Telenomus remus (Nixon) (Hymenoptera: Scelionidae) Biology and Life Table on Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae) eggs

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Abstract. Telenomus remus (Nixon) (Hymenoptera: Scelionidae), is an endoparasitoid on eggs of Spodoptera frugiperda (J. E. Smith). T. remus information as a natural enemy of S. frugiperda is limited. The research objective was to determine some biological aspects of T. remus, i.e., longevity, fecundity, and life table variables. The demographic statistics used the jackknife method. The parasitoids were obtained from the eggs of S. frugiperda from a maize plantation in the field. The released parasitoids were identified in the laboratory. Parasitoid identified as T. remus used to biological observations, life tables, sex ratios, and parasitization rate. The immature stage of T. remus reached 8.13 days, the longevity of the male was 10.07 days, while a female was 10.29 days with a fecundity of 75 eggs, and a sex ratio of male and female was 1:2.03. The life table parameters of T. remus, i.e., gross reproduction rate (GRR) was 74.987 individuals/generation, net reproduction rate (R0) was 67.485 females/female/generation, with generation period (T) was 8.541 days, and intrinsic growth rate (r) was 0.493 females/female/day. The Parasitization rate of T. remus reaches 91%. This research showed that T. remus has the potential natural enemy to control S. frugiperda.

1. Introduction
Spodoptera frugiperda, fall armyworm from North, Central, South America, has become an invasive pest on cereals crops in Africa, and three other countries, notably India, Myanmar, and Thailand, that causes significant damage [1]. The species was first identified in Indonesia in January 2019 in West Pasaman, West Sumatra, and Lampung and soon expanded to West Java and other regions [2]. The models of Geographical distribution indicated that vast areas in Indonesia might be suitable for the existence of the deadly pest [3]. This insect, which is polyphagous, can jeopardize the commerce and exports of plants from afflicted areas. The assault of S. frugiperda can result in the losses of significant maize production, ranging from 87.5 percent to 87.5-100 percent [4].

Synthetic pesticides are widely used by farmers in the control of S. frugiperda [5]. Farmers tend to use synthetic pesticides more because they are quicker, more effective, and efficient. Insecticides are used in high dosages and intensity. On the other hand, they can most affect the environment, human health, natural enemies, and other insects [6]. The establishment of S. frugiperda pest resistance in maize is one of the detrimental consequences of pesticide usage excessively [7]. As natural enemies in the field, parasitoids can provide alternative management that is more ecologically and developed...
widely. *Telenomus remus* is a parasitoid that has been used to manage *S. frugiperda*. The level of *T. remus* parasitization against *S. frugiperda* in the highlands ranged from 50%-90% [8]. *T. remus* is a moderate parasitoid in America but used successfully as the agent of augmentative biological control in several countries [9].

*T. remus* can be reproduced eggs of *S. frugiperda* and other hosts before releasing into the field. A female of parasitoid lays 270 eggs on average per day. Individual eggs are stored on each host egg [10]. *T. remus* can parasitize all eggs in a group of eggs, but other egg parasitoids as *Trichogramma* sp. only parasite on the outer layers [11]. The difficulties of mass-producing natural hosts and the necessity to create maintenance systems on alternate hosts are the primary obstacles to the widespread use of the *Telenomus* species. On the other hand, it is being explored to be introduced to Africa as a reaction to *S. frugiperda* [12]. *T. remus, T. rowani, T. dignus*, and *T. dignoides* have the potential as a biological agent in Indonesia, with percentages of 67%, 22%, 7%, and 4%, respectively, in reducing the population of various pests [13]. *T. remus* has been able to reduce the population of FAW in many locations on the island of Java due to a high level of parasitization compared with other species.

*S. frugiperda* population will continue to increase because there are no natural enemies to keep the population is under control and below the economic threshold [14]. Several studies have indicated that the releasing of parasitoids in large numbers in the field can cause parasitoids to spread and find hosts, ensuring that *T. remus* will always remain the agent of local biological control [15]. *T. remus* in the plant of maize host of spring has been proved in related research to positively affect the plant of host maize of spring of *T. remus*. It is used in the laboratory to study the maintenance of large-scale mass. Although it is possible to reduce the number of *S. frugiperda* [16], research on this approach is still limited. Therefore, this research objective is to determine some biological aspects of *T. remus*, i.e., longevity, fecundity, and life table variables. The results from this research are expected can use as basic information on the utilization of *T. remus* to control the population of *S. frugiperda*.

2. Methodology

2.1 Preparation

*S. frugiperda* larvae were collected from a plantation of maize in Bojong Hilir Village, Bogor, West Java, and used as hosts. The insect's hosts were removed using a brush and kept in plastic vessels. After the pupae entered the adult phase, *S. frugiperda* of male-female imagoes were moved to large plastic jars (60 x 30 x 25 cm) that are hollow and glued with gauze in their midsts as a cover. Tissue was used lining the inside of the jar walls, which functions as a location to lay female imago. The hatching eggs were placed in plastic jars (10 x 10 x 5 cm) and fed by semi-corn feed for 2-3 days before refilling.

The identification of parasitoids began with immersion in 70%, 80%, 95%, and 100% of alcohol for 10 minutes. It was soaking the parasitoid in clove oil for 10 minutes. The formulation was dried and labeled. The identification using the digital microscope of Leica M205C with the digital camera of Leica DFC450 and the application of LAS.V.4.4.0 (version: 454) were connected to the computer to identify the species. Parasitoids were identification through written books by [17,18] and scientific articles that contained the key of *Telenomus* sp species and supporting materials for parasitoids identification. The temperature and humidity of the laboratory are 22-27°C and 66-70%, respectively. The study was conducted at the Insect Biocontrol and Biosystematics Laboratory, Faculty of Agriculture, IPB University. The research has done from July 2020 and March 2021.

2.2 Observation in the immature phase

The immature phase observation dissected the eggs that had been exposed. The dissection of egg parasitoids was performed at 0-10 days after exposure (HSP). The measurements of the body with the application of Optilab Image Raster 3.0. Specimens were put into test tubes containing 95% of alcohol for three minutes. The boiled samples were placed in the ciracus cup. The samples boil into a test tube containing 10% KOH and slight 95% alcohol. The addition of acid fuchsin was done to color the
mandible to be more apparent. The specimens were soaked into clove oil for 5 minutes to remove the containing remaining alcohol. The last stage was tidying up the samples in an excellent position to observe the mandible and cover it with a cover glass. The preparat glass was dry in an insect drying oven for one week.

2.3 Observations in the imago phase

The imago parasitoid's observation, i.e., morphological characteristics, fecundity, and sex ratio, succeeded in becoming adults. Observations of fecundity were conducted using two different types, the observation of fecundity based on the dissection of the host egg and fecundity based on the number of offspring that became imago. The observation of sex ratio was based on the success of offspring becoming adults. According to [19], to calculate the proportion of the population:

\[
\text{Sex ratio} = \frac{\text{Number of female imago}}{\text{Number of male imago}}
\]

2.4 Parasitoid Life Table Observation

Observation of life table of parasitoids was carried out by sticking 100 eggs of *S. frugiperda* on parchment paper, then put into a test tube and exposed for 6 hours, and repeated ten times. The Observation of the total of living parasitoid of individuals from hatching to the next phase until the parasitoid died to calculate the average overall survival rate \( l_x \), age-specific \( s_i \), where fecundity \( m_x \) was calculated by observing the number of eggs produced per female in daily specific. And then, we replaced the host with the same number of individuals until the imago parasitoid died. After one pair of imagos die, count the number of eggs producing new parasitoid individuals to determine the average parasitoid reproduction rate \( R_0 \). Calculate by dividing the net reproduction rate and the average generation time to calculate the intrinsic growth rate \( r \). Count the length of life of the imago parasitoid to produce new individuals who are used to calculating the generation time \( T \).

2.5 Parasitization of Parasitoids in the Laboratory

The female parasitoid *T. remus* was taken from the imago that just came out of the pupa, then paired with the male imago and then reared and exposed to the egg host of *S. frugiperda* in a parasitoid rearing tube ten times. Every egg group contained 100 eggs placed on parchment paper. Every group of eggs was exposed for 6 hours to a pair of parasitoid imago. *T. remus* was a solitary parasitoid, so the level of the egg’s parasitization was calculated by determining the number of parasitoids that came out divided into several eggs with the following formula [14]:

\[
\text{Parasitization Percentage} = \frac{\text{Number of Parasited Eggs}}{\text{Eggs exposed}} \times 100\%
\]

2.6 Data analysis

Parasitoid morphology was presented in the form of descriptive data. The demographic data of the jackknife method is calculated using the following formula [20,21,22]:

- The Gross Reproductive Rate (GRR):
  \[ \text{GRR} = \sum m_x \]
- The Net Reproductive Rate \( R_0 \):
  \[ R_0 = \sum l_x m_x \]
- The Generation time \( T \):
  \[ T = \frac{\sum x \cdot l_x m_x}{\sum l_x m_x} \]

The Intrinsic growth rate \( r \):
\[ r = \frac{R_0}{T} \]
The Population doubled (DT):

\[ \text{DT} = \frac{\ln 2}{r} \]

\( x \) = Observation time or number of days

\( l_x \) = General survival rate or proportion of individuals surviving to age x

\( m_x \) = Fertility rate or the specific personality of each individual in each age group.

Adjust the correction of \( r \) value according to the Euler equation [4]: intrinsic growth rate (\( r \)),

\[ \sum l_x m_x e^{-m_x} = 1. \]

Calculation of biological data of parasitoids and creation of the survival curve of Telenomus sp. using Microsoft Excel 2016 software.

3. Results and discussion

Parasitoid species utilized in this research are more related to T. remus than T. dignoides or T. rowani, according to morphologic characteristics given by [9,1,23]. Therefore, parasitoid can be identified that the parasitoid species is T. remus. The parasitoid antennae of T. remus exhibit sexual dimorphism. Male antennae have 12 segments, whereas female antennae have 11 parts, including four mace segments [24].

3.1 Imago of Telenomus remus

T. remus is a parasitoid of egg parasitic of S. frugiperda that is from America [25]. T. remus morphological imago, the body has a measurement of 0.44–0.60 mm that colors black from the tip of the head to the tip of the metasoma (Figure 1a). The antennae's scapus and flagellomere are dark brown, with extremely small funiculus 1-4, considerably smaller than the pedicel and funiculus 6-8, which are almost the same size in females, but the male antennae tip is broad (Figure 1b). The hind wing tuft is longer than the wingspan (Figure 1c). Male genitalia is short and wide, with a concave median plate near the digits (Figure 1d).

![Figure 1. Morphological features of Telenomus remus: a) body measuring 0.44–0.60 mm (lateral view), b) scapus and flagelomer of female antennae, c) long hind wing tuft, d) male genitalia short and broad.](image)

The body is less more than cylindrical on the lateral side, about as vast as its height and only slightly more comprehensive, with a higher scutellum than the oblique metanotum and propodeum. The tufts of the male hindwings exceed the size of the wingspan. The limbs and antennae of males are lighter in color than those of females. The funicular in the last section of the male antenna is slightly enlarged. The antennae are generally 9-10 flagellomeres, and the third segment of the male is modified. We were then following the description of [25], who points out that the tips of male antennae are more comprehensive than the other segments. The male genitalia is short and slightly wider, whereas the female thorax protrudes from the abdomen and the bent body.

3.2 Pre-adult of Telenomus remus

The stages of T. remus development comprises eggs, larvae from the first to the fifth stage, prepupae, pupae, and adults. Telenomus sp. is an encyrtiform egg (placed inside the host body) [26]. T. remus eggs are white, but the tip of the egg stalk sticks out and functions as a respiratory aid,
measuring 117.97 mm (Figure 2a). The first instar larvae of *T. remus* have a different morphology from the next instar, so the type of development includes hypermetamorphosis (Figure 2b). The second instar larvae body structure of the first instar is divided into three parts, head, metasoma, and mesosoma (Figure 2c). The pupa phase is characterized by unsclerotized body appendages (Figure 2d).

**Figure 2.** *Telenomus remus* immature: a) encyrtiform eggs, b) first instar larvae, c) second instars larvae, d) pupae.

The first instar has a round and hollow mesosoma, with the last segment of the mesosoma curved like a hook and fine hairs surround the top of the mesosoma. Changes in the larval phase are characterized by moulting. It can be seen from the presence of exuvia in the first instar on the posterior part of the abdomen in the second instar and include the type of teleaform larvae. Type second instar larvae are hymenopteriform type (cylindrical body with body extension not visible). The second instar is larger than the second instar with a more pronounced body shape. The second instar of *T. remus* has pale yellow, and the growth form begins to harden. The pupa of *T. remus* is dark brown with visible at this stage, forming ocelli, and the dorsal thorax will show unsclerotized wing buds. The pupa is an exarate type [27]. The pupa stage is characterized by the change of skin, wrinkled body shape on the outer surface of the body, and the appearance of the body parts between the head, mesosoma, and metasoma visible, and there will be body appendages such as antennae and limbs.

### 3.3 Time of Development of Telenomus remus

Based on *T. remus* that was invented in the type of holometabola development. Complete metamorphosis consists of development stages of eggs, first instar larvae, second instar larvae, pupae, and adults. *T. remus* eggs have a length of approximately 1.51 days with 96 individuals (Table 1).

**Table 1.** Stages of development of the egg parasitoid *Telenomus remus* in *Spodoptera frugiperda* eggs

| Stage of Development | Mean Stadia Length (days) | N  |
|----------------------|---------------------------|----|
| Egg                  | 1.51                      | 96 |
| First Instar Larvae  | 2.06                      | 94 |
| Second Instar Larvae | 1.89                      | 93 |
| Pupae                | 2.68                      | 91 |
| Male                 | 1.95                      | 30 |
| Female               | 2.16                      | 61 |

According to the table above, the developmental period of each stage from hatching eggs to first instars larvae was 94, with an average longevity of 2.06 days. The number of larvae that grow into second instars was 93, with a longevity of 1.89 days. The pupa stage consists of were 91 individuals with a longevity of 2.68 days. The immature phase of *T. remus* lasted 8.13 days. Only 30 adults grew up into male imago. With average longevity of 1.95 days. Whereas 61 grow up into female imago, with an average of the longevity of 2.16 days. Stadia has an average of 10.07 days from egg to male imago and 10.29 days from egg to female imago. Overall, the life table of *T. remus* is 10.18 days.
3.4 Sex Ratio and Parasitization Rate of Telenomus remus

According to observation, the average population of males is 30, and females are 61. The proportion of the population is based on the number of laying eggs every day. *T. remus* imago is generally comparable to other egg parasitoids since *T. remus* determines the initial percentage of laying offspring (Table 2).

| Sex ratio | Average Population | Success Parasitization (%) |
|-----------|--------------------|-----------------------------|
| Male      | 30                 | 91%                         |
| Female    | 61                 | 91%                         |

According to the table above, the ratio of male-female of *T. remus* in the laboratory is 1:2.03. It indicates that for every one male, there are 2.03 females. The sample of eggs found in the field has a relatively large average, with a *T. remus* that reaches 91%. The availability of host insects. The quality of honey as a substitute for nectar for the demands of parasitoid imago feeding. The capacity to identify hosts are all factors that can impact the amount of parasitization of *T. remus* in the laboratory. According to [28], female parasitoid imagos seek hosts in environments with the highest likelihood of containing hosts. And the distribution of parasitoids is influenced by the plant of fruit juice source and its host.

3.5. Life Table of Cohort of Telenomus remus

Based on the data, the curve of survival *T. remus* indicates the low death rate at first, with mortality commencing on the tenth day appointed by a declining red line (Figure 3). The red line (lx) shows the line is continuing to fall. The steepest drop occurs on the twelfth day. It is followed by the most significant reduction in overall fatalities on the next day. The survival curve is classified into three kinds. According to [29], when the organism is young, the angle of type 1 displays a low death rate. As the organism ages, the rate of mortality increases. The curve of type 2 depicts a species with relatively constant survival, but rising age is directly related to the mortality rate. The type 3 is the inverse of the curve of type 1. In the type 3, young organisms have the high death rate. On the contrary, older organisms have a reduced mortality rate of *T. remus* species with low survival (increased mortality) and a steady population in the next phase.

![Figure 3. The survivorship curve of Telenomus remus](image_url)

According to the figure above, *T. remus* has the first type of survival curve. The population of observations has a significant drop in the number of deaths and tends to stay stable until it completes its life cycle. According to the findings of [30], the success of insect life is determined by the quality of the meal. Individuals are maintained in a vessel to prevent assaults by natural enemies, in addition
to paying attention to feed. Figure 3 indicates that the laying of *T. remus* eggs produced the highest fecundity on the 10th day and with the highest number of eggs produced was 742 eggs, and the lowest number of eggs on day 11 was 436 eggs. The fecundity (mₐ) of *T. remus* showed that the average number of eggs was 75 eggs. As a result of the personality value, each is calculated with the rate of individuals net reproduction (R₀) observed (Table 3).

### Table 3. Life table of the *T. remus* cohort

| Population Parameters | Mean   | Unit                |
|-----------------------|--------|---------------------|
| GRR                   | 74.987 | Individuals/generation |
| R₀                    | 67.485 | Females/females/generation |
| r                     | 0.493  | Females/female/day  |
| T                     | 8.541  | Days                |
| DT                    | 1.406  | Days                |

In the table above from the data, we can see that the variables of life balance of *T. remus* include 74.987 the total of individuals/generation of reproductive rate (GRR), that is, the life between the parasitoid the host. It shows the rate of net reproductive (R₀) suitability is 67.485 females/females/generation, which means that the population will increase 67.485 times over the total population of the previous generation. The rate of implicit growth (r) is 0.493 females/female/day. And the development of the population occurs during the period of evaluation for each age. The average generation period (T) is 8.541 days, which means that the time required to complete the stadia in one generation will double. The shorter the T value, the faster the time of reproduction. DT represents the ratio of population multiplied by 1.406 days. Demographic processes occur through death, birth, immigration, immigration which affect the size and composition of populations.

### 4. Conclusion

*T. remus* longevity of male imago was 1.95 days, whereas females were 2.16 days with a fecundity of 75 eggs. *T. remus* has a gross reproduction rate (GRR) of *T. remus* was 74.987 individuals/generation, net reproduction rate (R₀) was 67.485 females/females/generation, generations period (T) is 8.541 days, and intrinsic growth rate (r) is 0.493 females/female/day. In the laboratory, *T. remus* was found to be 91% in these places. So *T. remus* could be developed as a biological agent to control *S. frugiperda*.

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