were recorded as kilogram-force (kgf). These were categorised as ripe when hardness was < 8.5±0.45 kgf, mature from 8.5-10.5±0.87 kgf and immature when hardness >10.5±0.55 kgf. Fruits were then placed individually in Plexiglass boxes of 20 cm X 15 cm X 7 cm covered at the bottom with sterilized sawdust with a thickness of 1 cm. A hole with a diameter of 8.4 cm was cut into the lid of each box and screened with netting materials to provide ventilation. Rearing conditions were maintained at 25 ± 1 °C, 75 ± 5% relative humidity (RH) and a photoperiod of L12:D12.

The boxes were checked after 7 days of culturing by sifting the sawdust to collect any pupated larvae. After 10 days, the fruit in each box was also cut open to ascertain that there were no more larvae left within the reared fruits. Collected pupae were then transferred into a Plexiglass box of 10 cm X 7.5 cm X 5.5 cm lined with tissue paper until emergence. Records of fruit weight, number of pupae and emerged flies were made for every fruit stage. Fruit that had suffered any type of physical damage, possessed exit holes or appeared diseased was excluded from the rearing experiment.

2.4 Data analysis

The data analyzed for this period were from the cultured guava fruits, weather information and insect counts. Because the fruit samples were of varying sizes, quantitative data were expressed as infestation indices following [16, 22], with the number of pupae expressed per weight of fruits (unit of 1 kg). Percentages of adult emergence per guava developmental stage for each sampling site was compared intraspecifically within the guava orchards using paired t-test statistics, and damage to the sampled guava trees observed in the field was expressed as percentage ranges.

Weather information (temperature, rainfall and relative humidity) was collected on a daily basis, then summarized into weekly and monthly data. The average number of flies caught per week for 53 weeks for each species and site was used to determine the relationships between the fly capture rate and weather variables (temperature, rainfall and relative humidity) by using correlation analysis (Spearman Rank Correlation).

Adult fly population collected by field mornitoring was compared intraspecifically as the species does responded to methyl eugenol differently. The means of the data generated for *B. papayae* was computed by dividing the corresponding data for each species by the number of traps employed per site. These were pooled into three groups as follows: (1) urban orchards, (2) agro-forest orchards, and (3) surroundings of agro-forest orchards, respectively. Fly was then compared based on the pooled data and site regrouping.

All trapped *B. papayae* counts were averaged per trap and per week and month separately for every studied site to compute the seasonality curves. Additionally, emerged fly from each guava developmental stage was counted. All fly counts were transformed using a log transformation (log[x+1]) to satisfy the assumption of homogeneity of variances. Standard ANOVA was then used to compare fly abundance. The Student-Newman-Keuls (SNK) test was adopted to compare means ($p<0.05$) [23].

3. Results and discussions

3.1 Fly population trapped

The mean populations of *B. papayae* trapped in agro-forest and urban sites over 53 consecutive weeks are summarized in Table 1 according to collection site.

Table 1: Mean (±SD) of *B. papayae* per trap over the period of a year

Environment	Trapping site	NT	*B. papayae*
Urban	Prince of Songkla University	3	4932.67 ± 72.31**bC**
	Hat Yai Nai	3	5762.33 ± 94.63**aB**
Agro-forest	Ban Koyai		
	1. Guava Orchard	6	1875.67 ± 38.82**bF**
	2. Around Guava Orchard	6	8278.67 ± 157.08**aA**
	Ban Phru		
	1. Guava Orchard	6	2444.33 ± 43.47**bE**
	2. Around Guava Orchard	6	3709.50 ± 55.37**aD**

*NT; number of trap

*Figures followed by different small letters in the same row for each site are significantly different and for those in the column followed by different capital letters are significantly different ($p<0.005$).

At the urban sites, monthly comparisons among orchards revealed that *B. papayae* population was significantly higher at HN than at PSU ($t=0.957$, $p=0.341$) (Table 1). Comparison within each agro-forest site revealed that significantly more *B. papayae* were trapped outside of the orchards than within the orchards ($t=5.436$, $p<0.001$, for BK and $t=2.469$, $p=0.015$, for BP, respectively) (Table 1). Comparisons among all sites revealed significant differences ($df=5$, $f=13.888$, $p<0.001$) (Table 1).

Comparison of species caught in (1) urban orchards, (2) agro-forest orchards, and (3) surroundings of agro-forest orchards revealed that significantly more *B. papayae* were trapped in urban orchards and in the vicinity of agro-forest orchards than within agro-forest orchards, but no significant difference was observed between urban orchards and the surroundings of agro-forest orchards ($df=2$, $f=18.908$, $p<0.001$).

Fly abundance was determined by comparing the population recovered from guava fruit rearing experiment. Fly recovered

population comparison revealed that flies were significantly more abundant at PSU than other sites, but no significant difference were observed among other sites (df=3, f=2.861, p=0.04). Pooled population of fly from the two environments (Agro-forest and urban) revealed no significant difference.

3.2 Fly population fluctuation

Continuous trapping at all study sites on a weekly basis for 53 weeks provided the seasonal abundance and distribution patterns of the studied fly species for a full year cycle. Figures 1 – 3 depict the mean number of flies trapped per week for all sites. The number of trapped flies fluctuated considerably. *B. papayae* were present in and around the guava orchards at all sites throughout the year. This was confirmed by the weekly trapping programme for the year (Figures 1 – 3). Captures of fly were recorded in all weeks, and *B. papayae* represented by a larger number of captured individuals. This scenario was common to all sites.

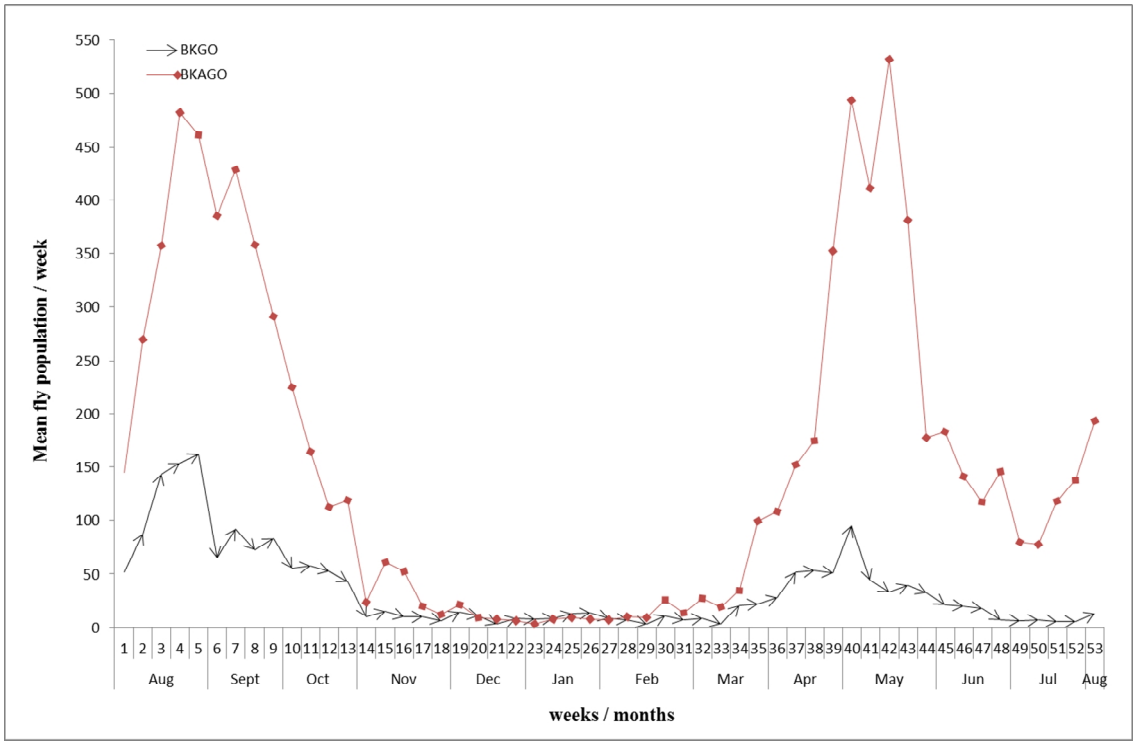

Fig 1: Weekly and monthly distributions of *B. papayae* in agro-forested areas: (a) BKGO = *B. papayae* trapped within Ban koyai guava orchard (b) BKAGO = *B. papayae* trapped Around Ban Koyai guava orchard.

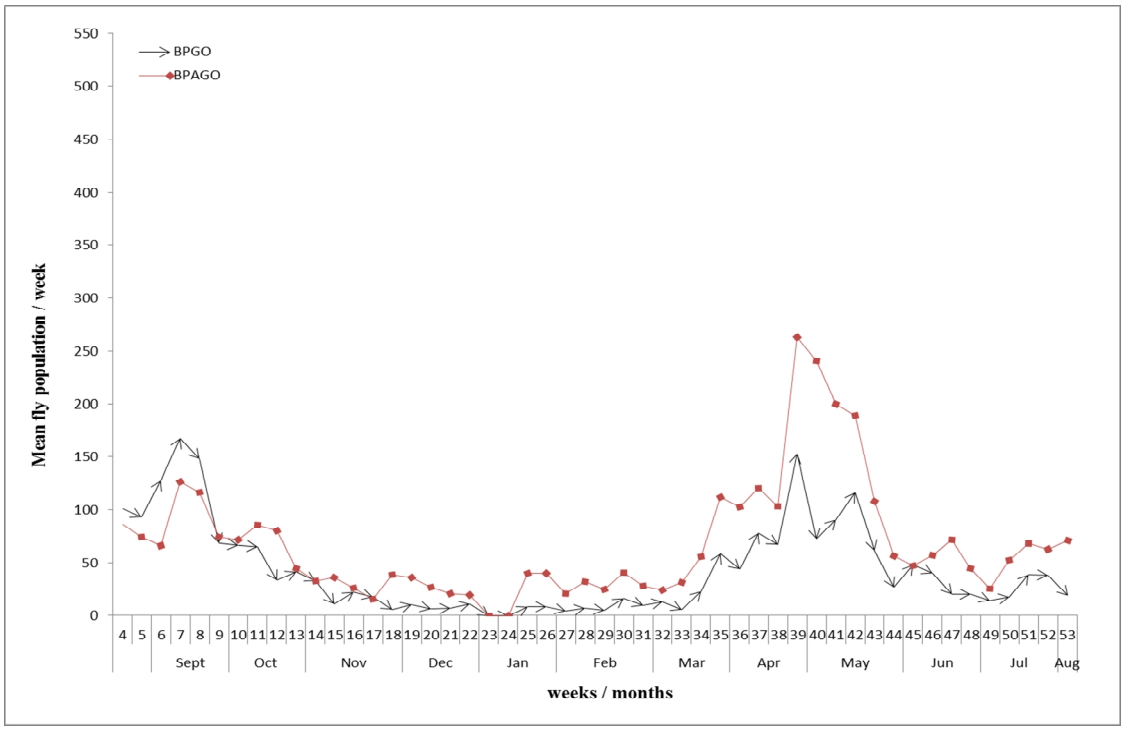

Fig 2: Weekly and monthly distributions of *B. papayae* in agro-forested areas: (a) BPGO = *B. papayae* trapped within Ban Phru guava orchard (b) BPAGO = *B. papayae* trapped Around Ban Phru guava orchard.

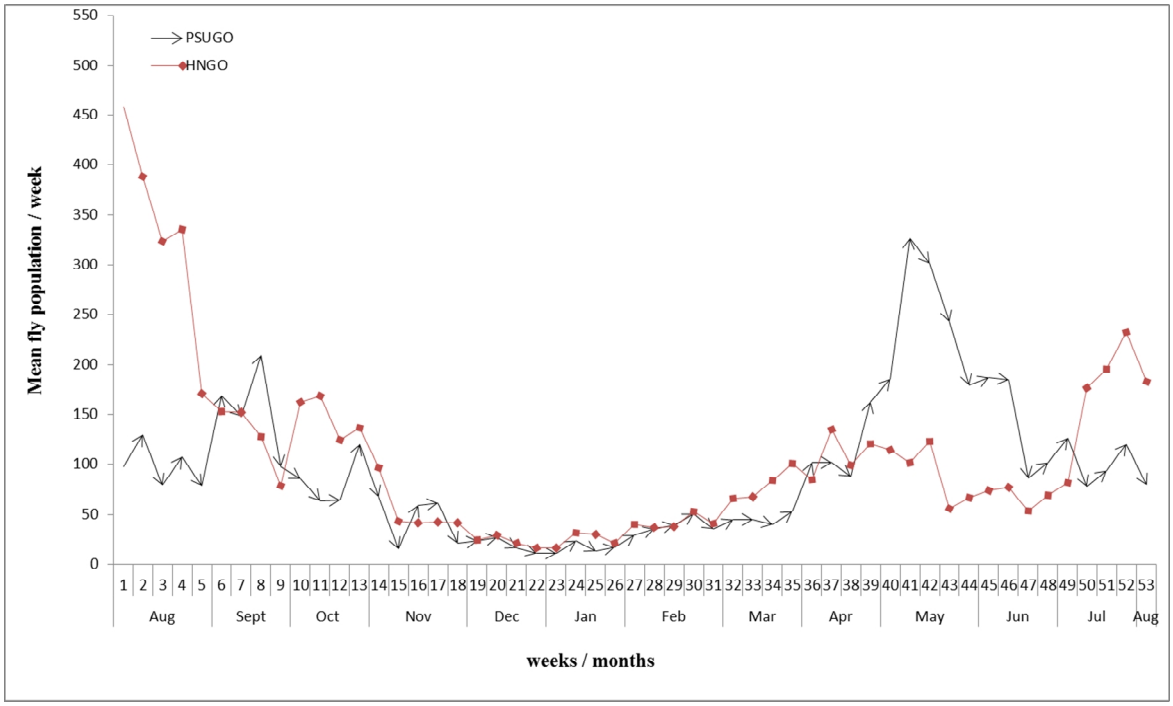

Fig 3: Weekly and monthly distributions of *B. papayae* in agro-forested areas: (a) PSUGO = *B. papayae* trapped within Prince of Songkla University guava orchard (b) HNGO = *B. papayae* trapped within Hat Yai Nai guava orchard.

The first peak period was observed to occur in August/September 2011 with a gradual decline from October 2011 through March 2012. The second peak period was noticed in April/May 2012 with a second decline from June–July 2012 (Figure 1 – 3). All peak periods corresponded with increase in temperature. Contrarily, the opposite was the case with rainfall.

3.3 Fly population fluctuations and weather data

The relationship between *B. papayae* captured and weather variables (Table 2) revealed inconsistency for all sampling sites. Significant correlation between number of flies captured and weather variables was detected for *B. papayae* trapped around guava orchards in the agro-forest areas and at PSU. A similar situation was revealed for *B. papayae* trapped at HN. All others were poorly correlated with weather variables.

Table 2: Results of correlation analysis for the relationship of *B. papayae* trapped at three weather variables (Weekly averages of temperature, rainfall and relative humidity) at two different environments in peninsular Thailand.

					Correlation (*r*)	
Environment	**Site**	**Farm**	**No of wk**	**Tem**	**R/fall**	**RH**
Agro- forested	Ban Koyai	GO	53	0.08ns	0.24ns	0.11ns
area		AGO	53	0.47*	0.48*	0.42*
	Ban Phru	GO	53	0.41*	0.09ns	0.28ns
		AGO	53	0.46*	0.21ns	0.36*
Human	HYN	GO	53	0.44*	0.30*	0.29*
Settlement area	PSU	GO	53	0.61**	0.43*	0.29*

ns=not significant; *=significant at p<0.05; **=significant at p<0.001. HYN: Hat Yai Nai; PSU: Prince of Songkla University; GO: Guava Orchard and AGO: Around Guava Orchard.

Correlation analysis revealed that temperature was clearly the most important variable at all sites, except for *B. papayae* trapped within the guava orchard at BK which exhibited no correlation with temperature. Except for this anomaly, medium to low correlations were observed between the number of flies trapped and other weather variables at all sites, respectively (Table 2).

3.4 Impact of guava fruit developmental stages on fly population

Improved guava trees produced fruits year-round during the sampling period. For the local varieties grown at PSU, fruit production peaked between April and May with a decline in production from June–July and an extended peak from August–September (Figure 3).

A total of 481, 369, 327 and 236 fruits were sampled at BK, BP, HN and PSU, respectively. The breakdown of total number of guava fruits sampled per developmental stage is presented in Table 3.

Table 3: Analysis of guava fruits sampled at various orchards based on developmental stages

Fruit	B K				B P				H N				PSU			
dev. stage	No of fruit	Inf. fruit (%)	pupae / kg	% fly em.	No of fruit	Inf. fruit (%)	pupae / kg	% fly em.	No of fruit	Inf. fruit (%)	pupae / kg	% fly em.	No of fruit	Inf. fruit (%)	pupae / kg	% fly em.
Ripe	188	173(92.02)	12.77cA	74.77	140	131(93.53)	13.96cA	80.39	125	107(85.60)	16.2bA	78.3	106	103(97.17)	20.18aA	75.05
Mature	149	102(68.46)	6.75cB	73.16	118	84(71.19)	8.49bB	65.26	89	59(66.29)	6.49cB	69.02	59	45(76.27)	9.75aB	63.37
Immature	144	46(31.94)	3.84aB	75.23	111	22(19.82)	1.42bC	65.05	113	26(23.01)	1.1cC	62.16	71	15(21.13)	0.75dC	64.52

* Each sampling site has four columns; first column shows numbers of guava fruit sampled per developmental stage, second column shows the number of infested fruits (% of infested fruits), third column shows pupae per kilogram of fruit, and fourth column shows % fly emergence, respectively.

* All pupae/kg of fruit per specific guava developmental stage in the same row followed by different letters are significantly different and for those in the column followed by different capital letters are significantly different ($p<0.005$).

Adult emergence from pupae ranged from 35 to 55%. This percentage was on the high side as evident from *B. papayae* pupae resulting from the fruit rearing The number of pupae recovered from each fruit developmental stage was significantly different within each developmental stage (df=3, f=3.818, $p<0.001$, df=3, f=2.852, $p<0.001$ and df=3, f=7.240, $p<0.001$ for Ripe, mature and immature fruits, respectively) (Table 3). Similarly, it was also observed that the number of pupae recovered among the fruit developmental stage were significantly different for all sites (df=2, f=9.479, $p<0.001$, df=2, f=20.999, $p<0.001$, df=2 f=19.793, $p<0.001$ and df=2, f=42.701, $p<0.001$ for BK,BP, HN and PSU respectively) (Table 3). It was clearly revealed that the ripe guava fruits supported high fly recovery than any other developmental stages. The percentage of damage observed in orchards ranged between 15 to 40% for the improved cultivar orchards and 60 to 90% for the local cultivar orchard.

4. Discussion

B. papayae was present at all study sites and the populations varied depending on the location and the prevailing weather conditions. The agro-forest sites revealed that the fly populations were large outside of the orchards compared to the smaller populations observed within the orchards. High trap catches were expected in host areas, however the high trap captures at the surrounding of the orchards were unexpected. This may be due to flies returning to nearby vegetation to roost after oviposition and feeding in the orchards [11, 12, 13] and / or to obtain food and shelter [24, 25, 26]. Furthermore, [12] reported high numbers of *Dacus dorsalis* (Hendel) consistently outside crop production areas. That could also be the reason why the mean populations of these flies were high for the urban orchards, as there was not much vegetation nearby for them to roost on [26]. Hence, fly population built-up in guava orchards and subsequently spread to other agricultural areas. [11, 27] further suggest that guava serve as a reservoir from which flies move into other cultivated areas. Many alternative hosts to guava were found at the agro forest areas and few at the urban areas. These hosts also contributed to fly abundance. This is evident from captured fly population during their production periods. However, as revealed from this study, the influence of these alternative hosts on the abundance of *B. papayae* was relatively low [11, 27]. Furthermore, [27] also reported that fruit fly population develops in guava, *P. guajuva*, and that population cycles are determined primarily by guava fruiting period. Similarly, [11] worked on *D. dorsalis* and reported that peak captures of this fly coincided with fruiting of *P. cattlelanum* and *P. guajava*.

Due to increase in population and high demand for food, the anthropogenic activities adversely affect the environment. Agricultural activities and urbanization have altered the rainforests in peninsular Thailand, and this has reduced the landscape to mere mosaic rainforest. These alterations have impact on the abundance and distribution of many insect species. However, how these alterations impact insects, whether negatively, neutrally and or positively, are not always clear [15]. *B. papayae* was found to be prevalent at all sites, especially around the orchards at the agro-forest sites. This is in contrast to the report of [28] that fly tends to predominate in orchards and urban areas. The fly was trapped at rainforest areas that were relatively close to urban areas [29]. Hence, it is tolerant of both urban and fairly forested habitat. [15] Worked with *B. tryoni* and observed a similar trend. [30] Presumed that suburbia was now the major breeding habitat of tephritid flies. The transformation of rainforest into suburbia and the cultivation of host plants have enhanced the abundance and distribution of *B. papayae* due to their preference for the improved varieties and monoculture of crops. Similarly, [31] reported that *C. capitata* occurs more frequently on introduced hosts.

Fly exhibited distinct patterns of seasonal occurrence, having a regular pattern defined by bimodal population peaks in August/September and May. Contrary to these findings, an earlier survey study by [5] in Thailand and peninsular Malaysia reported a unimodal population pattern for *B. papayae* in Thailand, with the peak late in the monsoon season (August/September). The observed disparity could be due to differences in frequency of trap clearance and trapping sites. Other seasonality studies of tephritids have revealed unimodal and bimodal patterns depending on the study locations. [11] studied *D. dorsalis* in Hawaii (Kauai) in a tropical climate and reported a unimodal population peak. [15] Observed the same unimodal trend in southeast Queensland in a sub-tropical climate. On the other hand, a bimodal pattern was revealed by [16], who worked on *B. invadens* in Kenya in a tropical climate and [32], who studied *B. tryoni* in Queensland in a sub-tropical climate, who recorded both unimodal and bimodal population patterns at different sites. The population density at a given time depends on the prevailing weather conditions, location, available hosts and species studied.

On a global scale, seasonal temperature and rainfall patterns constitute the major factors that determine the distribution of organisms in space [9, 33]. The role of temperature as a determinant of abundance in tephritids, as in all poikilothermic animals, is mediated either directly or indirectly through its effects on rates of development, mortality, and fecundity [33]. During dry season in peninsular Thailand, rainfall becomes critical, therefore *B. papayae* survival depends on relative humidity and temperature. Dry atmospheres and high temperatures were particularly

detrimental to survival of fly. Mature larvae and newly emerged adults are most susceptible to desiccation resulting in great reduction in number of adults that comes into being and indirectly reduceing emigration to other areas [33]. This may suggest why fly population fluctuates greatly even when hosts were available. The weather factors have been reported to exert pressure on populations of other tephritid flies [4, 16, 32, 34].

Although flies co-infest guava fruits, but the population of *B. papayae* was always larger as revealed by the rearing experiment, which was evidence of niche overlap. Co-occurrence of fruit fly species and intergeneric polyphagy on host fruits do occur [16, 20, 35, 36]. It was revealed in this study that the local cultivar of guava yielded more fruit flies than the improved cultivar. This might be due to the aromatic nature (strong smell) and its genetic closeness to the guava's wild natives. Similarly, [11] recovered large number of *D. dorsalis* pupae per kg from *P. cattleinum* and *P. guajava.* The genetic modifications to the improved cultivar, such as little or no smell, a rough surface, the hardness and thickness of the mesocarp etc., may be responsible for the lower rate of fly infestation. Notwithstanding, the number of emergent larvae was always greater for *B. papayae* than for any other fly. This suggests some type of interspecific interaction, which might be responsible for the great disparity observed in the fly densities. Such interactions could consist of competition for limited resources, displacement and/or niche differentiation [36]. *B. papayae* have an intermediate body size and exhibit mixed traits of r-k strategy. Their reproductive patterns and the required developmental periods of their immature stages may be useful characteristics for predicting the differences observed in their population fluctuations. *B. papayae* is faster in completing its immature stages [37]. The mechanisms behind population decline and infestation rate as the fruiting season progresses are insufficiently known [1]. Therefore, the observed patterns need to be confirmed through continuous sampling over successive years prior to any control programme.

Finally, population fluctuations could also be linked to host availability. Several other hosts of this fly were available in their respective seasons at the study sites, most significantly in large numbers at the agro-forest sites. Previous studies have revealed that host availability has a positive impact on the seasonal abundance of fruit flies [16, 38]. *B. papayae* are polyphagous species, and their hosts' fruiting seasons span from April–September. Therefore, the variable fruit availability from the fly assorted hosts could be responsible for its occurrence in these periods and likely helped to maintain this species in areas where the orchards were located [25]. Though a fly might be polyphagous, there is still a primary host that it favours most. [7] have recovered larger numbers of *B. papayae* from guava fruits than from any other sampled host. Similarly, guava has been reported to have presented the greatest tephritid species diversity, confirming its condition of host with the highest number of fruit fly species in Brazil [31]. Related to this apparent preference, increase in the population of *B. invadens* has been reported to be directly linked to the ripening of different mango cultivars [4, 16]. In the same vein, host availability and abundance have been reported to be partly responsible for population fluctuations in *Bactrocera* species and other fruit flies [13, 38, 39, 40, 41].

5. Conclusions

Conclusively, *B. papayae* are expected to occur around commercial farm and residential areas where cultivated host plants may be found and in native vegetation where their hosts abound. Therefore, similar vegetation among peninsular Thailand agro forest areas may be expected to have similar *B. papayae* seasonality. The species responded greatly to methyl eugenol, population fluctuation information by habitat revealed the time of the year when populations of these fruit flies are lowest and mass trapping will be most appropriate at this period. Destruction of flies host plants in agro forest areas will reduce roosting sites and consequently limit the possibility of re-infestation.

The findings presented in this study have important implications for both research and pest management. Because the studied species belong to the *B. dorsalis* complex, which encompasses several world quarantine pests, this study would be pertinent for further studies of other complex members. It will also be a useful reference in the development of suitable control measures against these notorious fly.

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