

Incidence of banana leaf roller and diversity of its parasitoids in Central Sulawesi, Indonesia

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Abstract. Pasaru F, Yunus M, Toana MH, Edy N, Anshary A, Saleh S. 2021. Incidence of banana leaf roller and diversity of its parasitoids in Central Sulawesi, Indonesia. *Biodiversitas* 22: 5023-5029. Incidence of banana leaf roller and diversity of its parasitoids in Central Sulawesi, Indonesia. Indonesia is still facing banana losses due to the leaf roller (*Erionota thrax*). Fortunately, it has several natural enemies potentially to control them. Therefore, a survey was done to measure the incidence of banana leaf roller (BLR) at different altitudes and banana cultivars as well as the diversity and parasitism of its parasitoids. The pra-imago stages of BLR were collected at different altitudes and banana cultivars in Central Sulawesi, Indonesia, and transported to the laboratory for rearing and parasitism observation. The study revealed that the incidence of *E. thrax* in the surveyed locations varied from 28.6% to 85.8%, whereas the parasitism level of the BLR parasitoids was 0.0 to 22.1%. Incidence of *E. thrax* tended to be higher at a higher altitude while Kepok cultivar seemed to be less prone to BLR infestation compared with Raja and Mas cultivars. A total of nine parasitoids of BLR were recorded. They were *Agiommatus sumatraensis*, *Pediobius erionotae*, *Ooencyrtus pallidipes*, *Brachymeria lasus*, *Brachymeria thracis*, *Cotesia erionatae*, *Xanthopimpla gampsura*, *Casinarina* sp, and *Palexorista solennis*. Among them, *B. lasus* was the most abundant, widely distributed, and had the highest parasitism rate. Our study figured out that BLR infestation is a major problem in Central Sulawesi. Nevertheless, the presence of parasitoids recorded in this study may potentially be used as the biological control.

Keywords: Banana skipper, BLR parasitoid, parasitism

INTRODUCTION

Bananas have mostly been planted in tropical countries. In Indonesia, it is developed by a big plantation company and as a garden plant. Banana occupies first place among other fruits in terms of distribution, area of planting, production, and as the most desirable fruits (Suyamto et al. 2005). However, there are some limiting production factors of the banana, including pest infestation. One of the main pests of bananas is the banana skipper, also known as the banana leaf roller (BLR). There are two species of skippers of the genus *Erionota* Mabilbe (Lepidoptera: Hesperidae) that feed on banana leaves recorded in Southeast and South Asia namely *E. thrax* L. and *E. torus* Evans (Cock 2015; Irulandi et al. 2018). The imago of these two species can usually be distinguished by the wing variations where the forewing of *E. thrax* has a straight outer margin and acute apex. In contrast, the forewing of *E. torus* is more convex in the outer margin and rounded apex (Poorani et al. 2020). The taxonomy, distribution, food plants, and natural enemies of the BLR have been decisively reviewed by Cock (2015).

BLR is a slightly important pest in Asia. However, during the last two decades, the outbreak of BLR expanded and caused serious defoliators (Cock 2015; Poorani et al. 2020). The feeding activity of the BLR larva causes considerable damage to the banana's foliage by rolling the leaf while feeding on it. Although banana plants can

tolerate up to 20% defoliation, a heavy infestation can damage the whole banana leaf, leaving only the midrib intact. At 50%, defoliation by BLR larva will cause about 28% of yield losses (Cock 2015). The lower yields of infested banana by BLR is due to the delayed fruit maturity and reduced the bunch size (Abdul and Gosh 2020).

The infestation area of *E. thrax* in Indonesia tends to increase. In Central Sulawesi, a new infestation area of this banana pest ranged from 35 to 108 ha from 2014 to 2018 (Ditlin 2019). Several studies in Indonesia reported the parasitic wasps (Hymenoptera) and flies (Diptera) that potentially control the banana skipper (e.g., Hasyim et al. 1994; Hasyim et al. 1999; Erniwati and Ubaidillah 2011; Rahmawati et al. 2018). Nevertheless, most of those studies were conducted in Sumatra and Java Island. Additionally, the environmental factors, including weather, altitudes, natural enemies, and the banana cultivars influencing the population and infestation of BLR (Sharanabasappa et al. 2016; Irulandi et al. 2018).

Therefore, information about the infestation of BLR, their parasitoid at different altitudes and banana cultivars in Central Sulawesi known as one of the biodiversity hotspots in the Wallacea region, is urgent to be discovered. This study provides baseline data of BLR incidence on different banana cultivars in this region as well as the diversity and parasitism of the BLR potentially use as biological control agents.

MATERIALS AND METHODS

Study area

The research was carried out in the banana plantation in four villages of three districts in Central Sulawesi, Indonesia, i.e., Parigi Moutong, Sigi and Poso districts. The map of study sites is plotted as coordinate locations of research sampling by using Tableau free edition (Figure 1). The majority of bananas are grown in the home garden. They are cultivated as a sole crop, border crop, or intercrop in coconut and cacao plantations and several other crops.

The study sites in each district were selected purposively based on environmental factors, particularly elevation, and cultivar of bananas (Table 1). Altitudes, wind speed, temperature, and moisture were measured at one meter from the ground by using a digital environment meter (MASTECH MS 6300, Mastech, Indonesia), while rainfall data was taken from the Meteorology, Climatology, and Geophysical Agency of Central Sulawesi.

Insect sampling and identification

The incidence of BLR was observed on each study site from April to August 2019. Eighty trees of the banana plants were observed at each study site. Plant with at least one leaf roll in a leaf was considered infested. For identification and parasitism observation, three eggs group and twenty leaf rolls per site were collected randomly and reared at the Plant Pest Laboratory, Faculty of Agriculture, Tadulako University. The BLR and parasitoids were identified using several determination keys (Goulet and Huber 1993; Zhang et al. 2005; O'hara et al. 2009; Erniwati and Ubaidillah 2011). Species identification was then verified by the taxonomist of Museum Zoologium Bogoriense (MZB) of the National Research and Innovation Agency (BRIN). The scientific name of parasitoids encountered was checked at the database available at the Global Biodiversity Information Facility (<https://www.gbif.org/>).

Data analysis

Descriptive and inferential statistics were used for the data analysis. The level of incidence or infestation of BLR was calculated as:

$$\text{Percent incidence (PI)} = \frac{\text{Number of infested plants}}{\text{Total plants observed}} \times 100\%$$

Categorization of pest incidence was modified from Pratiwi et al. (2020) as follow: low (<25%), medium (>25-50%), quite high (>50-75%), and heavy (>75%) levels. Parasitism level was calculated as:

$$\text{Percent parasitism} = \frac{\text{Number of parasitized of eggs or larvae}}{\text{Number of eggs or larvae observed}} \times 100\%$$

Data were checked for the normal distribution by Shapiro-Wilk's W-test and normalized using the Arc-sin transformation. Differences in pest incidence and total parasitism among study sites were tested by ANOVA followed by Honestly Significant differences (HSD). All analyses were done by using R 3.6.2 (R Core Team 2019).

RESULTS AND DISCUSSION

The incidence of *Erionota thrax* and parasitism

The study recorded *E. thrax* as the BLR in our study area. The incidence of *E. thrax* at the banana plantation was varied from low to heavy levels. The lowest incidence of BLR was recorded at Maku, Sigi districts, where the banana population is dominated by Kepok cultivar, while the highest incidence was at Kawende, Poso district. The leaf losses due to infested by BLR was vary from only a minor part of the leaf (Figure 2.A) to quite high where most parts of the leaves are defoliated (Figure 2.B). The pra-imagos stages inside the leaf rolls were found at both condition of leaf damages (Figure 2.C-F).

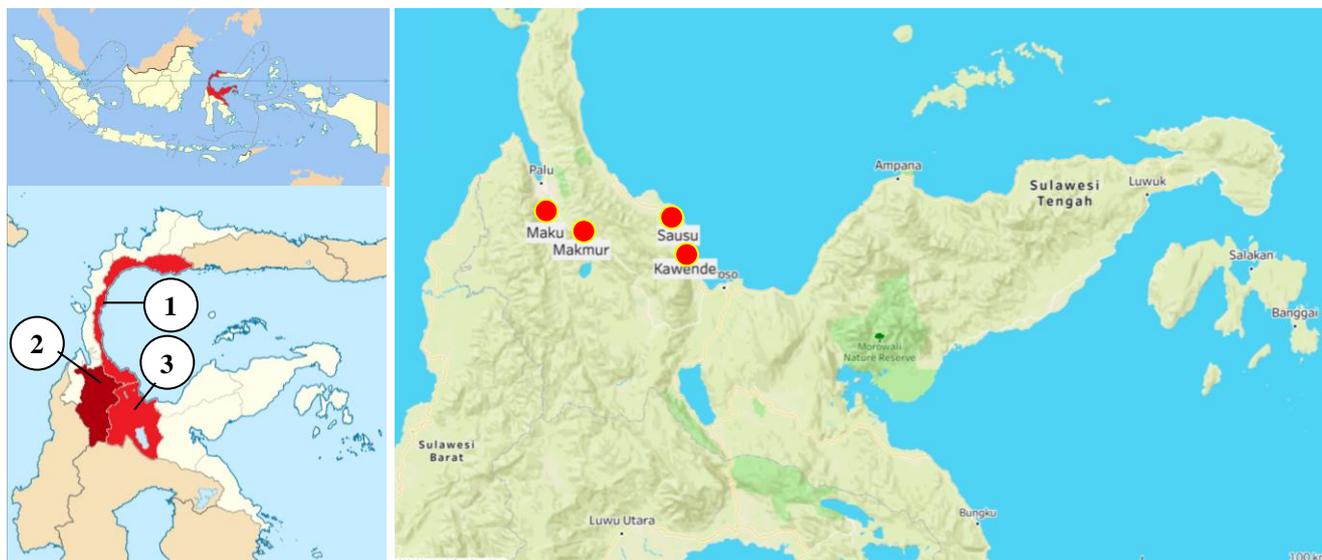


Figure 1. Location of the study sites (indicated by red circles) in Central Sulawesi Province, Indonesia. 1. Parigi Moutong District, 2. Sigi District, 3 Poso District

Table 1. Description of study sites

Environmental parameters	Parigi Moutong District	Sigi District	Poso District	
	Sausu	Maku	Kawende	Makmur
Coordinates	-1.065816 S, 120.526795 E	-1.0519472 S, 119,8880582 E	-1.230886 S, 120.561421 E	-1.137919 S, 120.058479 E
Altitude (m asl)	58 m	56 m	13 m	543 m
Wind Speed (m/s)	0.0 - 1.0	0.1 - 0.4	0.0 - 0.6	0.0 - 0.1
Temperature (°C)	31.9 - 33.8	33.1 - 35.0	31.2 - 32.2	32.7 - 33.4
Relative humidity (%)	60.9 - 72.3	60.6 - 63.0	64.5 - 73.0	58.7 - 65.0
Rainfall (mm/year)	146.21	66.44	126.32	160.38
Banana cultivars	Raja and Mas	Kepok	Raja and Mas	Raja

Overall, the BLR incidence at the study sites was in the range of 28.6% to 85.8%, whereas the total parasitism of the BLR parasitoids also varied among sites, and it was between 15.1% and 36.4%. BLR incidence was significantly different among sites; $F_{(3,12)} = 77.321$, $p < 0.000$ but total parasitism was not; $F_{(3,12)} = 2.010$, $p = 0.1663$. Interestingly, parasitism levels tended to increase following the incidence of BLR (Figure 3).

Diversity and parasitism of BLR parasitoids

The study recorded nine species of parasitoids of *E. thrax*. Eight of them belonged to Hymenoptera, i.e., *Agioimmatus sumatraensis* Crawford, 1911; *Pediobius erionotae* Kerrich, 1973; *Ooencyrtus pallidipes* (Ashmead, 1904); *Brachymeria lasus* (Walker, 1814); *Brachymeria thracis* (Crawford, 1911); *Cotesia erionotae* (Wilkinson, 1928); *Xanthopimpla gampsura* Krieger, 1914, and *Casinaria* sp., whereas one species i.e., *Palexorista solennis* (Walker, 1858) is a Diptera (Figure 4).

The parasitoid size was in the range of 1.2 to 14.9 mm with the bigger size was *X. gampsura* than followed by *B. lasus* and *P. solennis*. The host stage infested by parasitoids was varied, i.e., egg, larva, and pupa of the BLR. They were also different concerning the numbers of immatures per individual host. Three parasitoid species were solitary

(one parasitoid per host), and the rest were gregarious (more than one parasitoid per host). The parasitoid *B. lasus* was the most gregarious parasitoids where the number of adult parasitoids that emerged from one host was about 7 to 15 individuals.

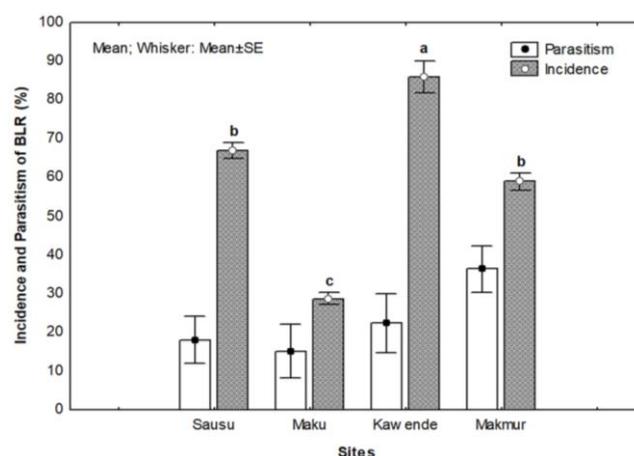


Figure 3. Incidence of banana leaf roller (*Erionata thrax*) and total parasitism in the study sites. Different letters indicate significant differences (HSD Test, $p < 0.01$)

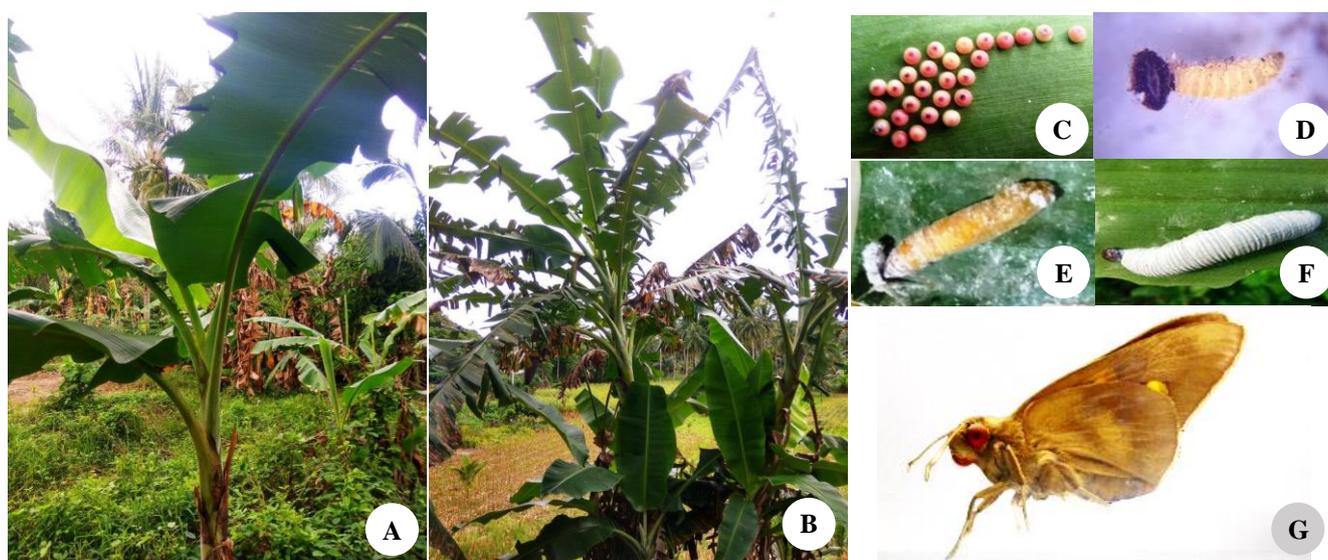


Figure 2. *Erionata thrax*. A-B. Symptoms of damages on banana; C-G. Life stages of *Erionata thrax*; C. Eggs; D. Early instar larva; E. Mature larva; F. Pupa; G. Adult

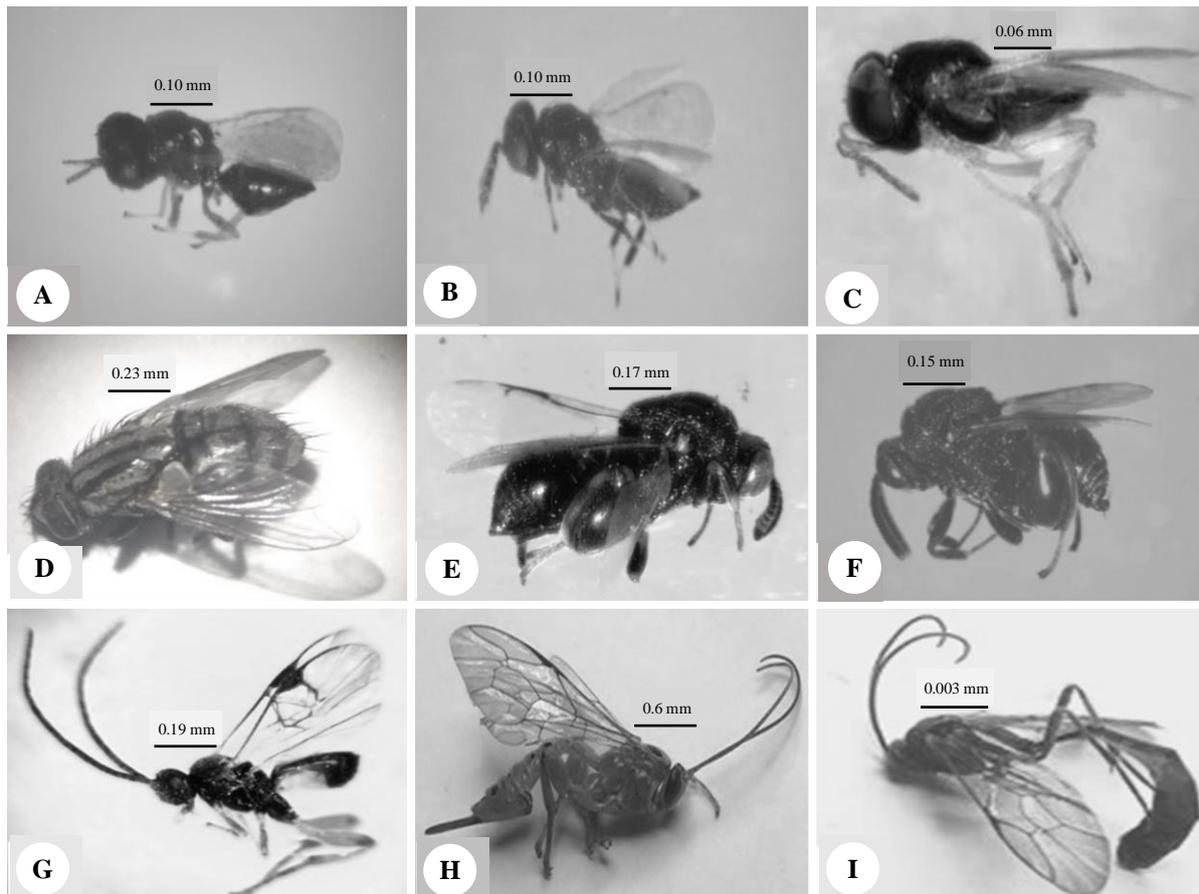


Figure 4. Parasitoids of BLR in Central Sulawesi, Indonesia. A. *Agiommatius sumatraensis*; B. *Pediobius erionotae*; C. *Ooencyrtus pallidipes*; D. *Palexorista solennis*; E. *Brachymeria thracis*; F. *Brachymeria lasus*; G. *Cotesia erionatae*; H. *Xanthopimpla gampsura*; I. *Casinaria* sp.

The number of parasitoids species was different between locations. There were six species found in Maku, five in Kawende, four in Makmur, and two in Sausu. Of nine recorded parasitoids, only *B. lasus* were distributed in all study sites, while other species were only present at a particular location. The parasitism level of different parasitoid species ranged from 0.0 to 22.1%. The higher parasitism was recorded by *B. lasus* ($15.9 \pm 2.2\%$), followed by *A. sumatraensis* ($9.4 \pm 2.9\%$) and *P. erionotae* ($8.8 \pm 2.1\%$), while the lowest parasitism was *C. erionatae* and *X. gampsura* ($0.5 \pm 0.1\%$) (Table 2).

Discussion

In this study, we investigated the incidence and parasitism of BLR at different elevates and banana cultivars. Previous studies have been reported the BLR attack on bananas in Indonesia and other tropical countries (Hasyim et al. 1994; Hasyim et al. 1999; Erniwati and Ubaidillah 2011; Irulandi et al. 2018). It is generally known that BLR attacks do not significantly reduce banana production except in high attack rates (Okolle et al. 2006). The population and infestation of this pest are influenced by various abiotic and biotic factors such as elevation,

weather, wind, natural enemies, and banana cultivars (Okolle et al. 2010; Irulandi et al. 2018).

For the first time, this study uncovers the incidence of BLR and diversity of its parasitoids at different altitudes and banana cultivars in Central Sulawesi, situated in the Wallacea region known as one of biodiversity hotspots. The study noted that BLR attacked all banana cultivars at the studied sites with a high incidence rate. Interestingly, the lowest incidence was recorded at Maku, Sigi district, where the banana population was dominated by Kepok cultivar. The highest was found at Kawende (Poso District), where three banana cultivars were planted (Raja, Kepok, and Mas). A study conducted in West Java, Indonesia, noted differences in BLR infestation between banana cultivars where Raja cultivar had the highest (Novianti 2008). In India, it has also been reported that BLR preferred a particular banana cultivar, and it might be related to the leaf character, such as the thickness of leaf lamina (Sharanabasappa et al. 2016; Irulandi et al. 2018). It suggests that further investigation might distinguish the resistance of banana cultivars against BLR.

Table 2. Parasitoids of *Erionata thrax*, parasitism, and their distributions in the study sites

Ordo/family/species	Size (mm) ¹	Host stadia	Type of parasitoids	Parasitism of each species at a different location ² (Sub-district/District)				Average
				Sausu, Parimo	Maku, Sigi	Kawende, Poso	Makmur, Poso	
Hymenoptera/Chalcididae								
<i>Brachymeria lasus</i>	5.4 ± 0.2	Pupa	Gregarious	13.3 ± 1.4	17.5 ± 0.3	11.3 ± 2.5	21.5 ± 4.5	15.9 ± 2.2
<i>Brachymeria thracis</i>	5.0 ± 0.3	Pupa	Gregarious	3.3 ± 1.4	0	5.0 ± 2.5	0	2.1 ± 0.9
Hymenoptera/Braconidae								
<i>Cotesia erionotae</i>	3.8 ± 0.2	Larva	Gregarious	0	2.5 ± 0.5	3.3 ± 1.4	0	0.5 ± 0.1
Hymenoptera/Ichneumonidae								
<i>Xanthopimpla gampsura</i>	14.9 ± 0.2	Pupa	Soliter	0	2.5 ± 0.5	0	0	0.5 ± 0.1
<i>Casinaria</i> sp.	1.2 ± 0.2	Larva	Soliter	0	0	3.3 ± 1.4	0	0.8 ± 0.4
Hymenoptera/Pteromalidae								
<i>Agiommatius sumatraensis</i>	2.6 ± 0.3	Egg	Soliter	0	22.1 ± 8.7	0	15.3 ± 3.2	9.4 ± 2.9
Hymenoptera/Eulophidae								
<i>Pediobius erionotae</i>	1.9 ± 0.5	Egg	Soliter	0	15.0 ± 3.9	0	20.0 ± 4.4	8.8 ± 2.1
Hymenoptera/Encyrtidae								
<i>Ooencyrtus pallidipes</i>	1.5 ± 0.3	Egg	Gregarious	0	3.3 ± 1.7	0	9.0 ± 1.4	2.3 ± 0.8
Diptera: Tachinidae								
<i>Palexorista solennis</i>	6.9 ± 0.3	Larva	Gregarious	0	0	5.0 ± 2.5	0	1.3 ± 0.6

Note: ¹an average size of three individual of imago, ²an average of four times observation. Data shown are mean ± standard error

Due to the insufficient data for statistical analysis, this study did not analyze the significant contribution of environmental factors on BLR incidence. However, the current study detected that the BLR incidence tended to be higher in the banana planted at lower altitudes (Sausu and Kawende). This result was different with Hasyim et al. (1994) reporting that the skipper population is more abundant at a higher elevation. Nevertheless, the results presented in the current study would support the hypothesis that weather parameters, including temperature, moisture, and altitude, together with banana cultivars, might be affecting the incidence of BLR (Kalshoven 1981; Okolle et al. 2010; Sharanabasappa et al. 2016). It is noteworthy that *E. thrax* may have a favorable condition to establish in banana leaves as long the host is present. Weather conditions may directly influence the larval development or mortality of *E. thrax* or indirectly the fitness of banana as the host plant of *E. thrax* (Okolle et al. 2010). However, modifying the environmental conditions related to management practices is almost impossible in relation to the cost of spending. Therefore, the presence of parasitoids *E. thrax* parasitoids is promising for biological control. Parasitoid insects are natural enemies that play an essential role in BLR population control (Hasyim et al. 2003; Okolle et al. 2010). This study found nine species of parasitoids associated with banana skipper pests, which is quite higher than those reported previously in Indonesia (Hasyim et al. 2003; Erniwati and Ubaidillah 2011; Wibowo et al. 2015; Rahmawati et al. 2018). The presence of *P. solennis* in Central Sulawesi is firstly reported by this study.

The study noted the different levels of parasitism. Of nine parasitoids found, *B. lasus* was the most distributed species found in all studied sites. This species also had the highest parasitism rate (13.3-21.5%) and was the most gregarious. Additionally, the size of *B. lasus* was the third larger among recorded parasitoids. All of these characteristics support *B. lasus* as the enormous potential

biological agent of BLR. According to the “adult size-fitness hypothesis” particularly in hymenopteran parasitoids, larger size individuals have several advantages, such as has a high capacity to find high-quality hosts, lifetime fecundity, longevity, and mating success than smaller parasitoids (Gao et al. 2016). The body size positively affects the parasitoids’ distances traveled (Fischbein et al. 2018), and these advantages are most likely related to their higher searching efficiency (Iranipour et al. 2020). Furthermore, gregarious parasitoids have several advantages compared with solitary parasitoids (Iranipour et al. 2020; Samkova et al. 2021). For example, *Cotesia erionotae* (Wilkinson), a gregarious larval parasitoid, has been successfully used to control *Erionota* spp. in some parts of the world (Kalshoven 1981; Cock 2015).

Other prospective parasitoids for control BLR recorded at the low and high altitudes in this study were *A. sumatraensis* and *P. erionotae*. The parasitism levels were 9.6-21.3% and 16.7-33.3%, respectively. The previous study in Central Sulawesi reported about 1.2% and 3.7% parasitism for *B. lasus* and *C. erionotae* (Rahmawati et al. 2018). Hasyim et al. (1994) recorded a 10-14% parasitism of eggs by *O. erionotae* and *P. erionotae*, 1-80% of larvae killed by *Casinaria* sp., and 50% of larvae attacked by *C. erionotae*.

Parasitoid, *P. solennis* that recorded in this study is also potentially to control the BLT. The parasitism level of this parasitoid was quite low. This is in line with Hasyim et al. (1994) and Poorani et al. (2020) highlighted the minor importance of the Tachinid flies (*P. solennis*). It has been reviewed that parasitizing of the leaf roller caterpillar by Tachinid flies was lower than Hymenoptera flies (O’hara et al. 2009). Nevertheless, Sharanabasappa et al. (2018) encountered two important tachinid parasitoids of *E. torus* in India.

Besides reported as the most common and effective biological control agency of banana skippers (Okolle et al. 2010), hymenopteran parasitoids were also important for another group of pests (Wang et al. 2019). However, the effectiveness of parasitoids to manage the banana skipper will increase by combining it with cultural or chemical controls in the scheme of integrated pest management (Okolle et al. 2010; Irulandi et al. 2018). Release the BLR parasitoids could be useful when the BLR population in the fields is low, while chemical control only needs if the population of this pest is high (Okolle et al. 2006).

The present study detected that a higher infestation of *E. thrax* tended to follow by higher parasitism at all studied sites. This result indicated that parasitoids of BLR performed well in the fields and most likely showed the density-dependent nature of the parasitoids. However, environmental factors such as elevation, rainfall, temperature, and humidity could also be the determining factors directly or indirectly. Differences in topography can result in differences in climate factors and plant phylogeny (Okolle et al. 2010).

It has been reported that incidence of *E. torus* was positively correlated with maximum temperature and sunshine hours, but negatively correlated with minimum temperature, morning and evening relative humidity and rainfall (Sharanabasappa et al. 2016). High infestation and parasitism of *E. thrax* usually occur during the rainy season and lower wind speed (Kalshoven 1981; Okolle et al. 2006), but heavy rainfall may roll down the young instar larvae in leaf and wind-torn leaves and interrupt the formation of leaf roll. Meanwhile, the larval period of the BLR was longer during lower temperature and higher humidity (Okolle et al. 2010; Irulandi et al. 2018). This condition might favour their natural enemies such as microbes or parasitoids to develop better.

Future studies would be essential to explore the diversity of the natural enemies of BLR besides parasitoids. Several predators such as a bug, *Platynopus melacanthus*, birds (particularly crows), ants, and spiders contributes to the mortality of the pra-imago of *E. thrax* (Okolle et al. 2010; Poorani et al. 2020). Another challenge is to explore the BLR-parasitoid association by using a DNA barcoding approach to cope with the problem of the identification due to the incompleteness collection of the BLR specimens (Cock et al. 2019).

In conclusion, this study provides insight into the current situation of BLR incidence in Central Sulawesi, Indonesia. BLR infestation is a major problem with incidence rich up to 85%. This pest incidence tended to be higher at a higher altitude. However, Kepok cultivar seemed to be less prone to BLR infestation compared with Raja and Mas cultivars. In addition, this study also recorded nine species of parasitoids for the pest *E. thrax*. These included eight species of insects in the wasp order and one in the fly order. They were *A. sumatraensis*, *P. erionataea*, *O. pallidipes*, *B. lasus*, *B. thracis*, *C. erionatae*, *X. gampsura*, *P. solennis*, and *Casinaria* sp. Parasitoid *B. lasus* was the most potential for controlling *E. thrax* followed by *A. sumatraensis*, and *P. erionotae*.

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REFERENCES

- Abdul JK, Gosh SM. 2020. Biology and damage of banana skipper *Erionota torus* (Evans) from Malabar region of Kerala. *Indian J Entomol* 82 (3): 429-434. DOI: 10.5958/0974-8172.2020.00112.1.
- Cock MJW. 2015. A critical review of the literature on the pest *Erionota* spp. (Lepidoptera, Hesperidae): Taxonomy, distribution, food plants, early stages, natural enemies and biological control. *CAB rev* 10 (7): 1-30. DOI: 10.1079/PAVSNNR201510007.
- Cock MJW, Buddie AG, Cafa G. 2019. Piloting the use of DNA barcoding in support of natural enemy surveys: New parasitoid records for banana skippers (*Erionota* spp., Lepidoptera, Hesperidae) in Malaysia. *J Asia Pac Entomol* 22: 183-188. DOI: 10.1016/j.aspen.2018.12.019.
- Ditlin Horti, Direktorat Perlindungan Hortikultura. 2019. Statistik Iklim, OPT dan DPI. Pusat Data dan Informasi Pertanian. <http://ditlin.hortikultura.pertanian.go.id>.
- Erniwati, Ubaidillah R. 2011. Hymenopteran parasitoids associated with the banana-skipper *Erionota thrax* L. (Insecta: Lepidoptera, Hesperidae) in Java, Indonesia. *Biodiversitas* 12 (2): 76-85. DOI: 10.13057/biodiv/d120204.
- Fischbein D, Villacide JM, De La Vega G, Corley JC. 2018. Sex, life history and morphology drive individual variation in flight performance of an insect parasitoid. *Ecol Entomol* 43: 60-68. DOI: 10.1111/een.12469.
- Gao S, Tang Y, Wei K, Wang X, Yang Z, Zhang Y. 2016. Relationships between body size and parasitic fitness and off spring performance of *Scleroderma pupariae* Yang et Yao (Hymenoptera: Bethyilidae). *Plos One* 11 (7): e0156831. DOI: 10.1371/journal.pone.0156831.
- Goulet H, Huber JT. 1993. Hymenoptera of the World: An Identification Guide to Families. Canada Communication Group, Ottawa, Canada.
- Hasyim A, Hasan N, Syafril, Harlion, Nakamura K. 1994. Parasitoids of the banana skipper *Erionota thrax* (L.) in Sumatera Barat, Indonesia, with notes on their life history, distribution and abundance. *Tropics* 3 (2): 131-142. DOI: 10.3759/tropics.3.131.
- Hasyim A, Hasan N, Syafril, Harlion, Nakamura K. 1999. Detection of egg parasitism and its mortality on the banana skipper, *Erionota thrax* (L.) eggs in the province of West Sumatera (Indonesia). *Jurnal Hortikultura* 8 (4): 1278-1283.
- Hasyim A, Kamisar, Nakamura K. 2003. Mortalitas stadia pradewasa hama penggugul daun pisang *Erionota thrax* (L) yang disebabkan oleh parasitoid. *Jurnal Hortikultura* 13 (2): 114-119. DOI: 10.21082/jhort.v13n2.2003.p114-119. [Indonesian]
- Iranipour S, Ahmadpour S, Asgari S. 2020. Gregarious development alters host utilization by the egg parasitoid *Ooencyrtus fecundus* (Hymenoptera: Encyrtidae). *J Crop Prot* 9 (3): 523-535.
- Irulandi S, Manivannan MI, Kumar AR. 2018. Bio-ecology and management of the banana skipper, *Erionota thrax* L. (Hesperidae: Lepidoptera). *J Entomol Zool Stud* 6 (2): 262-265.
- Kalshoven LGE. 1981. The Pest of Crop in Indonesia. Ichtar Baru van Houve, Jakarta.
- Novianti F. 2018. Hama Penggugul Daun Pisang *Erionota thrax* Linnaeus (Lepidoptera: Hesperidae) dan Musuh Alaminya di Tempat-Tempat dengan Ketinggian Berbeda. [Thesis]. Institut Pertanian Bogor, Bogor. [Indonesian].
- O'hara JE, Shima H, Zhang C. 2009. Annotated catalogue of the Tachinidae (Insecta: Diptera) of China. *Zootaxa* 2190: 1-236. DOI: 10.11646/zootaxa.2190.1.1.
- Okolle NJ, Mansor M, Ahamd A. 2006. Seasonal abundance of banana skipper, *Erionota thrax* (Lepidoptera: Hesperidae) and its parasitoids in a commercial plantation and a subsistence farm in Penang,

- Malaysia. *Intl J Trop Insect Sci* 26 (3): 197-206. DOI: 10.1079/IJT2006116.
- Okolle NJ, Abu AA, Mashhor M. 2010. Bioecology and management of banana skipper (*Erionota thrax*). *Tree For Sci Biotech* 4 (1): 22-31.
- Pratiwi IY, Supriyadi, Sholahuddin. 2020. Hubungan antara penyobekan daun secara mekanik terhadap serangan penggulung daun pisang. *Agrosains: Jurnal Penelitian Agronomi* 22(1): 7-11. DOI: 10.20961/agsjpa.v22i1.29834. [Indonesian].
- Poorani J, Padmanaban B, Deshmukh S, Thanigairaj R, Ragesh G. 2020. A review of the pest status and natural enemy complex of banana skipper *Erionota torus* Evans in South India and its management. *Indian J Entomol* 82 (3): 479-492. DOI: 10.5958/0974-8172.2020.00123.6.
- Rahmawati, Pasaru F, Yunus M. 2018. Observasi jenis parasitoid larva penggulung daun pisang *Erionota thrax* Linnaeus (Lepidoptera: Hesperidae) pada ketinggian tempat yang berbeda di Kabupaten Sigi. *Agrotekbis* 6 (2): 239-246.
- R Core Team. 2019. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. <https://www.R-project.org>.
- Samková A, Raška J, Hadrava J, Skuhrovec J. 2021. A novel two-generation approach for understanding the population dynamics of gregarious parasitoids. *bioRxiv* 1-14. DOI: 10.1101/2021.02.22.432341.
- Sharanabasappa, Kalleshwaraswamy CM, Adivappan N, Lavanya MN. 2016. Population dynamics and natural enemies of *Erionota torus* Evans (Lepidoptera: Hesperidae) on two cultivars of banana in Karnataka. *Pest Manag Horticult Ecosyst* 22 (1): 34-39.
- Sharanabasappa, Kalleshwaraswamy CM, Maruthi MS, Shima H. 2018. Population dynamics and new record of larval parasitoids, *Senometopia* sp. and *Winthemia sumatrensis* (Townsend) (Diptera: Tachinidae) on banana skipper, *Erionota torus* Evans (Lepidoptera: Hesperidae) from South Karnataka. *J Biol Control* 32 (1): 48-51. DOI: 10.18311/jbc/2018/18744.
- Suyanto I, Djatnika, Sutanto A. 2005. Banana R&D in Indonesia: Updates and highlights. Proceedings of the 3rd BAPNET Steering Committee. Guangzhou, China, 23-26 November 2004.
- Wang Z, Liu Y, Shi M, Huang J, Chen X. 2019. Parasitoid wasps as effective biological control agents. *J Integr Agric* 18 (4): 705-715. DOI: 10.1016/S2095-3119(18) 62078-7.
- Wibowo L, Indriyati, Purnomo. 2015. The abundance and diversity of the parasitoid of banana leaf skipper pest (*Erionota thrax* L.) in South Lampung Regency. *Jurnal HPT Tropika* 15 (1): 26-32. DOI: 10.23960/j.hptt.11526-32. [Indonesian].
- Zhang Y, Li W, Huang D. 2005. A taxonomic study of Chinese species of *Ooencyrtus* (Insecta: Hymenoptera: Encyrtidae). *Zool Stud* 44: 347-360.