Spatial distribution pattern, bionomic, and demographic parameters of a new invasive species of armyworm *Spodoptera frugiperda* (Lepidoptera; Noctuidae) in maize of South Sumatra, Indonesia

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Abstract. *Hutasoit RT, Kalqutny SH, Widiarta IN. 2020. Spatial distribution pattern, bionomic, and demographic parameters of a new invasive species of armyworm* Spodoptera frugiperda *(Lepidoptera; Noctuidae) in maize of South Sumatra, Indonesia. Biodiversitas 21: 3576-3582.* The fall armyworm, *Spodoptera frugiperda,* has reportedly been found in Indonesia since 2019. The main hosts of this new invading insect are food crops and several other crops. This study aimed to examine the spatial distribution pattern, bionomic, and demographic parameters for developing a sampling plan and strategy to control the pest. The study was conducted by observing the total population of *S. frugiperda* on nine plots of maize plants weekly. The development of *S. frugiperda* from egg to adult was also observed in plastic containers (diameter of 4 cm x height of 8 cm) fed with maize in controlled room conditions (temperature = 29 ± 2.1°C, 74 ± 10.1% RH). Observations were made on several bionomic and demographic parameters. The results of the study showed that the *S. frugiperda* distributes in groups, and each group spreads with a low grouping rate. The life cycle of *S. frugiperda* occurs for an average of 25.11 days with a range of 24-26 days. The net reproduction rate (Ro) of *S. frugiperda* was 422.46 individuals/parent/generation. *S. frugiperda*'s intrinsic rate of increase was 0.22 individuals/parent/day. The length of generation (T) and *S. frugiperda* doubling time (DT) were 26.59 and 3.04 days, respectively. This species has survived well on the maize in the new habitat, so it will threaten the food crops, especially the maize. A sampling plan can be developed based on spatial distribution parameters to monitor population density to implement a control threshold and control measures from the early stage of maize during adult pre-emergence.

Keywords: Bionomic parameter, demographic parameter, fall armyworm, spatial distribution pattern

INTRODUCTION

Fall armyworm (*Spodoptera frugiperda* J.E. Smith) is a pest originated from the tropical and subtropical region of America (Baloch et al. 2020), where it is a serious pest of corn and also known to attack more than 100 hosts (Sharanabasappa et al. 2018). *S. frugiperda* was first reported in the African continent in early 2016 (Goergen et al. 2016; Cock et al. 2017). In 2018, this pest was reported to have attacked the maize crop in India (Sharanabasappa et al. 2018; Sidana et al. 2018). Nonci et al. (2019) reported that this pest has entered and attacked the maize plantation in Indonesia, precisely in Koto Baru, Luhak Nan Duo West Pasaman, West Sumatra. This pest quickly spread to several locations in Indonesia (Maharani et al. 2019; Lestari et al. 2020). Based on the survey results conducted to farmers, the damage and loss of yield caused by *S. frugiperda* in maize plantations in Africa were reported to be very serious. This pest has caused estimated losses of up to 250-630 million US dollars per year (Bateman et al. 2018). Day et al. (2017) revealed that 22%-67% of damage occurred in Ghana and Zambia, causing the loss up to millions of dollars. Up to 32% and 47% of the damage was reported in Ethiopia and Kenya (Kumela et al. 2018). Baudron et al. (2019) mentioned that the estimated damage in Zimbabwe was 11.57%.

Fall armyworm is classified as a polyphagous pest. Although it has a preference for the Poaceae family, this pest has a broad range of hosts and can attack several other types of plants (Barros et al. 2010; Kergoat et al. 2012). This causes polyphagous pests such as *S. frugiperda* to be able to utilize various other types of hosts to develop in the conditions where the main host is not available, and then it might migrate to the plantation area in which the main host is available again (Montezano et al. 2018). *S. frugiperda* adults can move up to 806.2 m and is likely to move further depending on the condition around the plant stage, oviposition site, food source, the availability of mate, and any other factors (Vilarinho et al. 2011; Nagoshi et al. 2012).

Fall armyworms cause damage to plants by eating the leaves. As a consequence, it may interfere with the plant photosynthesis, damage the plant growth structure and reproduction, or damage the cob directly (Chimweta et al. 2019). There are several types of symptoms of plant damage caused by *S. frugiperda*, that the early instar is usually eating by leaving some semitransparent parts on leave. Instar with later stage tends to enter and eat the leaf whorl in maize, so the typical symptoms of leaves with holes become more apparent along with the development of

plants. That eating preference at the plant's growing point may inhibit plant growth and sometimes lead to lethal damage. In older plants, the late-stage instar may damage the maize cobs so it can reduce the quality and yields obtained (Sisay et al. 2019).

The information about the biology of *S. frugiperda* in Indonesia is still limited. The study about the spatial distribution pattern, bionomic, and demographic parameters of *S. frugiperda* are important to determine the distribution patterns and growth rates of these pest populations. Further information is needed as a basis for developing a sampling plan and the strategy to control this pest in order to reduce the risk of damage and loss of maize yields. Therefore, this study aimed to determine the spatial distribution pattern, bionomic, and demographic parameters of *S. frugiperda* at their new habitat in Indonesia.

MATERIALS AND METHODS

Spatial distribution pattern analysis

The study was conducted in July-August 2019 in a maize field in a wetlands area, located in Tirtaharja Village, Muara Sugihan Sub-district, Banyuasin District, South Sumatra, Indonesia. Observations were made on a total of nine plots, each measuring 1.5 x 2.5 m^2 with a plant spacing of 70x20 cm^2 set up. Visual observations and a population count of the *S. frugiperda* were carried out on 30 plants in each plot weekly for four consecutive weeks by recording the number of individuals of *S. frugiperda* larvae in each plant. Observations were made without harming the plant or *S. frugiperda* larvae. The *S. frugiperda* spatial distribution pattern between the mean density (m) and mean crowding (m*) number of larvae in each plot for four consecutive weeks was analyzed by using Iwao's linear regression analysis (Iwao et al. 1968). The mean crowding is calculated using the formula:

$$m^* = \sum_{i=1}^{n} (x_i-1) \, x_i \, / \sum_{i=1}^{n} (x_i)$$

Where; x_i is the number of individuals in each plot and n is the total number of plots. The relation m*- m is shown by the regression as:

$$m^* = \alpha + \beta \, m$$

Where; an intercept α is an index of basic contagion, and the slope β is a density-contagiousness coefficient.

Propagation of *Spodoptera frugiperda*

Propagation of *S. frugiperda* and test plants were carried out in a greenhouse at *Balai Penyuluhan Pertanian* in Muara Sugihan Sub-district, Banyuasin District, South Sumatra. The late instar larvae of *S. frugiperda,* which were used as the initial insect population, were collected from the maize fields in Tirtaharja Village, Muara Sugihan Sub-district, Banyuasin District. A total of 100 late instar

larvae were kept in plastic cages (diameter of 15 cm x height of 25 cm) and were fed daily with the maize leaves until they reached the pupal stage. The adults obtained from previous propagation were kept in confinement (diameter of 30 cm x height of 60 cm) with the inner surface covered with paper as a medium to lay eggs. The adults were fed with a solution of 10% honey/water (wt/vol) by soaking cotton rolls in the solution then placed in a plastic container in a cage that was replaced every day.

Observation of bionomic and demographic parameters

A total of 100 eggs in a cohort population from previous propagation were kept on maize leaves in plastic cages (diameter of 4 cm x height of 8 cm). The number of larvae that lived died, and molted was observed and recorded daily until the adult stage. The larval development from first to the sixth instar was separated from each stage by molting and was marked by the presence of exuviae (Figure 1). Maize leaves were replaced every day. The newly emerged adults were identified and the data of the sex ratio were collected as well as the data of the stage duration of 1st-6th instar.

The longevity of male and female adults was observed separately in an insect cage (30 cm x 60 cm). Each cage was infested with one adult male. The female adult was observed by maintaining an adult in an insect cage with the paper as the oviposition media. Each cage was infested with a female adult and two male adults. Female and male adults were transferred to new cages every day. The transfers were carried out every day until the last female adults were dead. The number of eggs produced by each female adult was calculated every day. Adults were fed with a solution of 10% of honey/water (wt / vol) by soaking cotton rolls in the solution then placed in a plastic container in a cage that was replaced every day until the male and female adults were dead.

The parameters observed including (i) development of the egg to first instar larvae; (ii) duration of development of 1st-6th instar larvae; (iii) the duration of development from the 6th instar larvae to pupae; (iv) the duration of development from pupae to adults; (v) life span of the adults; (vi) pre-oviposition and oviposition periods; and (vii) the number of eggs laid.

Analysis of demographic parameters

Data of the longevity and fecundities were compiled in the form of statistical demographics (life table). The life table can provide a detailed description of the growth rate (birth, development, reproduction, and death) of each individual in a population (Hutasoit et al. 2017). The data collected were: (i) x is cohort age class (days), (ii) lx is the chance of a life of each individual at age x, (iii) mx is fecundity per individual at age x, (iv) lxmx is the number of offspring born in the age class x. The calculation was made by using the Jackknife method, which is a calculation technique by removing one observation data repeatedly (resampling). The Jackknife method was used as a general approach to test the hypotheses and calculate the confidence intervals. The demographic parameters observed were; (i) Gross reproduction rate (GRR) =Σ mx,

(ii) net reproduction rate (R0) = Σ lxmx, (iii) intrinsic rate of increase (r) = ln (R0) /T, (iv) average generation time (T) = Σ xlxmx /Σ lxmx, and (v) doubling time (DT) = ln (2)/r.

RESULTS AND DISCUSSION

Spatial distribution pattern of *Spodoptera frugiperda*

Regression analysis between the mean density (m) and mean crowding (m*) in Table 1 described the spatial distribution pattern of the *S. frugiperda* sample population in the field. The intercept of regression values was greater than 0, and the regression slope value was around 1.

Bionomic parameters of *Spodoptera frugiperda* in maize

Daily observations results showed that the average life cycle of *S. frugiperda* lasted for 25.11 days, with a range of 24-26 days (Table 2). The life cycle duration of *S. frugiperda* in this study was shorter than reported by Murua and Virla (2004) and Sharanabasappa et al. (2018). The larvae developmental period to the pupal stage for the male tend to longer than female, and the pupal stage duration for the male was significantly longer than female. The beet armyworm, *S. exigua* reared on different host plants including maize also shown larvae development period for male longer than female (Farahani et al. 2011). Interestingly, the tendency for males to emerge after females of the armyworm is not common in insects with discrete, nonoverlapping generations (Bulmer 1983). In the opposite of the larvae period, female adults longevity was significantly longer than male adults. A similar trend on the longevity of female *S. exigua* was reported by Mardani-Talaei et al. (2012). The sex ratio of *S. frugiperda* in maize plants was 1: 1.72 (female: male). A higher number of males compared to females in this study might be affecting the preimaginal stage duration of the male. Similar results were also reported in Guinea grass, where the ratio of females and males is 1: 1.5 (Murua and Virla 2004).

Survivorship and fecundity of *Spodoptera frugiperda* on maize

Daily survivorship and fecundity of *S. frugiperda* are presented in Table 3 and Figure 2. The survivorship of *S. frugiperda* showed that the chances of survival began to decline when entering the sixth instar larvae and pupal stage (Table 3). The highest mortality occurred during adult. The survivorship curve from daily observations suggested that the *S. frugiperda* survival type has a type I pattern. Type I curves describe the death of small numbers of organisms in the early population and higher numbers of deaths in the later stage of the population (Price 1997). High mortality in later stages will result in a higher population in the next generation compared to high mortality in the early stage.

Fecundity curve of *S. frugiperda* showed that the egg-laying began on the 25th day after the infestations (Figure 2). The female adult preoviposition period lasted for 3-4 days, while the oviposition period lasted for 2-8 days. The average fecundity of adult females reached the peak of the curve on the 27th day after the infestation (350.89). The female adult of *S. frugiperda* laid eggs in large quantities in the early phase of adults and the number continued to decrease along with age and it fluctuated again before adult's death.

Demographic parameters of *Spodoptera frugiperda* in maize plants

The demographic parameters of *S. frugiperda* consisted of Gross Reproduction Rate (GRR), Net Reproduction Rate (Ro), Intrinsic Rate of Increase (r), Average Generation Time (T), and Doubling Time (DT) (Table 4). Ro and r values obtained were lower than the ones reported by Murua and Virla (2004) using corn as food source. The lower Ro and r values in this study might be influenced by the fewer number of females compared to males. However, the T value in this study is lower, the lower T value illustrates the faster reproduction rate of an organism.

Table 1. Regression statistics of Iwao's mean crowding and mean density to describe spatial distribution pattern of *Spodoptera frugiperda* population sample

| Data source | n | Intercept | | | Slope | | | r^2 |
		$\alpha \pm$ SE	t Stat	P-value	$\beta \pm$ SE	t Stat	P-value	
S. frugiperda field population of Tirtaharja Village, Muara Sugihan Sub-district, Banyuasin District, South Sumatra in 2019	36	-0.399 $\pm$ 0.139	-2.883	< 0.01	1.216 $\pm$ 0.068	17.849	< 0.001	0.904

Figure 1. Egg and larval stage of *Spodoptera frugiperda*. A. Egg, B. 1st lnstar, C. 2nd instar, D. 3rd instar, E. 6th instar. arrow: inverted Y shape on the head, circle: four black dots (pinacula) in the eighth segment

Table 2. Bionomic parameters of *Spodoptera frugiperda* in maize

Parameters	Mean ± SE (days/eggs)	Range (days/eggs)
Egg incubation	2.62 ± 0.08	2-3
1st to 6th instar period		
Female	12.69 ± 0.16	11-15
Male	12.84 ± 0.15	11-15
Pupal stage		
Female	6.31 ± 0.08	5-7
Male	6.76 ± 0.12	5-9
Life cycle	25.11 ± 0.11	24-26
Pre-oviposition phase	3.33 ± 0.07	3-4
Fecundity	1165.83 ± 43.6	766-1572
Longevity of the adults		
Female	10.06 ± 0.33	7-16
Male	8.60 ± 0.28	6-14

Table 3. The survivability and stage durations of *Spodoptera frugiperda* on maize

Stage	Number of individuals	Stage duration (days)
Egg	100	2-3
1st Instar	100	2-3
2nd Instar	100	2-3
3rd Instar	100	1-3
4th Instar	100	2-3
5th Instar	100	1-2
6th Instar	99	2-4
Pupa	98	5-9
Adults	98	6-16

Table 4. Demographic parameters of *Spodoptera frugiperda*

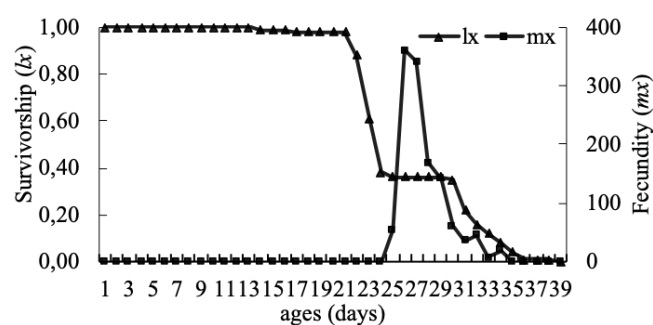| Parameters	Mean ± SE
Gross Reproduction Rate (GRR)	1233.94 ± 0.48 ind./generation
Net Reproduction Rate (Ro)	422.46 ± 0.59 ind./parent/generation
Intrinsic Rate of Increase (r)	0.22 ± 0.00 ind./parent/generation
Generation Time (T)	26.59 ± 0.00 days
Doubling Time (DT)	3.04 ± 0.00 days

Figure 2. Survivorship (lx) and fecundity (mx) of *Spodoptera frugiperda* on maize

Discussion

The mean crowding value represents the average number of other individuals per individual in a unit of space (Wade et al. 2018). The intercept of regression values in this study was greater than 0. This indicated that armyworms spread in groups (consisting of several individuals), and the groups spread with a low grouping rate on the fields because the regression slope value is around 1. The spatial distribution pattern obtained from this study was similar to the study conducted by Rios et al. (2014) in Southern Pernambuco state, Brazil, as well as the study result of Nava et al. (2018). Intercept values (α) that are positive or greater than 0 might be due to the behavioral preferences of *S. frugiperda* that prefer certain spots in their habitat (leaf whorl) plus their characteristics of laying eggs in a group. The regression slope (β) describes the distribution pattern of individuals and groups of individuals in space, which is related to population density (Iwao et al. 1968). Accurate sampling design for monitoring to implement an action threshold and for studying population dynamics can be arranged based on spatial distribution patterns (Butler and Trumble 2012; Widiarta 1995; Iwao 1975; Kuno 1969).

The short incubation period of the eggs, 1st-6th instar larvae and pupae will shorten the overall life cycle period of this pest. A short life cycle indicates that maize is indeed a suitable host for the development of *S. frugiperda*. This is in accordance with Hay-Roe et al. (2016) who reported that *S. frugiperda* caused damage to various types of crops, especially maize, sorghum, rice, and various types of grass. It was further explained that there were two strains of *S. frugiperda*. Both strains are morphologically identical but differed in ecology, genetics, and physiology (Saldamando and Velez-Arango 2010). One strain identified as strain C (maize strain), mainly attacks maize plant, while another strain was identified as strain R (rice strain) attacking rice and grasses.

Optimum temperature and humidity conditions during the rearing may shorten the life cycle of *S. frugiperda*. Kondidie (2011) reported that *S. frugiperda* completes its life cycle about 30 days during the summer. The duration of the life cycle increases to 60 days in spring and autumn, while in winter, it can reach 80-90 days. The average room temperature and relative humidity during the study were 29 ± 2.1°C and 74 ± 10.1%, respectively. The life cycle of *S. frugiperda* in this study, which was observed to be shorter than previous reports from other parts of the world, may indicate a higher level of risk on the spread and attack in the tropics with optimum conditions, particularly Indonesia compared to regions with other climates.

The average number of eggs placed by an *S. frugiperda* female adult was 1,165.83 ± 43.6 (766-1,572) eggs. Murua and Virla (2004) reported that the average fecundity of adult females by feeding a mixture of honey/water (1: 1 vol/vol) was 1,044 ± 411 in the temperature range of 25 ± 2 °C, and the humidity of 70-75%. Sharanabasappa et al. (2018) further reported that the average fecundity of adult females by feeding honey 10% is 1,064.80 ± 109.53 (835.00-1169.00) eggs. The difference in the number of eggs produced by *S. frugiperda* female adults might be influenced by temperature (Combs and Vilario 1980). Berger et al. (2008) explained that in conditions of high temperatures the female adults will divert its energy to produce more eggs, while at low temperatures the female adults will accumulate its energy to form the body's structure.

The survivorship curve in this study showed that the chance of survival began to decrease at 14 days after infestation (Fig. 2). It showed that maize is the ideal host for the survivability of *S. frugiperda*. In addition, we also suspect that this condition was also affected by the optimum temperature and humidity for the development of this pest. A similar survivorship curve was also reported by Murua and Virla (2004) in maize and guinea grass, where the death was starting to occur at 14th days and 19th days in guinea grass. Newly invaded species such as *S. frugiperda* is lack of natural enemies in the new habitat. Therefore it may contribute to high survivorship during larvae period (Sisay et al. 2018). Thus, the comprehensive control efforts should be at the beginning from the early stage of maize are important such as intensive population monitoring to implement a control threshold for the justified use of pesticides. Finding pre-adult emergence control measures such as using the botanical pesticide, chemical pesticide, and physical control method are necessary.

The Ro value of *S. frugiperda* in this study was smaller than the result reported by Murua and Virla (2004). The number of female individuals (sex ratio) may affect the value of fecundity, meaning that as the number of female adult increase, the number population will be also likely to increase. The *S. frugiperda* sex ratio in this study was 1: 1.72 (female: male). The survivorship of female adults might also influence the value of Ro. The average longevity of female adults lasted only for 10.06 days, which means the oviposition period was shorter, and the number of eggs produced was less. Net Reproduction Rate (Ro) values indicate the level of compatibility between insects and host plants. The higher the Ro and GRR values, the higher the level of insect compatibility to the host plant. The individual intrinsic rate of increase in the population in a constant environment and the condition of an unlimited resource is illustrated by the r-value. The r-value of 0.22 indicates that in an unlimited condition, individuals in the population can increase by 0.22 times, or they increase by 22% individuals per day. The intrinsic rate of increase of *S. frugiperda* in maize is higher than several other species of armyworm that have previously existed in Indonesia, such as *S. exigua* and *S. litura*. Farahani et al. (2011) reported that the intrinsic rate of increase of *S. exigua* in maize is 0.207. Mardani-Talaei et al. (2016) further reported that the intrinsic rate of increase of *S. exigua* in four varieties of hybrid maize, namely Keynes410, Keynes540, KSC260, KSC400 is 0.131, 0.137, 0.136, and 0.102, respectively. The intrinsic rate of increase of *S. litura* in peanuts under different rearing conditions (25 ºC, spring and autumn) in Taiwan were reported at 0.18, 0.13, and 0.15, respectively (Tuan et al. 2014). Fand et al. (2015) reported the intrinsic rate of increase of *S. litura* was 0.11 in soybeans with a temperature range of 25 ± 1 ºC. Various aspects, which are related to the organism's life cycle, including death, birth,

and development time, determines the intrinsic rate of increase.

The average value of the generation time (T) and doubling time (DT) were 26.59 and 3.04, respectively. This value was smaller than the results by Murua and Virla (2004). Smaller T value indicates a faster time for an individual in the population to multiply. This also correlates with DT value, that high DT value causes an increase in gross reproduction rate (GRR) and net reproduction rate (Ro) value in a certain time unit.

In conclusion, the fall armyworm *S. frugiperda* tends to distributes in groups consisting of several individuals. The group spreads with a low grouping rate in the field. *S. frugiperda* can develop well in corn in the conditions of temperature and relative humidity 29 ± 2.1°C and 74 ± 10.1%, respectively. This can be seen from the short life cycle and the number of eggs laid by the female. This new pest has the potential to spread rapidly and can cause higher attacks and damage in tropical regions like Indonesia compared to where it originated. Finding effective pre-adult emergence control measures are necessary due to their high survivorship during larvae period under room condition.

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