ENTOMOLOGY

Fruit flies (Diptera: Teprithidae) and their parasitoid (Hymenoptera: Braconidae) species from registered snake fruit production during early rainy and dry seasons in the Special Region of Yogyakarta, Indonesia

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Abstract

Exportation of snake fruit from Indonesia to China, Australia, and New Zealand has been hindered due to fruit fly infestations (Diptera: Teprithidae). The goal of this study was to identify fruit flies and their parasitoid species from registered snake fruit productions in Turi, Sleman, that have reached packaging houses during early rainy and dry seasons. Fruit fly species were morphologically identified from collected rejected or damaged snake fruit. Parasitization was calculated by dividing the number of emerging parasitoid species by the total number of parasitoid and fruit fly individuals. The population of fruit flies and parasitoids was then compared to climatic data. Female fruit flies that emerged from snake fruit possessed spots on their front preapical femur, concluding that these species were *Bactrocera carambolae*. The average fruit fly that emerged per fruit was 16.5 individuals. Only one parasitoid species emerged and possessed *notauli on mesonotum* that elongated to the center and *petiole* and longitudinal *metasomal tergum* 2, implying that this parasitoid species was *Fopius arisanus* with an average population of 5.71 individuals with a parasitization percentage of 26.86%. Results from this research concluded that the fruit fly species collected from registered snake fruit productions in Turi, Sleman, during the early rainy season and dry season was *Bactrocera carambolae* with a low parasitization level by *Fopius arisanus*. This parasitization level may be affected by fruit fly density and climatic factors, such as humidity and rainfall.

Introduction

Snake fruit [*Salacca zalacca* (Gaertner) Voss] originates from Southeast Asia and is popular in Indonesia, with potential interest from domestic and international markets. Central Java, Bali, South Sulawesi, Yogyakarta, and North Sumatera are snake fruit production centers in Indonesia (Wijayanti, 2019). Indonesian snake fruit exportation in 2019, 2020, and 2021 was 1698 tons, 1100 tons and 1651 tons evaluated at 1.89, 1.29, and 1.78 million dollars, with exportation destinations of Cambodia, Malaysia, China, Thailand, Belanda, France, Singapore, Saudi Arabia, and Qatar (Republic of Indonesia Ministry of Agriculture, 2019, 2020, 2021).

Fruit flies (*Bactrocera* spp.) are a major challenge during production and exportation (Agriculture Quarantine Agency, 2020). Fruit fly occurrence can reduce the quality and quantity of yield during production and its quarantine pest status in China, Australia, and New Zealand may hinder snake fruit exportation

(Agriculture Quarantine Agency, 2014, 2020) and increase management costs during packaging. Detection of fruit flies during exportation in the destination port may lead to rejection or destruction and lead to cost loss and release of notification of non-compliance from the destination country. This will later lead to the postponement or rejection of snake fruit exportation from Indonesia. Fruit fly management has been done by maintaining sanitary standards and installing methyl eugenol traps in snake fruit productions, but populations have not been fully managed. Therefore, other approaches, such as the use of biological control parasitoids, have been explored due to the success of this approach in different countries and commodities (Stibick, 2004; Harris *et al*., 2010; Vargas *et al*., 2012; Nanga *et al*., 2019; Moquet *et al.,* 2023). Information on fruit flies that infest certain commodities and their parasitoids is important to developing biological control programs (Chinajariyawong *et al*., 2000; Yaakop and Aman, 2013).

This research aimed to i) determine fruit fly species from snake fruit and their parasitoids from registered production in Turi, Sleman, Special Region of Yogyakarta that reached packaging houses; ii) determine fruit fly population, parasitoid population, and parasitization levels during early rainy and dry seasons.

Materials and Methods

Research location and sampling period

Snake fruit was sampled from packaging houses in Combined Farmer Groups in Turi that export produce from registered snake fruit productions. Snake fruit produced in these packaging houses came from ten fields, including the County of Girikerto (Nangsri Lor, Sokorejo, and Pelem), the County of Wonokerto (Kembang, Becici, Imorejo, Tlatar), the County of Bangunkerto (Ledhok nongko, Wonosari) and the County of Purwobinangun (Ngelodadi). Four samples were taken between February and March 2023 during the early rainy season and August and September 2023 during the dry season.

Host rearing of fruit fly and parasitoid

Fruit fly and parasitoid rearing was done in the Basic Entomology Laboratory, Department of Crop Protection, University of Gadjah Mada, using methods modified from Suputa *et al*. (2007). Snake fruits sampled were rejected fruits with 70-80% ripeness and weight between 80-100 g harvest 6 months after pollination that showed fruit fly infestation. Fruits were placed in 750-mL plastic containers with mesh placed on lids to maintain air circulation, and sawdust was placed on the bottom of each container for pupation sites. One fruit was placed in each plastic petri dish and tissue, with a total of 18 snake fruit for each sampling period.

Identification of fruit flies and their parasitoids

Fruit flies that perfectly emerged into imago with clear morphological features and colors were morphologically identified as species using determination keys by Suputa *et al.* (2006), Drew and Romig (2013), and Plant Health Australia (2018). Parasitoid identification was done using morphological features using identification keys by Carmichael *et al*. (2005) and online resources (Wharton and Yoder, 2023).

Parasitization level

Parasitization levels were calculated by dividing the number of emerging parasitoids by the total number of emerging parasitoids and imago fruit flies and multiplying by 100%, which followed methods from Baranowski *et al*. (1993). The formula used was as follows (Equation 1):

$$\text{Parasitization level (\%)} \quad \frac{\sum X}{\sum (X+Y)} \times 100\% \qquad \text{[Eq. 1]}$$

Where X is the number of emerging parasitoids and Y is the number of emerging imago fruit flies

Data analysis

Observation results were tabulated and processed using MS Excel 2019 (Microsoft, Redmond, WA, USA) and analyzed using one-way analysis of variance using post-hoc Tukey (α=0.05) in SPSS version 25 (IBM, Armonk, NY, USA). Daily average climates from Meteorological, Climatological, and Geophysical Agency (BMKG, 2023) online were visualized and compared to fruit fly and parasitoid populations.

Results

Fruit fly species

Imago fruit fly identified during the 4-month observation was *Bactrocera carambolae* with the main morphological feature of parallel or subparallel lateral postsutural vittae that end at the end of seta intra alar (Figure 1a). Costal band overlapped the R2+3 and slightly expanded on top of R2+3 and cross R4+5 with a hook shape (Figure 1b). Terga Abdomen III-IV had a "T" pattern with a wide longitudinal medial (Figure 1c) and square-shaped anterolateral corner terga IV (Figure 1d). All tibia were dark, and females had spots on the front preapical femur (Figure 1a).

Parasitoid species

Parasitoid species observed during the 4-month observation period was *Fopius arisanus*. Some of the main features were clypeus that did not bulge to the medial, margin ventral almost completely covered labrum when lower mandibles are closed (Figure 2a), mesonotum with notauli was present to the median (Figure 2b), wings venation and cells Vena RS + M, while vein

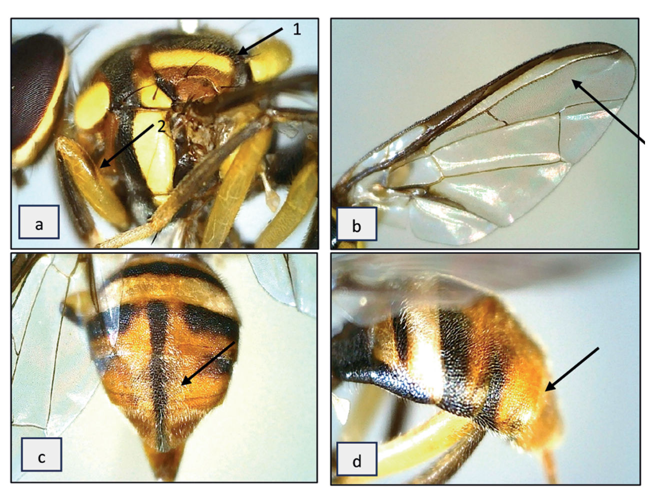

Figure 1. *Bactrocera carambolae*. a) Seta intra alar (1), spots on front preapical femur (2); b) wing; c) dorsal abdomen; d) lateral abdomen.

2m-cu was not present (Figure 2c), petiole and metasomal tergum 2 with longitudinal striates (Figure 2d).

Fruit fly and parasitoid population fluctuation in registered snake fruit productions in Turi, Sleman

Fruit fly and parasitoids were detected in every observation month and were analyzed and compared between seasons (Table 1). In February, the highest average fruit flies of 25.39 individual/fruit was significantly different from the average fruit flies observed between August and September of 8.61 and 9.67 individual/fruit, respectively, while the average fruit flies in March was 22.33 individual/fruit. The average number of parasitoids during the four observation months was between 3.61 and 7.06 individual/fruit. The highest parasitization level was 42.51% in August and it was similar to the levels in February and September, which were 18.25% and 30.53%, respectively. The lowest levels were observed in March (16.17%). The sex ratio male:female of fruit fly and parasitoid were 44.97% and 48.54%.

Population fluctuation of fruit flies and parasitoids was correlated to season with effects varying depending on observed parameters. The average fruit fly population was higher during rainy seasons compared to dry seasons while parasitoid populations were similar across seasons. In contrast, parasitization levels were higher during dry seasons and were not due to the non-existence of parasitoids but the low numbers of fruit flies. These results were in line with previous research that showed that these parameters are affected by biotic and abiotic factors (Bateman, 1972; Garcia, 2009). The relationship between the average daily climatic factors (air temperature, humidity, and rainfall) and the fruit fly population is presented in Figure 3.

Discussion and Conclusions

The fruit fly species collected from snake fruits sampled in Turi, Sleman, Special Region of Yogyakarta was identified as *B. carambolae*, which is a species well distributed in Malaysia, France, Guyana, India, Indonesia, Thailand, Suriname, and Vietnam with 75 host species belonging to 26 families (Allwood *et al.*,1999; Drew and Romig, 2013) but has not been reported on *B. carambolae* (Allwood *et al.*, 1999; Suputa *et al.,* 2010; Drew and Romig, 2013). Aryuwandari *et al.* (2020) and this research found snake fruit to be a host and should be recorded as a host of *B. carambolae.* Aryuwandari *et al.* (2020) reported that *B. carambolae* and *B. dorsalis* are collected from snake fruit and these differences may be due to different locations that differ in the biotic and abiotic factors that later correlate to population fluctuations (Bateman, 1972; Garcia, 2009). The biotic factors that affect the fruit fly population include host availability, microsymbionts, and the presence of natural enemies, while abiotic factors include temperature, humidity, or rainfall. Fruit fly attraction is highly correlated to host availability and abundance. Fitrah *et al.* (2020) reported that guava is a host of *B. dorsalis* followed by starfruit and snake fruit, while in the same research, half of the observations demonstrated that *B. dorsalis* did not infest snake fruit.

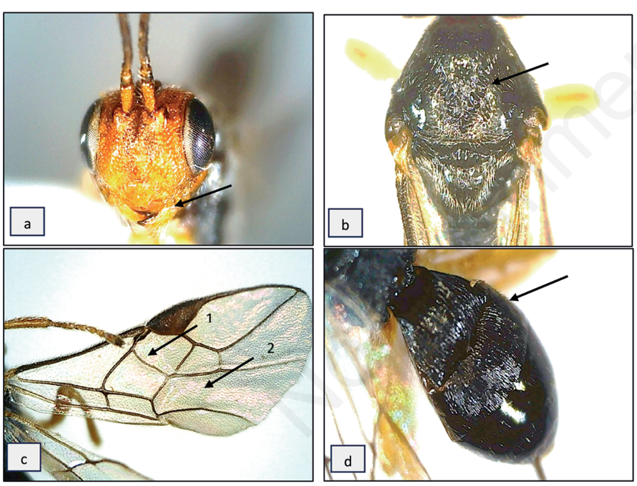

Figure 2. *Fopius arisanus*. a) Head; b) thorax; c) cells vena RS + M (1) and vein 2m-cu was not present (2); d) abdomen.

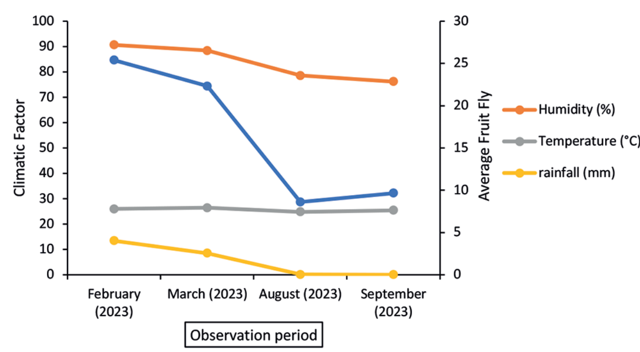

Figure 3. Climatic variables (temperature, humidity, and rainfall) and average fruit fly population per snake fruit.

Table 1. Average fruit fly and parasitoid population, parasitization levels, and sex ratio of fruit flies and parasitoids.

Month	Fruit fly (individual/fruit)	Parasitoid (individual/fruit)	Parasitization (%)	Fruit fly sex ratio male:female (%)	Parasitoid sex ratio male:female (%)
February	25.39 b	3.61 a	18.25 ab	45.08	47.69
March	22.33 ab	5.61 a	16.17 a	46.98	32.38
August	8.61 a	6.56 a	42.51 b	39.58	54.24
September	9.67 a	7.06 a	30.53 ab	48.24	59.84
Average	16.5	5.71	26.86	44.97	48.54

Means followed by different letters within the same column were significantly different based on Tukey α=0.05.

Koswanudin *et al*. (2018) demonstrated that *B. carambolae* were attracted to starfruit and mango, while *B. dorsalis* was more attracted to papaya and mango in laboratory settings. Both studies elucidate the complex interaction of different possible hosts in an area and may affect fruit fly species attraction. Several plants surrounding snake fruit fields in Turi include watery rose apple (*Syzygium aqueum*), guava (*Psidium guajava*), malay apple (*Syzygium malaccense*), mango (*Mangivera* sp.), mangosteen (*Garcinia mangostana*), jackfruit (*Artocarpus heterophyllus*), papaya (*Carica papaya*), banana (*Musa* sp.), bitter melon (*Momordica charantia*), squash (*Sechium edule*), rambutan (*Nephelium lappaceum*), indian almond (*Terminalia catappa*), chilli (*Capsicum annuum*), tabasco pepper (*Capsicum frutescens* L), eggplant (*Solanum melongea*), tomato (*Solanum lycopersicum*), cucumber (*Cucumis sativus*), and several species of citrus (Fitrah *et al.,* 2020; Putri, 2023; authors observations). This variety of available hosts is believed to affect *B. carambolae* and *B. dorsalis* populations. *B. dorsalis* was expected to prefer to oviposit in other plants, such as guava, papaya, mango, and chili. *B. carambolae* and *B. dorsalis* captured using methyl eugenol varied depending on location and sampling period where *B. carambolae*:*B. dorsalis* from a location south of Thailand was 22.77:75.69% (Danjuma *et al*., 2013), 46.70:6.75% in tropical forest in Lombok, Indonesia (Hudiwaku *et al.,* 2021), 0:92.42% from Depok, Indonesia (Herrahmawati *et al*., 2023), dari habitat kebun buah di kabupaten Majalengka, Indonesa 72,28%:27,71% (Kolopaking *et al*., 2023), 54.26:32.24% from Bogor, Indonesia (Larasati *et al.,* 2013), 44.23:55.33% from snake fruit productions in Sleman, Yogyakarta (Putri, 2023), 4.70:95.29% from mango fields (Susanto *et al*., 2022) while another study from Bogor and Depok showed 50.8:44.37% (Tarno *et al*., 2022).

These results only indicate the population ratio between the two species in a location, but to determine the host, host rearing is required. *B. carambolae* dan *B. dorsalis* from watery rose apple in Gianyar, Indonesia, was 39.84:19.90% (Susila *et al*., 2022), mango in Sumedang, Majalengka and Indramayu was 14.27:85.02% (Susanto *et al*., 2022), guava 55.82:44.17%, mango 1.19:98.80%, watery rose apple 90.14:9.85% and starfruit 99.44:0.5% in Subang (Fujii *et al*., 2016). The overlap of host usage, host preferences, and population fluctuation may be related to the similar host species these two fruit fly species infest and also due to their similar gut microsymbiont compositions (Yong *et al*., 2017).

Results from this research do not clearly show the effect of *F. arisanus* on *B. carambolae* dominances. *Fopius arisanus* has been reported to show higher preferences for *B. tryoni* and *B. jarvisi* than *B. cucumis* (Quimio and Walter, 2001) and these preferences may change depending on what fruit fly species have infested, as shown previously in *B. dorsalis* work done by Nanga *et al.* (2019) and Eitam and Vargas (2007). *F. arisanus* fitness has also been shown to be affected by what fruit *B. dorsalis* has infested (Cai *et al.*, 2022) and implies that *F. arisanus* may prefer fruit flies in certain host species. *B carambolae* and *F. arisanus* association to surrounding fruit species surrounding snake fruit productions should be done to answer this question.

This research showed an increase in the average fruit fly population compared to the one by Aryuwandari *et al.* (2020), which showed 4.13 individuals from snake fruit, although different numbers of samples were used. This implies that fruit fly populations have been established and may be due to the continuous presence of suitable host plants over a wide area (BPS Sleman, 2016), availability of alternative host species, low parasitization levels, and growers that have not yet adopted available good agriculture practices that later serve as reservoirs of fruit flies for registered fields (personal communication with farmer group). These differences in population are caused by host availability (Peng *et al*., 2006; Ofori *et al.*, 2023; Putri *et al.*, 2024) and climatic factors, such as temperature, humidity, rainfall, and light period (Peng *et al.,* 2006; Khan *et al.,* 2021; Putri *et al.,* 2024). Results from this study show a relation between fruit fly population and humidity and rainfall, while air temperature did not show any effects (Figure 3), which was in line with findings from Putri *et al.* (2024) that showed that *Bactrocera* spp. Population correlated with rainfall and humidity but not air temperature and wind speed.

This study first reports *F. arisanus* parasitizing *Bactrocera carambolae* on snake fruit. Aryuwandari *et al*. (2020) work reported parasitoids associated with *B.carambolae* and *B. dorsalis* that infested mango, snake fruit, Indian almond, startfruit, god's crown, and *B. mcgregori* on *gentum gnemon* but has not reported the parasitoid species in Sleman. *F. arisanus* has also been reported by Suputa *et al.* (2007) on *B. carambolae* that infested starfruit in Yogyakarta besides *Agasnaspis* sp., and *Asobora* sp. Ardiyanti *et al*. (2019) also reported *F. arisanus* and *F. vandenboschi* as parasitoids of *B. carambolae* and *B. dorsalis* that infested starfruit, water rose apple, citrus and santol. Putra *et al.* (2019) reported *Diachasmimorpha* sp., *Opius* sp., and *F. arisanus* as parasitoids of *B. carambolae* and *B. papayae* (synonym species of *B. dorsalis*) that infested starfruit from Kabupaten Gianyar. These parasitoids, host fruit fly species, and fruit host species data should be compiled to later determine tri-trophic interaction among these actors in Indonesia, as has been done by Yaakop and Aman (2013) from Malaysia, Chinajariyawong *et al.* (2000) from Thailand and Malaysia, and Moquet *et al*. (2023) from La Reunion.

The average *F. arisanus* individual from each snake fruit was 5.71, with a male-to-female sex ratio of 48.54% and parasitization level of 26.86% (Table 1). The higher parasitization levels have been reported by Suputa *et al.* (2007) on starfruit of 0.5495±0.3843% to 1.2935±0.8206%, which was similar to the findings of Aryuwardani *et al.* (2020) in snake fruit from Turi (24.8%) and parasitization levels in starfruit of 19.7% from Ardiyanti *et al.* (2019). The parasitoid population was not significantly different between seasons, while parasitization levels were significantly different with the highest levels during August, similar to levels in February and September of 18.25% and 30.53% (Table 1). This implies that parasitization levels are not directly affected by parasitoid population levels but by the fruit fly population. *F. arisanus* parasitization is considered low in this study due to no human intervention to increase its population in snake fruit fields (Stibick, 2004). Human intervention for the conservation of *F. arisanus* may increase 65-70% parasitization of fruit flies (Vargas *et al*. 2012). Augmentarium using 2 mm^2 meshes was reported to be able to contain 100% of the fruit fly population while allowing 90% of *F. arisanus* to be released (Harris *et al.*, 2022).

Results of this research showed that the fruit fly that infests snake fruit was *B. carambolae*. Parasitoids that emerged was *F. arisanus,* with an average low parasitization level of 26.86%, which may be affected by the fruit fly population, humidity, and rainfall. To increase *F. arisanus* and parasitization levels, the sanitary standard should be increased and infested fruit should be placed in an augmentarium.

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