INSECT ECOLOGY

Infestation level of banana fruit fly (*Bactrocera musae*, Tryon) on Kalapua banana (*Musa* sp.) in Gazelle Peninsula, Papua New Guinea

Kari Iamba,[1,2] Loretta Abraham,[1] Anastasia P. Kawi,[3] Thecla Guaf,[3] Alex Nugi,[1] David Tenakanai[4]

[1]Department of Agriculture, School of Natural Resources, PNG University of Natural Resources and Environment, Vudal, Papua New Guinea; [2]University of South Bohemia, Faculty of Science, Department of Zoology, České Budějovice, Czech Republic; [3]National Agriculture Quarantine Inspection Authority, Tammur Centre, Papua New Guinea; [4]National Agriculture Quarantine Inspection Authority, HQ, NCD, Papua New Guinea

Abstract

The banana fruit fly (*Bactrocera musae* Tryon), belonging to the family Tephritidae and subfamily Dacinae, is the main pest of bananas responsible for significant crop losses. In order to monitor the *B. musae* infestation, we collected banana fruit samples from four locations on the Gazelle Peninsula: Burit, Kereba, Vudal, and Vunapalading. On each field collection date, twelve banana bunches were chosen at random from the corresponding study sites. Following the removal of 100 individual fruits (fingers) from each fresh bunch at each study site, the fruits were weighed, thoroughly cleaned with rainwater three times, and then incubated in containers until the larval developmental stages were finished. When compared to the other three sites, the number of adults in the Kalapua bananas sampled from Burit was the highest. The banana fruits were divided into three main groups: "mature green", "mature ripe", and "immature green". Mature green fruits produced a higher adult abundance than mature ripe fruits. Compared to the other two stages, immature green had the fewest adults. By fruit weight, Burit had the highest infestation (20.9%), while Vunapalading had the lowest (11.9%). After Kereba (14.7%), Vudal had the second-highest infestation (16.8%). Mature ripe fruit had the highest infestation (37.1%) by fruit weight, while immature green fruits had the lowest infestation (2.04%). A moderate level of infestation was observed in mature green fruits (17.1%). Regarding fruit count, the least infected fruits were immature green fruits (1.8%), moderately infected mature green fruits (17.0%), and highly infected mature ripe fruits (26.9%). Geographically, the Gazelle Peninsula has a Kalapua infestation level ranging from 11.9 to 20.9%, and a different maturity stage infestation level ranging from 2.04 to 26.9%. In general, the degree of infestation has escalated, and *B. musae* has established itself in the Gazelle Peninsula.

Correspondence: Kari Iamba, Department of Agriculture, School of Natural Resources, PNG University of Natural Resources and Environment, Private Mail Bag, Vudal, Kokopo 613, Papua New Guinea.
E-mail: kari.iamba@gmail.com

Key words: *Bactrocera musae*; banana; Kalapua; infestation; sites; maturity stages; Gazelle Peninsula.

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Introduction

The banana fruit fly (*Bactrocera musae* Tryon) which belongs to the subfamily Dacinae is a major pest of some bananas (Drew *et al.*, 2011, Leblanc *et al.*, 2001). It is distributed in northern Queensland, the Torres Strait Islands, Papua New Guinea (PNG) (Drew, 1989, Drew *et al.*, 2011) and primarily feeds on bananas with papaya and guava as occasional hosts (Plant Health Australia, 2018). Eggs are laid in mature green to ripe fruits by females. The emerging larvae feed on tissues and cause complete destruction of fruits, rather than cosmetic damage caused by many other insect pests. The damaged fruits thus become unmarketable or not fit for consumption. Sar *et al.* (2001) reported that eighteen fruit fly species have been bred from commercial or edible fruits in PNG. In the East New Britain (ENB) province of PNG, three of the damag-

ing species include the melon fly (*B. cucurbitae* Coquillett), mango fly (*B. frauenfeldi* Schiner) and banana fly (*B. musae* Tryon).

The most destructive species that causes significant losses to bananas is *Bactrocera musae* (Tryon). The first biological study on the management and damage assessment of Cavendish varieties was conducted by Smith (1977) in the Northern province of PNG. Trapping and host fruit surveys prior to 1999 indicated the absence of *B. musae* but a possible incursion was reported by mid-1999 in the Gazelle Peninsula of ENB (Mararuai, 2010). The banana fly is native and widely distributed throughout mainland PNG and Australia (Drew *et al.*, 2011; Noushini *et al.*, 2020), and is believed to have migrated to ENB from food relieve suppliers during the 1994 volcanic eruptions (Mararuai *et al.*, 2002). From banana host surveys conducted by Mararuai *et al.* (2002) in 1999, infestation levels caused by banana flies was 3% in market surveys and 0.2% in garden surveys. Findings from a study at Laloki in the Central province of PNG indicated a low infestation of bananas up to 0.3% (Mararuai, 2010). The mean infestation of bananas in some provinces of PNG includes Central 22.9%, ENB 0.3%, and Morobe 17.6% (Leblanc *et al.*, 2001). Both Central and Morobe are located on mainland PNG while ENB is part of New Britain Island. These varied infestation levels would most probably be related to the population abundance of banana flies in each locality.

Sar *et al*. (2001) reported that *B. musae* can cause a mean infestation of 22.9% of bananas in ENB from mature to ripe stages. Studies on *B. musae* infestation in bananas have been focused on four fruit development stages: green, mature green, ripe, and fallen (Mararuai, 2010, Sar *et al.*, 2001). Tenakanai (1997) reported that all banana varieties are susceptible, however Mararuai *et al*. (2002) suggests from her field observations that there may be varietal resistance amongst bananas. Banana is considered a staple in the northeast lowlands of the Gazelle Peninsula (Bourke and Harwood, 2009). We focused on the Kalapua subgroup, which is of genome group ABB and known locally as Kalapua in Melanesia pidgin language (Odani *et al.*, 2018). ABB is a genome group produced as a result of crossing between *Musa acuminata* (AA genome) and *Musa balbisiana* (BB genome) (Premjet *et al.*, 2022). The shape of fingers is unique, short, and angled with thick peel and are significantly important variety used in ENB for customary obligations such as bride price and death ceremonies.

There is limited updated information known on the infestation levels caused by banana flies on the Kalapua variety in the Gazelle Peninsula of ENB province. This has resulted in us conducting this research to determine the infestation levels caused by banana fly *Bactrocera musae*. We expect an increase in *B. musae* infestation after 30 years of establishment in the Gazelle Peninsula. We anticipate higher infestation in mature green fruits since females have been reported to oviposit eggs in immature green bananas (Allwood and Drew, 1997). We also expect higher infestation in less disturbed sites as forest fragments can serve as refugia and resting sites for *B. musae* (Balagawi *et al.*, 2014).

Materials and Methods

Sampling sites and design

Field sampling was done at four locations within Gazelle Peninsula primarily Burit (4° 24' 50.54" S, 151° 57' 57.51" E), Kereba (4° 21' 10.89" S, 152° 02' 00.61" E), Vudal (4° 20' 51.39" S, 152° 00' 08.81" E) and Vunapalading (4° 21' 57.77" S, 151° 59' 01.21" E) (Figure 1). These sites are more than 2 km apart from each other and were selected based on the widespread banana gardens which are owned by locals. The four sites are resettlement portioned blocks which are owned by individuals, and they grow bananas as the main crop for consumption. The sampled sites are food gardens with bananas growing as the dominant crop (*Musa* spp). Other fruits and vegetables commonly grown in the areas included mangoes (*Mangifera indica*), star fruits (*Averrhoa carambola*), Aibika (*Abelmoschus manihot*), and vegetables from Solanaceae and Curbitaceae family. The Vudal farming system holds a diversified variety of bananas. The study concentrated on the Kalapua variety because it is one of the important economic varieties used in customary obligations and provides food sources to people in ENB.

For this study, we focused on the variety Kalapua, as it is a very common banana grown within ENB Province. In order to study the impact of *B. musae* on Kalapua, we collected fruit samples randomly of different maturities specifically immature green, mature green, and mature ripe stages from each location. The protocols and procedures used for this study were adopted by Leblanc *et al.* (2012). We did field collection of one hundred (100) fruits per site at five different dates in 2021 specifically on the 30th of July, 7th of August, 20th of August, 1st of October, and 13th of October.

Sample collection and preparation

Twelve banana bunches were randomly selected from respective study sites at each field collection date. Samples were carried securely in paper bags to the rearing shed. A total of 100 single fruits were removed from the fresh bunch per study site and washed thoroughly with rainwater three times. Then they were weighed and incubated in containers until the larval developmental stages were completed. We did 5 collections (replicates) of 100 fruits per site, so each site had a total of 500 fruits and 2000 fruits for the whole study. Each site required 100 plastic containers, so we used a total of 500 containers per replicate. The plastic rearing container had a length of 16.5 cm, a width of 7.5 cm, and a height of 10 cm. The same containers were used for the duration of the study and were only replaced if considered damaged. Since we had a total of 2000 fruits and did the rearing concurrently, we required additional containers. So, we often had two batches (replicates) running concurrently. Since the collection was done five times corresponding to the five collection dates, we collected a total of 2000 fruits.

Fruits were collected from areas with a history of minimum or non-use of chemical insecticides. Fruits were set up individually, according to the type of fruiting stage per site. We assigned the fruits to three maturity stages specifically to immature green, mature green, and mature ripe. The fruits were collected regardless of the presence of fruit-feeding marks or not. Banana fruits can be broadly classified into three main categories specifically: i) 'under-mature' characterized by dark green color with <34 mm finger diameter and 21 cm finger length; ii) 'mature' characterized by pale green color with 34-35 mm finger diameter and 21-22 cm finger length; iii) 'over-mature' characterized by yellowish green color with >35 mm finger diameter and 22 cm finger length (Surya Prabha and Satheesh Kumar, 2015). Following Surya Prabha and Satheesh Kumar (2015), we used the term 'finger' to refer to a single banana fruit and to differentiate it from the banana bunch. Following the same description, we used 'immature green' instead of under-mature, 'mature green' for mature, and 'mature ripe' for over-mature.

Rearing of fruit flies (laboratory study)

Rearing of fruit flies was conducted at the University of Natural Resources and Environment (PNGUNRE) which is situated at Vudal. Vudal is a farming center for the Gazelle Peninsula since it consists of animal farms, vegetable gardens, and cash crop plantations. Most of the locals living in Vudal own cocoa and balsa plantation blocks. We built a rearing shed equipped with shelves and a

well-ventilated area at the University Campus (152° 54' 33.44" E, 4°, 21' 01.90" S, 0-200 m above sea level). Vudal has a humid tropical climate with an average annual rainfall of 2413 mm | 95.0 inches with a moderate dry season from July to October, and a mean air temperature of 25.8°C | 78.4 F (McAlpine *et al.*, 2001).

To allow for aeration, the middle part of the lids was cut into a rectangle shape *viz.* 9×3 cm, then covered with fine gauze fabric using adhesive wood glue. The aerated portion allows air to circulate into the fruit during the holding period. So, we had 100 uniform-sized aerated containers for each site, and they were carefully labeled with the site name, sample number, date of collection, and name of the collector. A handful (*i.e.*, 10 g) of fine-sieved sawdust was placed in the bottom of plastic containers and moistened with water using a handheld sprayer. After individual fruits were weighed and recorded, single fruits were placed in containers and lids covered. After 8-10 days individual containers were checked for the presence of adults, larvae, or pupae. After 10-14 days (*i.e.*, 2 weeks) of incubation, the samples were checked again by dissecting fruits to collect any remaining larvae, and by sieving the sawdust to extract puparia. According to Leblanc *et al.* (2001), after oviposition, it takes 1-2 days for eggs to hatch into larvae and after 10-14 days, the adult fly emerges from the puparium and digs its way out of the soil or organic matter. If larvae were still present, the fruits were placed on new sawdust. Any puparia from the fruits were separated from the sawdust, counted and placed in moistened, sterilized sawdust in a clean plastic container. When the flies emerged, they were fed with sugar and water for 5-7 days, before killing by freezing. This allows the colors and markings to be intact and thus necessary for correct species identification. We identified the banana fly by using the Australian handbook for the identification of fruit flies (Plant Health Australia, 2018), taxonomic notes (Leblanc *et al.*, 2001), and the expertise of experienced entomologists from the National Agricultural Quarantine Inspection Authority.

After each replicate, all containers were cleaned using 70% alcohol and reused again. Puparia from each sample were counted, carefully transferred by forceps and kept in moist sawdust in a petri dish. Then placed inside a small plastic container having a top covered with fine gauze fabric. Emerged flies were supplied with sugar and water for five days. We recorded the number of puparia, number of emerged adults, sample number, date of fruit collection, site name, name of collector, maturity stage, weight of fruit, number of fruits, number of males, number of females, total abundance, and parasitoid emergence. Lab data collection of fruit flies was done five times, specifically on the 13th of August, 21st of August, 3rd of September, 15th of October, and 22nd of October of 2021.

The room had an average temperature of 29.5±1.7°C, 75±0.81% relative humidity and 13:11 light:dark photoperiod. We recorded the ambient temperature during the study using a dry bulb thermometer that was hung on the wall inside a rearing shed. A data recording sheet was provided to capture the data. We found out in a previous

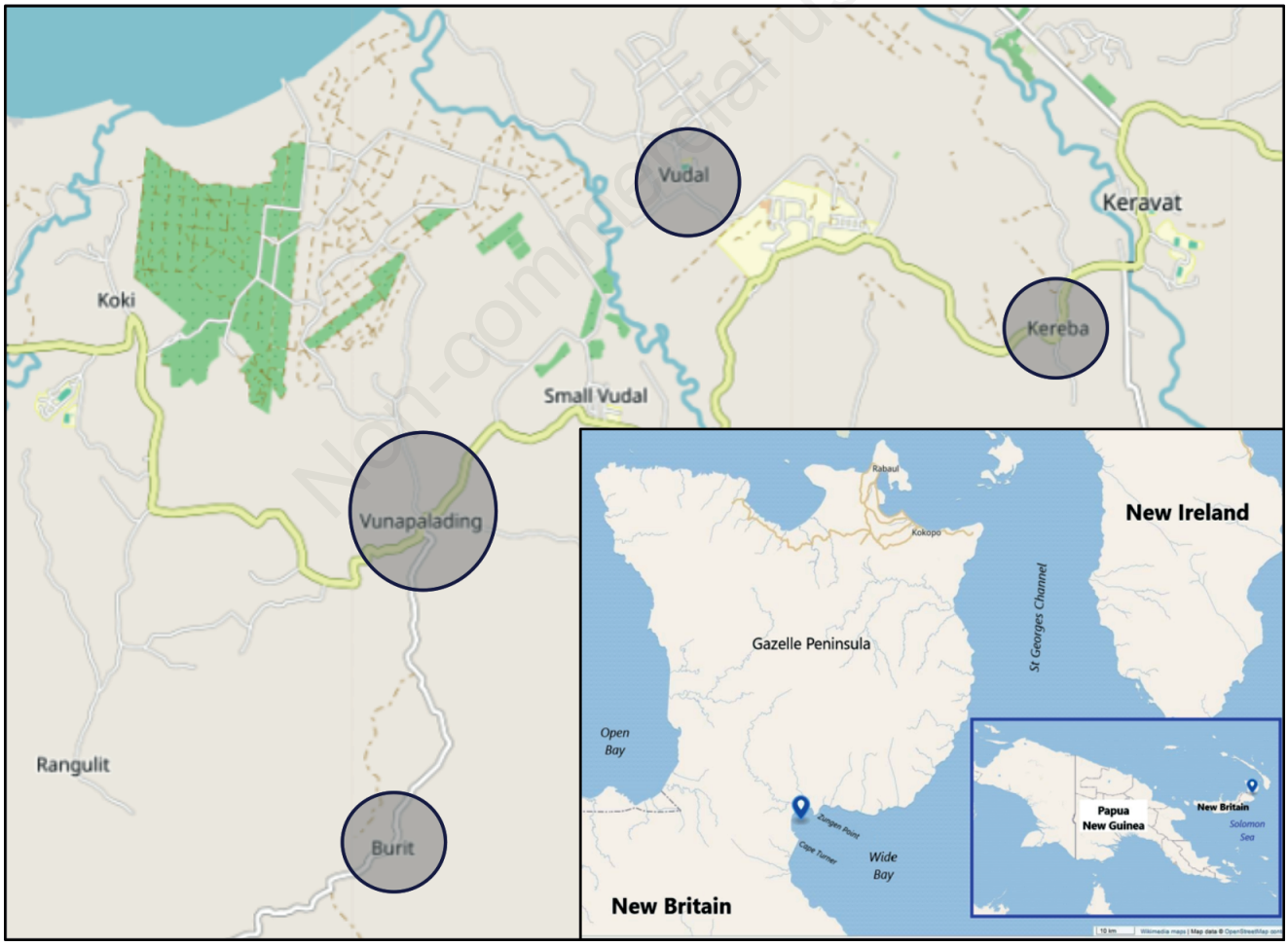

Figure 1. Map of the four sampling sites located within the Gazelle Peninsula of East New Britain. The sites are at least 2 km apart from their nearest neighbor. The sites also differ in their elevation: Burit (243 m), Kereba (82 m), Vudal (41 m), and Vunapalading (25 m).

study that temperature is a critical factor that regulates the activity and distribution of fruit flies (Iamba *et al.*, 2021). We wanted to see how the average daily fluctuations in temperature would influence the emergence of adults on a temporal scale.

Data analysis

The abundance data of *B. musae* were not normally distributed. This was confirmed by running a Shapiro-Wilk test of the abundance (W=0.26, P<0.001). Following the recommendation of O'Hara and Kotze (2010) that count data should not be analyzed by a log transformation, we instead used the generalized linear model (GLM) based on Poisson distribution. The Poisson error distribution accounted for the count data of abundances. We ran separate models with site and maturity stage used as predictors respectively and adult abundance as the response. We ran another GLM model to take into consideration the effect of maturity stages on the gender of adult fruit flies. Test of model significance was done using ANOVA test and further separation of means using estimated marginal means (emmeans) package and grouping of similar means using cld function from multcomp package. We also did a pairwise comparison of adult abundance between sites and maturity stages. To assess the influence of temperature, we converted the ambient temperature values in their continuous form to factor and then used it as a predictor variable. We recorded the daily temperatures during the study; however, we recorded the number of puparia and adults after 2 weeks to coincide with the 10-14-days period. The total adult abundance was pooled within these five temperature predictors. Finally, we did two calculations to determine the infestation level of *B. musae.* Determination of infestation by fruit weight (kg) and infestation by fruit number. We used the following formula to determine the infestation level:

(1) Infestation by fruit number: $\frac{A}{B}x100$

where A=number of infested fruits, B=total number of harvested fruits, and

(2) Infestation by fruit weight: $\frac{A}{B}x100$

where A=weight of infested fruits, B=total weight of harvested fruits (Rasmiya and Mubarak, 2018). A fruit is considered infested if it contains a single larvae or pupa. Infestation by fruit weight and fruit number were plotted against sites and maturity stage. Plots and figures were done with ggpubr and ggplot2 packages. All data analyses were performed using R statistical software v. 4.3.3 (R Core Team, 2023).

Results

A total of 2000 banana fruits were collected and reared during the study. These samples weighed approximately 117.84 kg from which immature green had 30.83 kg, mature green 69.06 kg, and mature ripe 17.95 kg. A total of 5945 pupae were reared from the samples, however 1320 did not hatch while the remaining 4625 emerged successfully. The hatched adults were predominantly identified as *B. musae* and we stored the voucher specimens in a freezer at -20°C for future molecular identification. The abundance of females, n=1932, was higher than their male counterparts, n=1423. Parasitoids, mainly *Diachasmimorpha* sp., were excluded from the analysis due to their very low numbers, n<5.

The sites have a significant effect on the number of adults reared from Kalapua banana (χ^2=1917.6, df=3, P<0.001; Figure 2). Burit has the highest number of adults compared to the other three sites (z=279.03, P<0.001). The number of adults in Burit is higher than Kereba (z=29.611, P<0.001), Vudal (z=27.504, P<0.001), and Vunapalading (z=29.727, P<0.001). There is no difference in the adult abundance between Kereba and Vunapalading (z=0.287, P=0.9918). The number of adults reared from bananas in Burit was six times higher than in the other three sites.

The maturity stages also have a significant effect on the number of adults reared from Kalapua banana (χ^2=1078.1, df=2, P<0.001; Figure 3). Immature green has the lowest number of adults com-

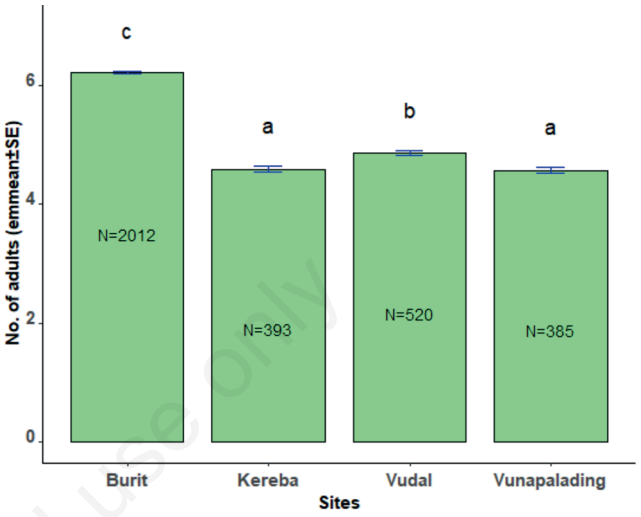

Figure 2. Barplots of generalized linear model (glm) with number of adults as response and sites as the explanatory variable. The bars on top of each plots are the standard errors. Based on the glm model, estimated marginal means (emmeans) are calculated and pairwise comparison is done with grouping of similar mean values. The symbol 'N' represents the total number of individuals at each site. Plots sharing the same letter are not statistically significant at α=0.05.

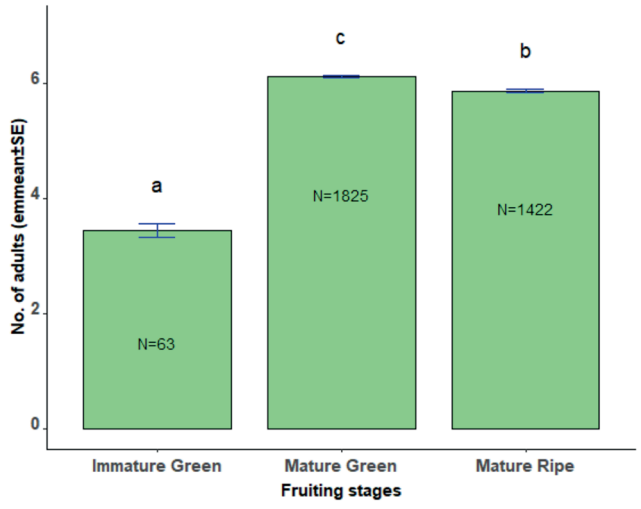

Figure 3. Barplots of generalized linear model (glm) with number of adults as response and maturity stage as the explanatory variable. The bars on top of each plot are the standard errors. Based on the glm model, estimated marginal means (emmeans) are calculated and pairwise comparison is done with grouping of similar mean values. The symbol 'N' represents the total number of individuals reared at each fruiting stage. Plots sharing the same letter are not statistically significant at α=0.05.

pared to the other two stages (z=27.38, P<0.001). The number of adults reared from immature green fruit is lower than mature green (z=-20.860, P<0.001) and mature ripe (z=-18.824, P<0.001). The difference between mature green and mature ripe was also significant with the former being higher (z=7.054, P<0.001). The number of adults reared from bananas in immature green was twice as low as mature green and mature ripe.

The maturity stages of fruits have a significant effect on the gender of *B. musae* (χ^2=19.630, df=2, P<0.001; Figure 4). There is no difference in the abundance of females and males in immature green fruits (z=0.880, P=0.9514). The ratio of female-to-male in immature green fruit is 1.25 [35/28] which is approximately 1:1. The number of females is significantly higher than males in mature green fruits (z=9.342, P<0.001). The sex ratio of female to male in mature green fruit is 1.59 [1051/661] which is approximately 2:1. To avoid resource-poor hosts (*i.e.*, immature green fruits), female fruit flies can manipulate the sex and number of offspring so that more females are produced from resource-rich hosts (*i.e.*, mature green fruits) and males on resource-poor hosts (Akol *et al.*, 2013). Although the number of females is slightly higher than their male counterparts in mature ripe fruits, the difference is not significant (z=2.643, P=0.0872) and it is a 1:1 sex ratio [750/651].

The five ambient temperatures (25°C, 26°C, 28.5°C, 31.5°C, 32°C) correspond to the five lab data collection dates. The influence of ambient temperature on total adult abundance is significant and shows a mid-peak pattern (F=8.8, df=4, P<0.001; Figure 5). The highest number of individuals was recorded at 28.5°C (1913). At this temperature, most *B. musae* were able to emerge from their pupal case. The lowest abundance was recorded at 25°C (89). There is a steep drop in total abundance at 31.5°C (202) and 32°C (180).

We calculated the infestation of bananas according to fruit weight in kg (Figure 6A) and fruit number (Figure 6B) for each site. The highest infestation by fruit weight was recorded in Burit (20.9%) and the lowest in Vunapaladingg (11.9%). Vudal had the second-highest infestation (16.8%) followed by Kereba (14.7%). In terms of fruit number, Burit experienced the highest fruit infestation (23.5%). Kereba (13.0%), Vudal (12.5%), and Vunapaladingg (12.0%) had lower infestation by fruit number. There are some variations between infestation by fruit weight and fruit number. However, in both cases, Burit experienced the highest infestation.

We also calculated the infestation of bananas according to fruit weight in kg (Figure 7A) and fruit number (Figure 7B) for each maturity stage. The highest infestation by fruit weight was recorded in mature ripe fruit (37.1%) and the lowest in immature green fruits (2.04%). Mature green fruits experienced moderate levels of infestation (17.1%). In terms of fruit number, immature green fruits also experienced the lowest infestation (1.8%), moderate infestation in mature green fruits (17.0%) and highest infestation in mature ripe fruits (26.9%). The level of infestation increases with increasing maturity age.

Discussion

Fruit flies could be potentially devastating to fruit agro-industries in tropical regions. The banana fruit fly, *B. musae*, has been reported to oviposit eggs in immature green bananas (Allwood and Drew, 1997). It is a major pest in ENB where banana is an important food source. From this study, we were able to rear some *B. musae* from immature green bananas. Females of tropical fruit flies (Diptera: Tephritidae: Dacinae) deposit their eggs into fruits and vegetables so that the developing larvae can consume them (White and Elson-Harris, 1992, Leblanc *et al.*, 2001). Apart from fruits as the main host, Dacine fruit flies can also oviposit in vegetables like cucumber, pumpkin, bell pepper, and chili (White and Elson-Harris, 1992, Vijaysegaran, 1996). Fruits vary in the resources they offer to larvae, which can influence the size, development time, pupal weight, adult eclosion rate, and reproductive maturation time of adult flies (Krainacker *et al.*, 1987, Bruzzone *et al.*, 1990, Khan *et al.*, 1999, Kaspi *et al.*, 2002). Very low *B. musae* in immature green fruits can be related to host fruit quality. Ovipositional sites by herbivorous insects partially depend on host plant quality (Wilson, 1988, DiTommaso and Losey, 2003, Van Nouhuys *et al.*, 2003) as gravid fruit flies often make ovipositional decisions based on fruit suitability for their progeny's per-

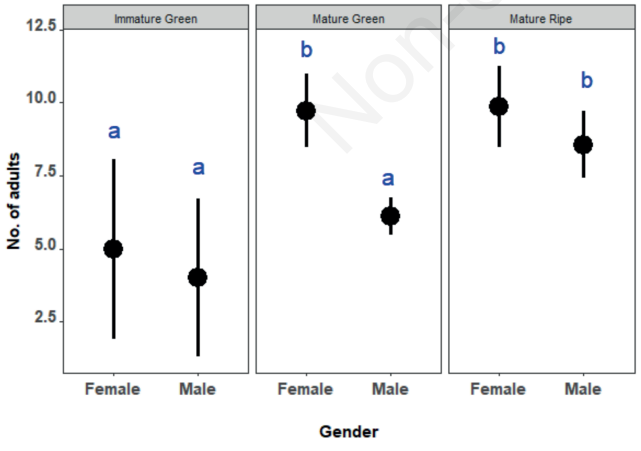

Figure 4. Point range plots showing the number of adults as response and, maturity stage and gender as explanatory variables. The point range is fitted using generalized linear model (glm) with Poisson distribution. The point range bars show the mean and standard errors. Based on the glm model, estimated marginal means (emmeans) are calculated and pairwise comparison is done with grouping of similar mean values. Plots sharing the same letter are not statistically significant at α=0.05.

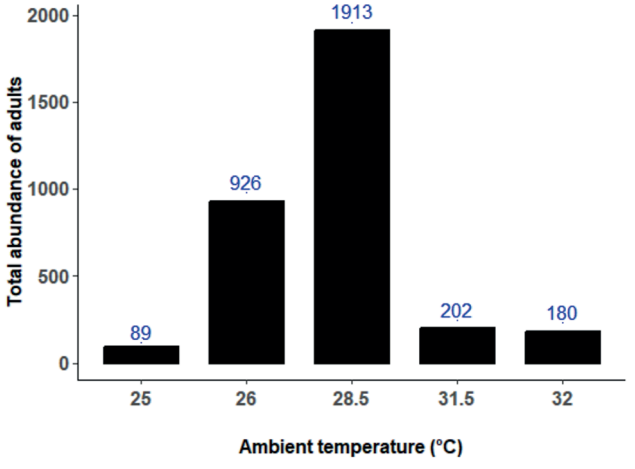

Figure 5. Influence of temporal fluctuations in temperature on adult emergence. The mid-peak shows that 28.5°C is optimum for emergence. Temperature fluctuates during the day with minimum of 25°C and maximum of 33°C. The ambient temperature corresponds to the five lab data collection dates.

formance (Fitt, 1981, Joachim-Bravo *et al.*, 2001, Fontellas-Brandalha and Zucoloto, 2004).

From this study, the overall male-to-female proportion was 0.74, which implies that females were prevalent. The ratio of female-to-male in mature green fruit was 1.59 and significantly different. According to Imran *et al*. (2013), the sex ratio of male *Bactrocera zonata* was significantly lower than its female counterpart in a free-choice test. A key finding of this study was that, at a mature green stage, more females are produced while immature green and mature ripe fruits host a stable sex ratio. The female-sex ratio of the pomegranate fruit butterfly, *Virachola livia* was 51.72 on pomegranate fruit and 53.34 on green pod of acacia (Gharbi, 2010). The overall

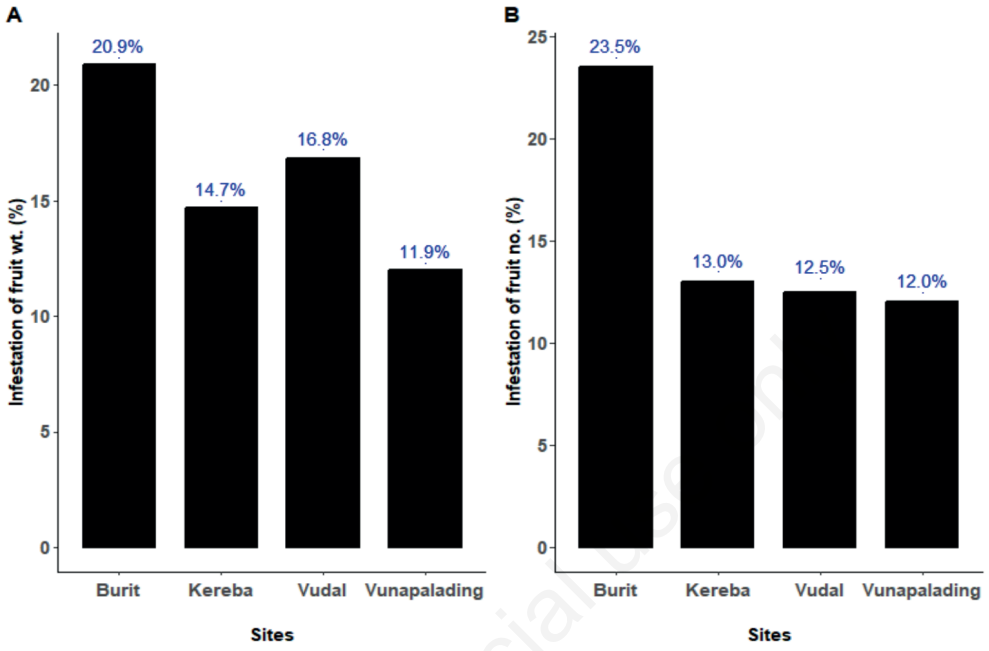

Figure 6. Column graph showing the infestation of fruit weight (A) and fruit number (B) at each site. The fruit weights are given in kilogram (kg). The values on the bars are the total infestation recorded at each site. Infestation values are conditioned as factor and infestation as response.

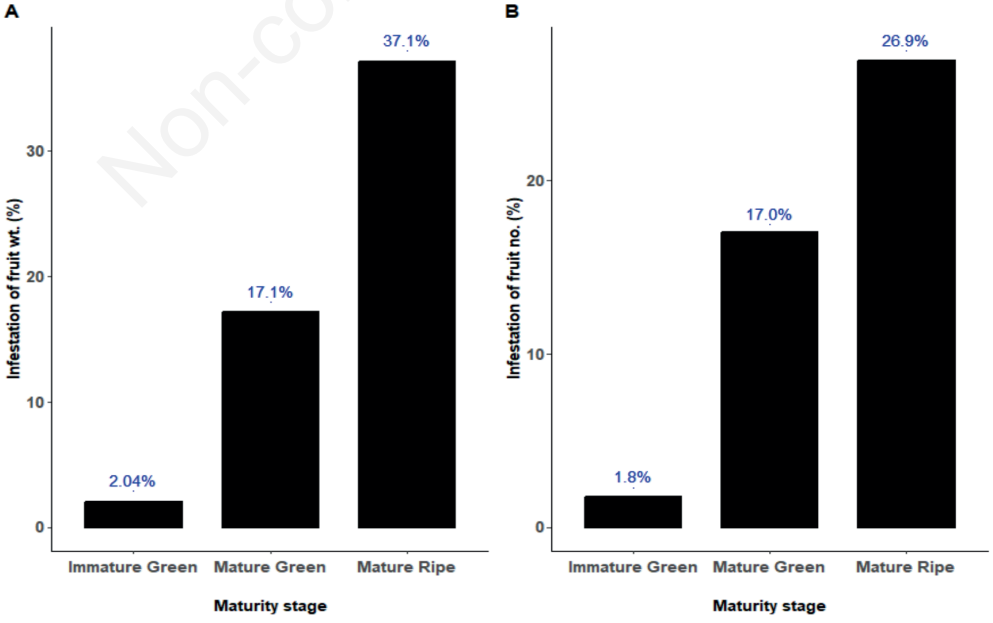

Figure 7. Column graph showing the infestation of fruit weight (A) and fruit number (B) at each maturity stage. The fruit weights are given in kilogram (kg). The values on the bars are the total infestation recorded for each maturity stage. Infestation values are conditioned as factor and infestation as response.

sex ratio of female pyralid moth, *Dichocrocis punctiferalis*, was more prevalent than males on chestnut, peach, and quince (52.7:47.3). Another study found that there were more females (n=27.6, SD=11.6) than males (n=6.8 males, SD=2.5) in guava (Howard and Kenney, 1987). Haq *et al*. (2019) found no significant difference in male:female sex ratio of adult Mediterranean fruit fly, *Ceratitis capitata.* According to host size models, solitary ovipositing species can manipulate the sex of their offspring in response to the characteristics of their hosts (Akol *et al.*, 2013).

The foraging patterns of fruit flies are often determined by changes in the seasonal distribution of food, spatial, and temporal factors (Hendrichs *et al.*, 1991). Amice and Sales (1997) reported that climatic variables such as rainfall and temperature play a role in the abundance of *B. invadens*. Temperature, humidity, and rainfall are ecological factors that adversely affect the population dynamics of fruit fly larvae and pupae (Faryad *et al.*, 2023). A previous study in the Gazelle Peninsula reported that the banana fruit fly, *B. musae*, is the most dominant species mainly due to the abundance of its host plants (Iamba *et al.*, 2021). Temperature was the abiotic factor that significantly influenced the temporal population of *B. musae* in our study. Our study showed that temperature affected the emergence of adult *B. musae.* The neonate emergence from pupal case peaks at 28.5°C but decreases sharply before and after this point. High summer temperatures limited the abundance of olive fruit fly, *Bactrocera oleae* (Wang *et al.*, 2009). Stress caused by temperature delayed the developmental stages, survival rates, and longevity of *Bactrocera dorsalis* when temperatures decreased to 0°C and increased to 36°C (Yu *et al*., 2022). It has been reported that the number of eggs deposited by females daily is restricted by temperature, the density of larvae in fruit, and suitability of fruit for oviposition while the reproductive activity of reproductive females and males decreases with rainfall (Yonow *et al.*, 2004).

The banana fruit fly, *B. musae,* is a major pest of bananas and plantains in mainland PNG and the New Guinea Islands. In order to measure the level of infestation caused by *B. musae,* banana fruits had to be reared in individual containers (Leblanc *et al.*, 2001). According to the report by Mararuai *et al.* (2002), the average infestation rate of market surveys was 3% and 0.2% for garden surveys in the Gazelle Peninsula of ENB province. These were the relative figures recorded after the 1999 incursion of *B. musae* in the Gazelle Peninsula. It was also reported that infestation of Kalapua banana by *Bactrocera musae* can reach 25% in ENB and 30% in Central Province (Sar *et al.*, 2001). The study by Mararuai *et al.* (2002) also confirms that damage caused by banana flies on the Cavendish variety in PNG was 10.5% in Gazelle. We did the study to reassess these past results on infestation levels of *B. musae* and to evaluate the current trend in the Gazelle Peninsula. The infestation levels have increased *viz.* banana fruits from garden surveys have exceeded 20% (Figures 6, 7). Burit for example, has exceeded 20% infestation level while Kereba, Vudal, and Vunapalading have exceeded 10% infestation. Burit is located inland with less disturbance from large-scale oil palm plantations and is situated close to forests and natural vegetation. Tephritid flies such as *B. musae, B. fraunfeldi* and *B. dorsalis* can move between habitats in search for food, mating, and refugia (Balagawi *et al.*, 2014, Hendrichs *et al.*, 1991, Danjuma, 2013). The vegetation and trees on the garden edges provide resting sites for adult flies as increasing height generally supports a greater abundance of *B. tryoni* (Balagawi *et al.*, 2012, Hooper and Drew, 1979).

These differences in infestation level can also be explained by *B. musae* being polyphagous as it utilizes 16 hosts from 9 families (Plant Health Australia, 2018). Fruit flies express low host specificity to congeneric plant species and similarly in respect to both confamilial genera and interfamilial (Novotny *et al.*, 2005). The impact of extensive oil palm plantations resulting in reduced gardening area and scarcity of host plant heterogeneity is evident in Vunapalading. *Ceratitis capitata* larvae are drawn to more nutritious parts of the food resource, which implies that in the nutritional environment, heterogeneity determines the response of larval foraging (Fernandes-da-Silva and Zucoloto, 1993). Competition among foraging individuals in heterogeneous nutritional environments might also drive frequent movements and/or to shift to suboptimal diets (Morimoto *et al.*, 2019).

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