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Population dynamics of the Carambola Fruit Fly Bactrocera carambolae Drew and Hancock (Diptera: Tephritidae) on guava Psidium guajava in peninsular Thailand.

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Abstract

Bactrocera carambolae (Drew and Hancock), a pest of fruits and vegetables was studied for a period of one year (August 2012 to August 2013) in guava orchards and its surrounding in peninsular Thailand to determine the population dynamics. The fruit fly were trapped with the aid of Steiner traps baited with methyl eugenol as an attractant. Guava fruits were sampled systematically and categorized into three developmental stages; riped, matured and immatured. Fly were trapped in the field throughout the season and exhibited very similar patterns of population dynamics at various sampling sites with marked single density peak, April – May. The population density was large for *B. carambolae* trapped around guava orchards than for those trapped within the guava orchards at the agro-forest sites ($p<0.001$). Fly population densities was not significantly different between agro-forest surrounding and the town orchards. Fly population density was affected by the interaction of temperature, rainfall and relative humidity. Fruit experinment revealed that fly species were recovered in large number from riped guava fruits. The finding generated would be important in the design of suitable IPM and control of this notorious pest.

Key words: *Bactrocera carambolae*, methyl eugenol, Steiner trap, guava, dynamics.

Introduction

Fruits and vegetables are widely cultivated in Thailand where they form good source of income and dietry nutrients to the teeming population (Lux et al., 2003). A constantly growing population, rising of incomes and urbanization levels lead to increase in the demand for fruits and vegetables. To fill the gap of this demand, better farming strategies are necessary. The presences of pests such as fruit flies constitute an obstacle in their production. These fruit flies are considered a very destructive group of insects that cause enormous economic losses in agriculture, especially in a wide variety of fruits, vegetables and flowers (Diamantidis et al., 2008). Amongst the numerous fruit fly species is the *B. carambolae* a member of the *Bactrocera dorsalis* (Hendel) complex which is a notorious pest of many fruits. Its notoriety and polyphagousness was confirmed from the numerous host it was recovered from (Drew and Hancock, 1994; Allwood et al., 1999; Clarke et al., 2001). Many authors had reported several percentages of damage as observed for many kinds of fruits. But Allwood and Leblanc (1997) reported damage losses of 40 – 90% for guava.

In peninsular Thailand, the damage to fleshy fruits is mainly caused by a limited number of highly polyphagous species which are mostly *B. dorsalis* complex members. Prominent of these polyphagous species is *B. carambolae* (Clarke et al., 2001). This fly has been found to be prevalent and restricted to peninsula Malaysia and Thailand (Drew & Hancock, 1994; Clarke et al., 2001). They have also been found to co-subsist better on guava fruits with other fruit flies from the preliminary study of this work–a circumstance of intergeneric polyphagy (Duyck et al., 2004). Hence, a critical study of their population dynamic and distribution pattern on guava orchard is pertinent at this juncture.

There are few ecological studies on fruit fly in Thailandn (Hardy, 1973). Study on seasonality, distribution and abundance of other fruit fly species have been studied in other parts of the world (Raghu et al., 2000; Mwatawala et al., 2006; Esculdero-Colomar et al., 2008). This paper presents the first results of trapping of this fly in guava orchards and its surrounding in peninsular Thailand. The aim of this study was to determine the population dynamic of *B. carambolae* in guava orchards and its surroundings and to elucidate the most suitable guava developmental stage for its development and survival. This was in order to discover specific attributes about this fly that will be handy for the development of its control and thereby minimise the damage caused by this pest.

Materials and methods

Study areas

The study was carried out in Songkhla province of Southern Thailand (latitude 7° 2' 56.7779"N and longitude 100° 28' 11.8945"E). The rainfall distribution pattern was unimodal and extended over 8 months (May-December). Relative humidity ranged from 61.23 – 87.19% and temperature from 24.02 – 30.03°C for the period of the study, respectively. Two guava orchards each were selected from agro-forest (Ban Koyai BK and Ban Phru BP) and town (Hat Yai Nai HN and Prince of Songkla University PSU), respectively.

Orchards size ranged from 0.2 – 0.8 hectares. Apart from the PSU orchard that was planted with local cultivar of guava, other sites were solely improved cultivar. The agro-forest sites were within extended rubber (*Hevea brasiliensis* Arg.) plantations. But other fruits bearing plants to the radius of 3 km from the orchards were observed. The town orchards were also screened for other fruit bearing plants to the distance of 200m.

Trapping

This follows the work of Danjuma et al. (2014).Trapping was conducted for the period of 53 weeks consecutively and it was focused on *B. carambolae*. Steiner trap (Thailand modification) was used for fly trapping. Male of the species studied have been found to largely respond to a parapheromone, methyl eugenol (Benzene, 1,2,-dimethoxy-4-(2-propenyl) (Drew & Hancock, 1994). Therefore, the combination of Steiner trap and methyl eugenol was a suitable trapping method for these species. The adult male fly were trapped and killed solely with the mixture of methyl eugenol and pyrethriod (Changzhou Kangmei Chemical Industry, China) at the rate of 0.5 ml of pyrethroid / 10 ml of methyl eugenol. One millilitre of the mixture was used to impreginate lid of 4.5 diameter packed with cotton wool.

Six Steiner traps were set up on each of the agro-forest guava orchards and six around each orchard. Three Steiner traps each were set up within town orchards, respectively. The radius of attraction of traps at all guava orchards ranged from 20 - 25m. Traps were also set up at the radius of 500 – 1,500m around the guava orchards at the agro-forest sites only. Traps were rotated anticlockwise at each inspection day. 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 changed at every 42 days (6 weeks).

Fruit fly specimens were identified on the basis of morphological characters detailed by White and Elson-Harries (1992) and Drew and Hancock (1994) with the aid of stereo microscope. Voucher specimens were deposited at the Entomology Research Unit of the Department of Biology, PSU, Hat Yai.

Guava fruit sampling

Guava fruits were sampled systematically on monthly basis from all study sites. The protocol for collecting, transporting and rearing largely followed the methodology described by Copeland et al. (2002) and Danjuma et al. (2014). Sampled fruits were classified into 3 developmental stages as; riped, matured and immatured, respectively. These classifications were first determined by observing the fruit colour, size and exert of pressure with the fingers to ascertain their level of hardness. Finally, the classifications were standardized with digital fruit firmness tester, Penetrometer (Agriculture Solution LLC, Strong ME, USA) of 11.1 mm plunger tip. The classification were; riped < 8.5kgf, matured 8.5-10.5kgf and immatured >10.5kgf.

Data analysis

Data analyzed were basically from guava fruits cultured, weather information and insect counts. As fruit samples were of varying size, quantitative data were expressed as infestation indices according to Cowley et al. (1992) and Mwatawala et al. (2006) with the number of adult tephritids expressed per weight of fruits (unit of 1 kg) for infested samples only. Average fly/kg of fruit for each sampling sites were compared for species within guava orchards.

Averaged fly caught per week for 53 weeks for each species and sites were used to determine the relationship between fly caught and weather variables (temperature, rainfall and relative humidity) by imploring correlation analysis accordingly.

All trapped *B. carambolae* counts were averaged per week and month for every studied site. Also fly emergent from each guava developmental stages were counted. All fly counts were transformed by using log transformation (log[x+1]) to satisfy the assumption and homogeneity of Analysis of Variance (ANOVA). Standard ANOVA were then used. Student-Newman-Keuls (SNK) was adopted to compared means accordingly ($p<0.05$). t-test statistics was also used for comparison accordingly (Sigmaplot 11.0).

Result

Population dynamics of *B. carambolae*

Bactrocera carambolae trapped in town and agro-forest sites were summarised in Table I.

Consecutive trapping at all study sites on weekly basis for the period of a year provided the population dynamic of this fly for a full year cycle. Figures 1 – 3 represent the mean number of flies trapped per week. The number of trapped flies fluctuated considerably. *B. carambolae* was available on and around the guava orchards at all sites throughout the year. This was revealed by the trapping

Table 1. Mean (±SD) of fruit fly per trap over the period of a year

			B. carambolae
Environment	**Trapping site**	**NT**	**Male**
Town	Prince of Songkla University	3	1346.33 ± 22.74**aB**
	Hat Yai Nai	3	848.00 ± 13.31**bC**
Agro-forest	Ban Koyai		
	1. Guava Orchard	6	440.50 ± 7.99**bD**
	2. Around Guava Orchard	6	1715.50 ± 41.46**aA**
	Ban Phru		
	1. Guava Orchard	6	567.83 ± 10.16**bD**
	2. Around Guava Orchard	6	869.83 ± 17.13**aC**

*NT; number of trap
*Figures followed by different small letters in the same row for each site are significantly different (p<0.005) and figures followed by different capital letters in the column across sites are significantly different (p<0.005).

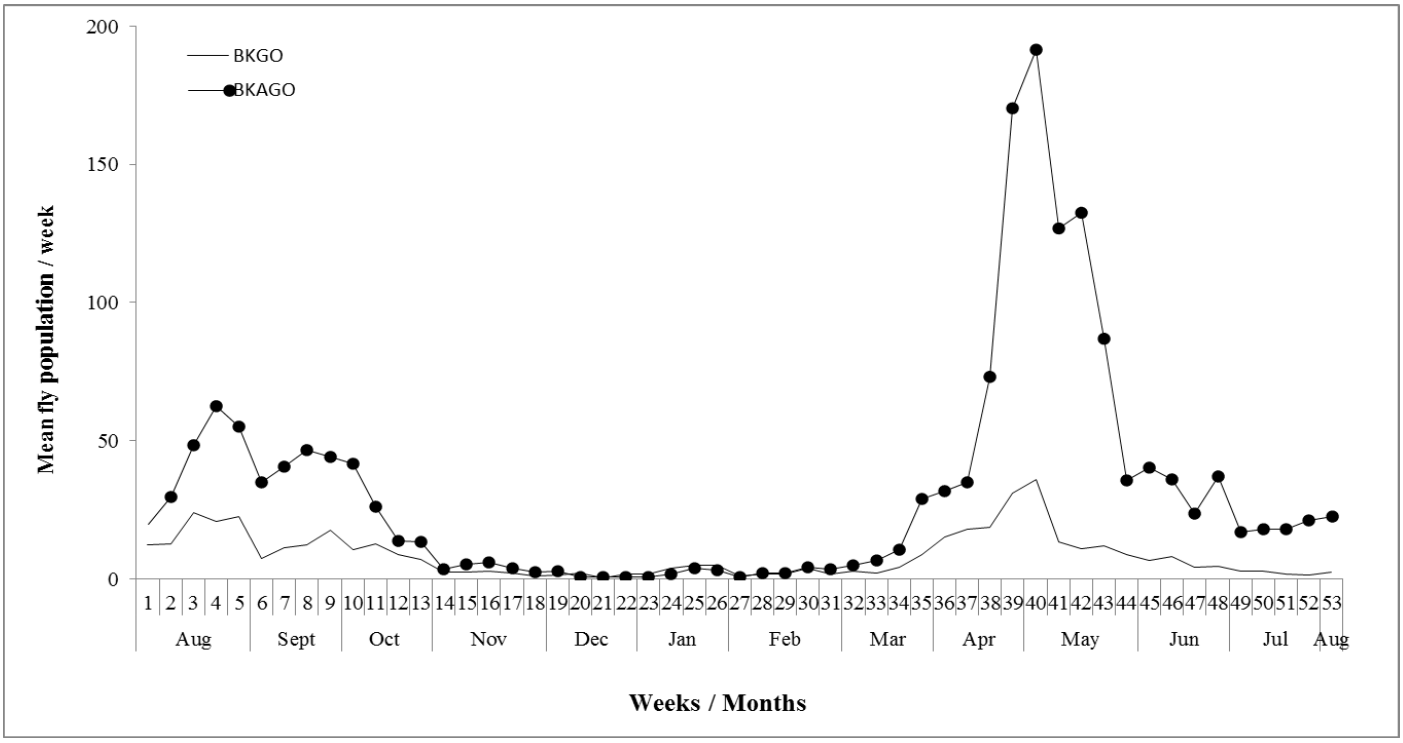

Figure 1: Weekly and monthly population dynamic of *B. carambolae* in agro-forest area: (a) BKGO = *B. carambolae* trapped within Ban koyai guava orchard (b) BKAGO = *B. carambolae* trapped Around Ban Koyai guava orchard.

programme for the year (Figures 1 – 3).

The fly population was observed to have expressed unimodal peak throughout the surroundings of agro-forest study sites and at PSU. While irregular patterns were peculiar to population trapped within the agro-forest orchards and at HN. The peak period was observed to fall in the range of weeks 35 – 45 (April – May) (Figures 1 – 3). *B. carambolae* population was observed to be very low in density for all other months. The peak period corresponded with increase in temperature. But contrary was the case with rainfall.

Comparison within each agro-forest site revealed that *B. carambolae* trapped around the orchards were significantly more than those trapped on the orchards (t = -4.148 , P = <0.001, for BK and t = -2.083 , P = 0.040, for BP, respectively). At the town orchards, it was found that *B. carambolae* was significantly more in population at the PSU orchard than the HN orchards (t = -2.598, P = 0.011). Pooled data of *B. carambolae* population generated from town orchards, agro-forest orchards and

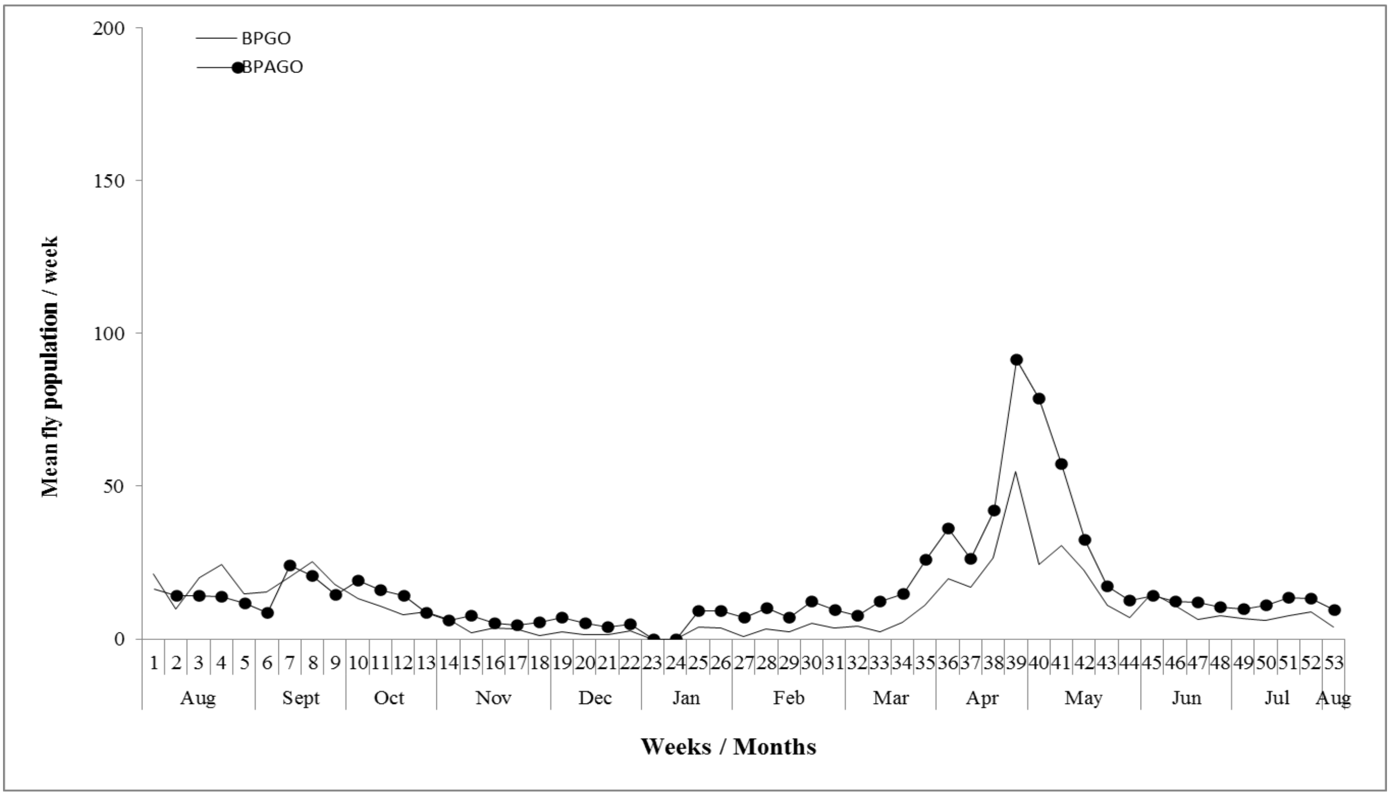

Figure 2: Weekly and monthly population dynamic of *B. carambolae* in agro-forest area: (a) BPGO = *B. carambolae* trapped within Ban Phru guava orchard (b) BPAGO = *B. carambolae* trapped Around Ban Phru guava orchard.

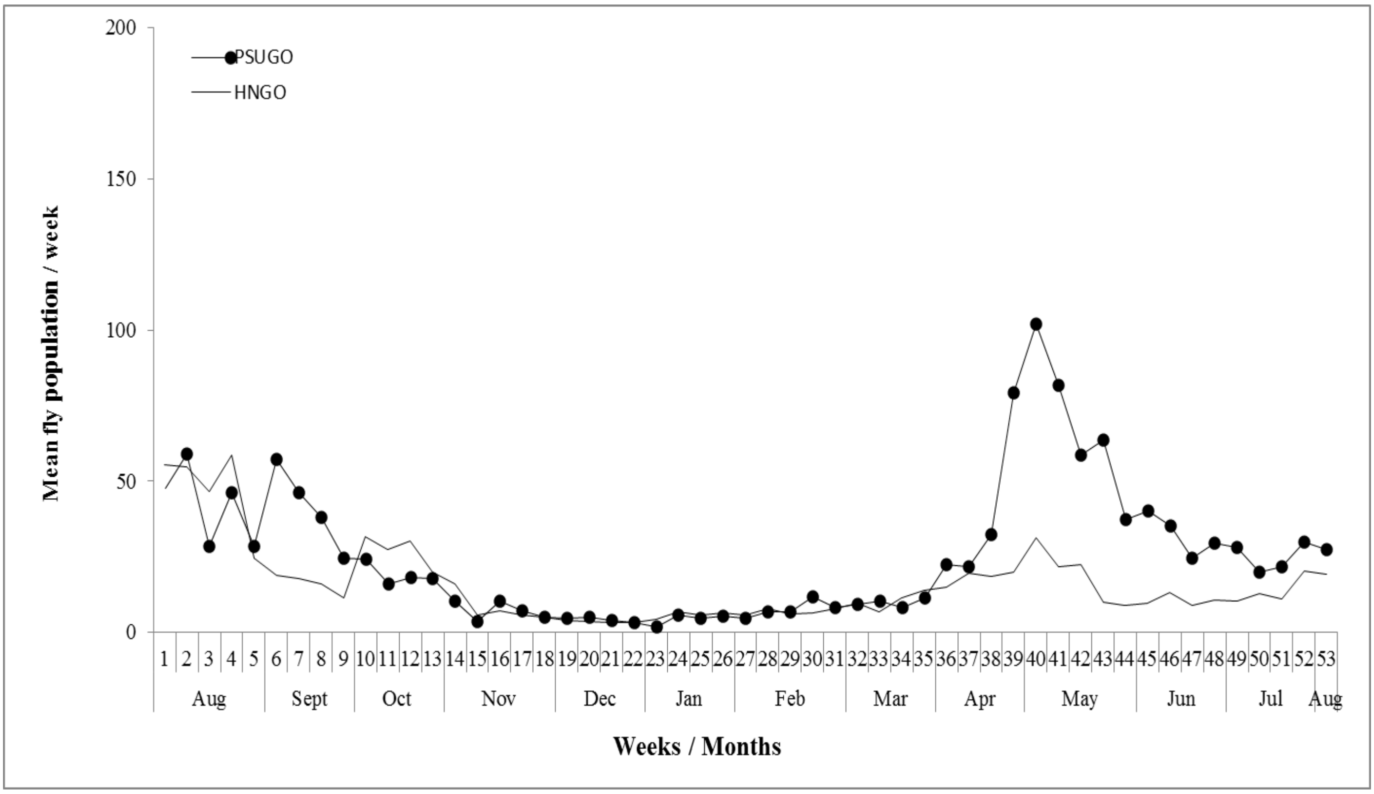

Figure 3: Weekly and monthly population dynamic of *B. carambolae* in town orchards: (a) PSUGO = *B. carambolae* trapped within Prince of Songkla University guava orchard (b) HNGO = *B. carambolae* trapped within Hat Yai Nai guava orchard.

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

Environment	Site	Farm	No of wk	Correlation (*r*) Tem	R/fall	RH
Agro- forest area	Ban koyai	GO	52	0.24ns	0.27ns	0.30ns
		AGO	52	0.50*	0.21ns	0.48*
	Ban Phru	GO	52	0.48*	0.39*	0.26ns
		AGO	52	0.48*	0.35*	0.44*
Town area	HYN	GO	52	0.36*	0.24ns	0.26ns
	PSU	GO	52	0.60**	0.23ns	0.33*

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; AGO: Around Guava Orchard;

Table 3. Total number of guava fruits sampled at various orchards based on developmental stages

Fruit dev stage	Site Species	Ban fruit	Koyai Ave fly /kg	Ban fruit	Phru Ave fly /kg	Hat Yai fruit	Nai Ave fly /kg	PSU fruit	Ave fly /kg
Ripe	*B. carambolae*	188(173)	19.15aB	140(131)	14.80aD	125(107)	16.50aC	106(103)	45.03aA
Mature	*B. carambolae*	149(102)	14.63bB	118(84)	14.24aB	89(59)	14.97bB	59(45)	31.86bA
Immature	*B. carambolae*	144(46)	10.97cA	111(22)	3.44bB	113(26)	2.71cB	71(15)	1.85bcC

PSU: Prince of Songkla University
* Each sampling site has two columns; first column shows numbers of guava fruit sampled per developmental stage (total fruits sampled were outside the brackets and positive fruits in brackets). The second column depict average fly per kilogram of fruit.
* All average fly per kilogram in the same column for a specific site followed by different small letters are significantly different (p<0.05) and those followed by different capital letters in the row for a specific guava fruit developmental stage are significantly different (p<0.05)

surroundings of agro-forest orchards were compared. *B. carambolae* trapped in town and around agro-forest orchards were significantly more than those trapped on agro-forest orchards (df=2, f=8.303, p<0.001). But comparisms between *B. carambolae* population trapped in town orchards and surroundings of agro-forest orchards were not significantly different.

Fly population fluctuation and weather information

The relationship between fly (*B. carambolae*) caught and weather variables (Table 2) revealed inconsistences for all sampling sites. Significant correlation between fly caught and weather variables were detected for *B. carambolae* trapped on and around guava orchards at agro-forest areas. High correlation was also observed for *B. carambolae* trapped at PSU, all others were medium-low correlated.

Correlation analysis revealed that temperature was clearly the most important variable at PSU guava orchard as it revealed strong correlation for the fly population. *B. carambolae* trapped on guava orchard at BK depicted no correlation with temperature. Except for this anomaly, medium-low correlations were observed between fly trapped and other weather variables at all sites (Table 2).

Impact of guava fruit developmental stages on fly population

Improved guava trees produced fruits all year round during the sampling period. But local varieties abound at PSU and fruit production peaks fell between April – May and with a decline in production from June - July and an extended peak from August – September.

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 were presented in Table 3.

Number of fly recovered from each developmental stage were significantly different (df=2, f=6.304, p=0.004, df=2, f=9.159, p<0.001, df=2, f=10.003, p<0.001 and df=2, f=17.579, p<0.001 for BK, BP, PSU and HN, respectively) in the order of Riped >Matured > Immatured, respectively. When each developmenetal stages were compared for all collecting sites, it was found that the riped fruits collected from PSU produced more significant fly population than for any other site df=3, f=4.571, p=0.008. Similarly, the matured fruits collected from PSU yielded significantly more fly population than for any other site df=3, f=5.321, p<0.001. Contrarily, the immature stage of the improved guava fruit from BK yielded more fly population than for any other site df=3, f=6.176, p=0.008. It was confirmed that more fly population were recovered from riped guava fruit.

Discussion and conclusion

Trapping programme and guava fruits rearing for a year, revealed fluctuated population dynamic in terms of abundance and distribution for *B. carambolae* on and around guava orchards. The species was present on the field throughout the year and exhibited very similar patterns of seasonal occurrence with single density peak, April – May. Hence, unimodal density peak structure was revealed around the orchards surrounded by different host plants. Contrary to this finding was the early survey study of Clarke et al. (2001) in Thailand and peninsula Malaysia which reported no repeatable pattern of population dynamics in terms of distribution and abundance. In the same vein, irregular pattern of population dynamics was only observed for the population trapped on the guava orchards. The disparity observed could be due to differences in frequency of trap clearance and trapping sites. Earlier population studies on other tephritids fly by other scientists revealed unimodal (Vargas et al., 1983; Raghu, 2000) and bimodal (Mwatawala et al., 2006; Muthuthantri et al., 2010; Danjuma et al., 2014) population patterns, depending on the prevailing weather condition at various locations, available hosts and species studied.

Host availability have been reported to expressed positive impact on seasonal dynamic of fruit flies (Tora Vueti et al., 1997; Mwatawala et al., 2006). *B. carambolae* was a polyphagous species and its hosts span from April – September. Therefore, variable hosts availability was responsible for their dynamic occurrence. Though a fly might be polyphagous, but there would be a primary host which it favours most. Reference to this, increase in population of *B. invadens* was reported to be directly linked to the ripening of different mangos cultivars (Vayssieres et al., 2005; Mwatawala et al., 2006). The fruiting of *P. cattlelanum* and *P. guajava* has been reported to coincide with increase in fly population (Newell and Haramoto 1968, Danjuma et al., 2014). In the same vein, host availability and abundance has been reported to be responsible partly for population fluctuation in *Bactrocera* species (Drew & Hopper, 1983; Vargas et al., 1990; Leblac & Allwood, 1997; Tora Vueti et al., 1997Danjuma et al., 2014).

The prevailing temperature and rainfall patterns represent the major factors that determined the distribution of organisms in space. Vagaries of weather play an indispensable role in seasonal abundance of *B. carambolae*. The interactions of weather factors have been reported to exert pressure on population of other tephritid flies (Amice and Sales, 1997; Vayssières et al., 2005; Mwatawala et al., 2006; Muthuthantri et al., 2010; Danjuma et al., 2014).

Bactrocera carambolae exhibited a strong preference for riped guava than for guava at any other developmental stage. This fly co-infest guava fruits with other tehritid fly especially *B. papayae* (Danjuma et al., 2014) as revealed by the rearing experiment. This finding confirmed the report of other researchers (Copeland et al., 2002, 2006; Duyck et al., 2004; Mwatawala et al., 2006) that co-occurrence of fruit fly species and intergeneric polyphagy on host fruits do occur. It was revealed from the study that the local cultivar of guava yielded more fruit fly than the improved cultivar. This might be due to its aromatic nature (strong smell) and their closeness to their wild relatives genetically. The genetic modifications in the improved cultivar such as little or no smell, rough surface, hardness and thickness of the mesocarp etc., may be responsible for low fly infestation. But notwithstanding, the emergent was always greater for *B. papayae* than for *B. carambolae*. This also suggested some kind of interspecific interactions which might be responsible for the great disparity observed in the fly densities. Such interactions could be competition for limited resources, displacement and niche differentiation (Duyck et al., 2004). Similar to its sibling species *B. papayae* (Danjuma et al., 2014), *B. carambolae* had intermediate body size, and exhibit mixed traits of r-k strategy. But reproductive patterns and required developmental periods of their immature stages may be useful characteristics for predicting the differences observed in its population dynamic. As the fruiting season of the improved cultivar of guava progresses, fly population varies. This was similar to the finding of Danjuma et al. (2014) working on seasonal occurrence of *B. papayae*. The mechanism behind this is unclear, hence the observed patterns need to be confirmed through continuous sampling over several successive years prior to any control programme.

Activities of man have adverse effect on the environment. Agricultural activities and urbanization has altered the rainforest in southern Thailand and this has reduced the thickness and wideness into mere mosaic rainforest. These anthropogenic activities have great impact on the abundance and distribution of many insect species (Danjuma et al., 2013; Danjuma et al., 2014). This alteration impact insects in several ways; whether negatively, neutrally and or positively are not always clear. Fruit fly trapped in town orchards were greater than those trapped on the agro-forest orchards. *B. carambolae* tends to predominate in orchard and urban areas (Vijaysegaran *et al*., 1991). It was also trapped in rainforest areas that were relatively close to urban areas (Danjuma et al. 2013). Hence, they are tolerance of both urban and fairly forest habitat. Raghu *et al*. (2000) worked with *B. tryoni* and had a similar trend. Courtice & Drew (1984) presumed that suburbia was now the major breeding habitat of tephritid flies. Conclusively, the transformation of rainforest into suburbia and cultivation of tamed hosts enhanced the abundance and distribution of *B. carambolae.*

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

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References

Allwood AJ, Chinajariyawong A, Drew RAI, Hamacek EL, Hancock DL, Hengsawad C, Jinapin JC, Jirasurat M, Kong Krong C, Kritsaneepaiboon S, Leong CTS, Vijaysegaran S (1999). Host plant records for fruit flies (Diptera: Tephritidae) in South-East Asia. The Raff. Bull. Zool., **7**: 1-92.

Allwood AJ, LeBlanc L (1997). Losses caused by fruit flies in seven Pacific island countries. In Allwood AJ, Drew RAI (eds): Management of fruit flies in the Pacific. Proceedings of Australian Centre for International Agricultural Research (ACIAR), Canberra, Australia, pp. 208-211.

Amice R, Sales F (1997). Seasonal abundance of fruit flies in New Caledonia. In Allwood AJ, Drew RAI (eds): Management of fruit flies in the Pacific. Proceedings of Australian Centre for International Agricultural Research (ACIAR), Canberra, Australia, pp. 134-139.

Clarke AR, Allwood AJ, Chinajariyawong A, Drew RAI, Hengsawad C, Jirasurat M, Kong Krong C, Kristsaneepaiboon S, Vijaysegaran S (2001). Seasonal abundance and host use patterns of seven *Bactrocera* species Macquart (Diptera: Tephritidae) in Thailand and Peninsular Malaysia. The Raff. Bull. Zool., 49: 207-220.

Copeland RS, Wharton RA, Luke Q, De Mayer M (2002). Indigenous hosts of *Ceratitis capitata* (Diptera: Tephritidae) in Kenya. Ann. Entomol. Soc. Am., 95: 672-694.

Copeland, RS, Wharton RA, Luke Q, De Mayer M, Lux S, Zenz N, Machera P, Okuinu M (2006). Geographical distribution, Host fruits and parasitoids of the African fruit fly pests *Ceratitis capitata*, *Ceratitis cosyra*, *Ceratitis fasciventris* and *Ceratitis rosa* (Diptera: Tephritidae) in Kenya. Ann. Entomol. Soc. Am., 99: 261-278

Cowley JM, Baker RT, Harte DS (1992). Definition and determination of host status for multivoltine fruit fly (Dipteral: Tephritidae) species. J. Econ. Entomol., 85: 312-317.

Courtice AC, Drew RAI (1984). Bacterial regulation of abundance in tropical fruit flies (Diptera: Tephritidae). Aust. Zool., 21: 251-268.

Danjuma S, Thaochan N, Permkam S, Satasook C (2013). Biodiversity of the genus *Bactrocera* (Diptera: Tephritidae) in guava *Psidium guajava* L. orchards in different agro-forested locations of southern Thailand. Inter. J. Chemi. Environ. Biol. Sc., 1: 538-544.

Danjuma S, Thaochan N, Permkam S, Satasook C (2014). Seasonality of the Asian Papaya Fruit Fly *Bactrocera papayae* Drew and Hancock (Diptera: Tephritidae) on guava *Pdisium guajava* in Peninsular Thailand. J.Entomol. Zool. Stud., 2: 276-284.

Diamantidis AD, Carey JR, Papadopoulus NT (2008). Life-history of an invasive tephritid. J. Appl. Entomol., 132: 695–705.

Drew RAI, Hooper GHS (1983). Population studies of fruit flies (Diptera: Tephritidae) in South East Queensland. Oecol., 26: 153-159.

Drew RAI, Hancock DL (1994). The *Bactrocera dorsalis* complex of fruit flies (Diptera: Tephritidae: Dacinae) in Asia. Bull. Entomol. Res., 2: 1-68.

Duyck PF, David P, Quilici S (2004). A review of relationships between interspecific competition and invasions in fruit flies (Diptera: Tephritidae). Ecol. Entomol., 29: 511-520.

Esculdero-Colomar LA, Vilajeliu M, Batllori L (2008). Seasonality in occurrence of the Mediterranean fruit fly [*Ceratitis capitata* (Wied.)F] in north-east of Spain. J. Appl. Entomol., 132: 714-721.

Hardy DE (1973). The fruit flies (Tephritidae – Diptera) of Thailand and borederin countries. Pac. Ins. Mono.,31: 1–353.

Allwood AJ, Lablanc L (1997). Mango fruit fly (*Bactrocera frauenfeldi*): Why so many in federal state of Micronesia? In Allwood AJ, Drew RAI, (eds). Manage. of fruit flies in the Pacific. Proceedings of Australian Centre for International Agricultural Research (ACIAR), Canberra, Australia, pp. 125-130.

Lux SA, Copeland RS, White IM, Manrakhan A, Billah MK (2003). A new invasive fruit fly species from the *Bactrocera dorsalis* (Hendel) group detected in East Afr. Ins. Sc. Appl., 23: 355–360.

Muthuthantri S, Maelzer D, Zalucki MP, Clarke AR (2010). The seasonality of *Bactrocera tryoni* (Froggatt)

(Diptera; Tephritidae) in Queensland. Aust. J. Entomol., 49: 221-233.

Mwatawala MW, De Meyer M, Makundi RH, Maerere AP (2006). Seasonality and host utilization of the invasive fruit fly, *Bactrocera invadens* (Dipt., Tephritidae) in central Tanzania. J. Appl. Entomol., 130: 530-537.

Newell IM, Haramoto FH (1968). Biotic factors influencing population of *Dacus dorsalis* in Hawaii. Proceedings of Hawaii Entomological Society. 20: 81-139.

Raghu S, Clarke AR, Drew RAI, Hulsman K (2000). Impact of habitat modification on the distribution and abundance of fruit flies (Diptera: Tephritidae) in southeast Queensland. Pop. Ecol., 42: 153-160.

Tora Vueti E, Ralulu L, Walker GP, Allwood AJ, Lewiniqila L, Balawakula A (1997). Host availability – its impact on seasonal abundance of fruit flies. In Allwood AJ, Drew REI (eds). Management of fruit flies in the Pacific. Proc. of Australian Centre for Int. Agricul. Res. (ACIAR), Canberra, Australia, pp. 105-110.

Vargas RI, Nishida T, Beardsley JW (1983). Distribution and abundance of *Dacus dorsalis* (Diptera: Tephritidae) in native and exortic forest areas on Kauai. Environ. Entomol., 12: 1185-1189.

Vargas RI, Strak JD, Nishida T (1990). Population dynamics, habitat preference and seasonal distribution patterns of Oriental fruit fly and Melon fruit fly (Diptera: Tephritidae) in an agricultural area. Environ. Entomol., 19: 1820-1828.

Vayssières J, Goergen G, Lokossou O, Dossa P, Akponson C (2005). A new *Bactrocera* species in Benin among mango fruit fly (Diptera: Tephritidae) species. Fruits, 60: 371-377.

Vijaysegaran S, Shamsudin OM (1991). Fruit flies in Malaysian peninsular: their economic importance and control strategies. In Kawasaki K, Iwahashi O, Kaneshiro KY (eds). Proceedings of the Int. Symposium on the biology and control of fruit. Ginowan, Okinawa, Japan, pp.105-115.

White IM, Elson-Harris M (1992). Fruit flies of economic significance: Their identification and bionomics. CAB Int., Wallingford, p. 601.