

# Ecological design for the propagation of *Sycanus dichotomus* in insectariums for sustainable oil palm pest management

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**Abstract.** *Primananda S, Soedijo S, Gazali A, Aidawati N, Fitriana CDA, Sukarman, Prasetyo AE, Rozziانشa TAP. 2025. Ecological design for the propagation of *Sycanus dichotomus* in insectariums for sustainable oil palm pest management. Biodiversitas 26: 617-627.* The oil palm industry plays a substantial role in national and global economies, and sustainable agricultural practices are critical to its longevity including aspects related to pest management. This study aimed to identify effective methods for propagating the predatory insect *Sycanus dichotomus* as part of integrated pest management in oil palm plantations. The primary focus is on ecological design within the insectarium, selecting appropriate refugia plants, and determining the sex ratio to support an efficient predator population. The study was conducted at an oil palm plantation in Central Kalimantan, Indonesia, which serves as a natural ecosystem for *S. dichotomus*. A multifactorial experimental design was employed, combining variables such as insectarium type manifested as paranet density, adults sex ratio, and refugia plant type. The most optimal results for enhancing the productivity of the predator *S. dichotomus* were achieved using an insectarium with 100% sunlight intensity, a sex ratio of males to females of 2:4, and *Cassia cobanensis* as the host plant. The maturation rate from eggs to nymphs increased in an insectarium with 25% sunlight intensity and *Antigonon leptopus* as the host plant, resulting in high fertility and the presence of 1<sup>st</sup>, 3<sup>rd</sup>, and 5<sup>th</sup> instar nymphs. The interaction between egg groups and the total eggs was highly correlated (80%), and the development of instar 1 and instar 3 showed a fair correlation at 60%, indicating key relationships that support the predator's growth and reproduction under these conditions. Additionally, the study demonstrated that balancing sunlight exposure and selecting appropriate host plants significantly affect the development and reproductive success of *S. dichotomus*. This research highlights the importance of microclimatic conditions in the insectarium, refugia plants, and sex ratio as crucial factors for rearing *S. dichotomus*. It provides important insights for the propagation of predator techniques to support the sustainable oil palm industry. These findings underscore the importance of an integrated approach to pest management, ensuring long-term sustainability and economic viability in oil palm cultivation.

**Keywords:** Biological control, ecological construction, insectarium, oil palm, refugia plants, *Sycanus dichotomus*

## INTRODUCTION

The oil palm plantation industry has a significant contribution to Indonesian economy and is a major source of foreign exchange. Purba and Sipayung (2023) reported that the export value of palm oil and its derivative products reached USD 40 billion, equivalent to IDR 600 trillion in 2022. This industry also supplies global demands on vegetable oils in various sectors, from food to cosmetics. Nevertheless, oil palm industry sparks global debates regarding its impacts on the economic, social, cultural, and environmental aspects, necessitating sustainable management. In term of environment, one concern in oil palm management is the extensive use of chemical pesticides which might cause pollution to soil, air and water, as well as harm to biodiversity. One of the primary strategies to reduce the negative impacts of chemical pesticides in oil palm plantation is through the adoption integrated pest management methods. This approach allows for efficient pest control in a more environment-friendly manner, aligning with the sustainability

principles set by several standards, such as the Indonesian Sustainable Palm Oil (ISPO) and Roundtable on Sustainable Palm Oil (RSPO), ensuring responsible, efficient, and environmentally minimal impact oil palm plantation practices (RSPO 2018; ISPO 2019).

Oil palm leaf-eating caterpillars, including nettle caterpillars and bagworms, are major pests in oil palm plantation, causing up to 70% of production losses in the first year after infestation if not managed properly (Sahari et al. 2019). Common types of bagworms include *Mahasena corbetti* Tams, 1928, *Cremastopsyche pendula* de Joannis, 1929, and *Metisa plana* Walker, 1883, while the nettle caterpillars generally include *Darna trima*, *Setora nitens* Walker, 1855, and *Sethotosea asigna* van Eecke, 1929. Controlling leaf-eating caterpillar pests through an integrated pest management approach is crucial to support the sustainability of plantations, which can be done by using predatory insects such as *Sycanus dichotomus* Stål, 1866 (Hemiptera: Reduviidae) (Syari et al. 2011; Farehan et al. 2013). *Sycanus dichotomus* is commonly known as assassin

bugs, it is native to Asia and can be found in various environments, including oil palm plantations (Zulkefli et al. 2004). Both male and female *S. dichotomus* adults can prey up to four bagworms per day (Ahmad et al. 2020). This predator has also been reported to effectively control the nettle caterpillar *S. asigna* (Afandi et al. 2019). The use of biological control agents, such as *S. dichotomus*, has been shown to effectively reduce pest populations in oil palm plantation, thereby minimising reliance on chemical pesticides (Syari et al. 2011; Farehan et al. 2013). This not only helps maintain ecological balance but also reduce cost which supports the sustainability goals of the industry.

Microhabitat conditions and plant diversity can enhance the efficacy of biological control agents (Landis et al. 2005; Hussain et al. 2022). In this regard, the population of *S. dichotomus* in oil palm plantations can be optimised through ecological construction and augmentation practices. Rearing activities can support rapid population increases of *S. dichotomus* to enhance augmentation process for faster field propagation. Several studies on rearing *S. dichotomus* have explored factors influencing its success, including the importance of selecting appropriate refugia plants to attract *S. dichotomus*, such as *Turnera subulata* J.E.Sm., *Antigonon leptopus* Hook. & Arn., *Cassia cobanensis* (Britton) Lundell, *Euphorbia heterophylla* L., and *Ageratum conyzoides* L. (Jamian et al. 2020). Feeding preferences for rearing activities have been reported to influence the predation efficiency of *Sycanus annulicornis* Dohrn, 1859 and *S. dichotomus* (Syari et al. 2011; Ahmad and Kamarudin 2016; Sahid et al. 2018; Yuliadhi et al. 2021). Maherni (2022) added that combining natural and artificial feeds, including *Tenebrio molitor* Linnaeus, 1758, *Oecophylla smaragdina* Fabricius, 1775, and honey, optimally develops *S. dichotomus*. Alternative feeds, such as larvae of *Alphitobius diaperinus* Panzer, 1797, *Pieris rapae* Linnaeus, 1758, *Spodoptera litura* Fabricius, 1775, *Plutella xylostella* Linnaeus, 1767, and *Corcyra cephalonica* Stainton, 1866, can also support the development of *S. dichotomus* (Sahid 2019; Truong et al.

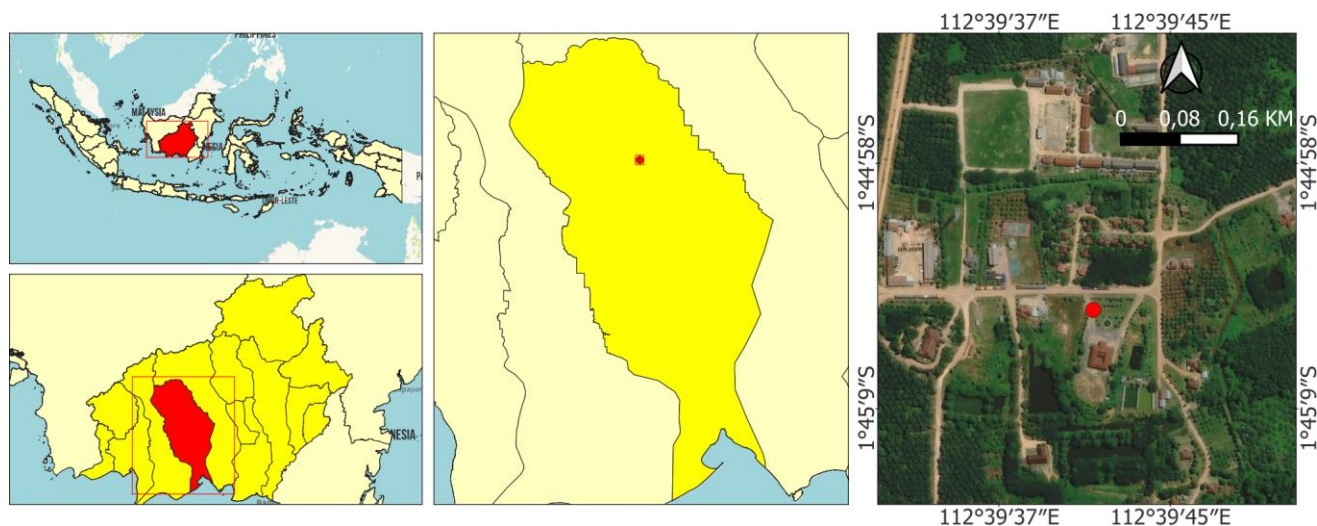
2020). Combining prey and plants also affects the productivity and longevity of *S. dichotomus* as a biological control agent (Jamian and Adam 2018).

As mentioned above, previous research has discussed the factors influencing the success of rearing *S. dichotomus*, including plant volatile compounds, predation capacity, and feed preferences; however, specific studies are required to optimise the role of *S. dichotomus* as a predatory insect in oil palm plantations. Studies related to the specific characterisation of *S. dichotomus* and optimum breeding practices in insectariums before their release into oil palm plantations remain limited. Evaluations related to insectarium type, host plants, and adult sex ratio are crucial, as they directly relate to the productivity of adults ready for augmentation in oil palm plantations. This study aimed to develop the most effective breeding methods for *S. dichotomus* in oil palm plantation setting (in situ) based on insectarium design, selection of host plants, and sex ratio to enhance its productivity and longevity. This study provides practical guidelines for plantation practitioners and researchers to develop *S. dichotomus* as a biocontrol agent to support sustainable oil palm cultivation.

## MATERIALS AND METHODS

### Study area

This study was conducted at an oil palm plantation in East Kotawaringin District, Central Kalimantan Province, Indonesia (Figure 1), which serves as the natural habitat of *S. dichotomus*. This location was chosen to optimise the habitat for rearing activities, enabling the predator to breed effectively as a biological control agent. This strategic location facilitates the reintroduction of insects into their natural habitat and ensures that the research findings are relevant and applicable. An integrated insectarium was constructed in this area to mimic the natural conditions of insects as accurately as possible, supporting their function as predators after being released into the oil palm plantation.



**Figure 1.** Map of research location of oil palm plantation in East Kotawaringin District, Central Kalimantan Province, Indonesia

## Procedures

### *Exploration and identification of Sycanus dichotomus in oil palm plantations*

*Sycanus dichotomus* were captured using a sweep net, being chosen for its ability to capture both flying and hiding insects, and thus providing reliable data on biodiversity. The sweep net method is suitable for capturing predator insects such as *S. dichotomus* in the field due to its efficiency and ability to reach active insects in dense vegetation, minimising habitat disturbance (Southwood and Henderson 2009). It is a cost-effective, non-invasive method that works well in various habitats. The insects were captured around refugia plants and weeds under the palm oil canopy. Trapping, conducted actively, utilised a 35-cm diameter "American-type" sweep net with the standard mesh (1.0-1.5 mm), swung above the plant leaves at a uniform speed (< 8 km/h) along a transect measuring approximately 2.5 meters in width, targeting the top 25% of the vegetation. In the final step, the net was rotated 180°. Capturing activities happened in the morning, between 07:00–10:00 am. The captured insects were then placed in falcon tubes containing 70% ethanol until fully submerged. Morphological identification of the insects was performed based on morphological parameters observed using an Olympus SZ61 stereo microscope with an Opti Lab Advance Plus camera (Canon EOS 700D, Canon EF-S 55-250 mm f/4-5.6 IS STM Zoom Lens). The identification of insects referred to several sources, including books by Davis (1957, 1966), True Bugs of the World [Hemiptera: Heteroptera]: Classification and Natural History (1996), and the work of Amyot and Serville (1843).

### *Experimental design of Sycanus dichotomus propagation in the insectarium*

The experimental design of breeding site for *S. dichotomus* in this study was established by combining three independent variables: insectarium type (4 treatments), sex ratio (3 treatments), and type of refugia plants (4 treatments), resulting in 48 different treatment combinations (Table 1). Each combination of treatments was replicated three times. The insectarium type was used as an independent variable to evaluate the environmental suitability of the insectarium to support the propagation of *S. dichotomus*. This variable focused on using different paranet densities in the construction of an insectarium to create varying microclimatic conditions. The used paranet had a thickness of 1 mm, while the insectarium roof was made of 200 UM-thick polyethylene material with 14% UV protection. The treatment of paranet densities (J) were 0%

(100% light intensity), 25% (75% light intensity), 50% (50% light intensity), and 75% (25% light intensity).

The second independent variable was the sex ratio (K) of the insects infesting the rearing box. The adults consisted of the ratio between males and females, specifically 2:2, 4:2, and 2:4. The adults selected for this study were chosen based on uniform criteria, having undergone moulting between 6-10 days, and originating from the oil palm plantations at the research location. The refugia plant variable consisted of four species, namely, *A. leptopus*, *C. cobanensis*, *T. subulata*, and *Nephrolepis biserrata* (Sw.) Desv.. These plants provide nectar, shelter, and prey, such as small insects, for *S. dichotomus*, making them essential to the predator's life cycle. Their role in supporting natural predators highlights their importance in promoting sustainable biological control in oil palm plantations. Refugia plants were grown in plastic pots with a diameter of 20 cm and a height of 7 cm. The refugia plants had matured for more than three months and had fully bloomed flowers. The copulation process was conducted by infesting male and female adults from an F<sup>1</sup>X crossbreed, which previously underwent a two-day quarantine in separate conditions for males and females to observe their behavior. The rearing box was designed with an iron frame measuring 120 cm in height and 20 cm in diameter and was coated with 1 mm thick plastic mica on the exterior. This design ensured good air circulation with the addition of small 10 × 10 cm boxes around it, facilitating the infestation process of *S. dichotomus* parents and egg collection. Environmental variables were controlled by maintaining a consistent temperature and relative humidity, providing the same type and amount of food across all rearing treatments, cleaning the rearing boxes and equipment daily to ensure the health of *S. dichotomus*, and randomising the placement of treatment groups within the insectarium to prevent bias due to environmental gradients.

## Data analysis

Data were collected through direct observations of *S. dichotomus* adults in the insectarium, reviewing the combined effects of several treatments, namely microclimate condition treated as paranet density, ration of male and female adults, and types of host plants, on insect productivity. Observed parameters included morphological characteristics, overall adult mortality rates, male and female adult mortality, oviposition period, number of egg clusters, fecundity, total number of eggs, and egg fertility, using the following formulas:

**Table 1.** Experimental design of treatment for rearing of *Sycanus dichotomus*

Paranet percentage		Sex ratio of imago		Refugia plants	
J1	Insectarium without paranet layer (0%)	K1	2 male + 2 female (2:2)	T1	<i>Antigonon leptopus</i> Hook. & Arn.
J2	Insectarium with 25% paranet layer	K2	4 male + 2 female (4:2)	T2	<i>Cassia cobanensis</i> (Britton) Lundell
J3	Insectarium with 50% paranet layer	K3	2 male + 4 female (2:4)	T3	<i>Turnera subulata</i> J.E.Sm.
J4	Insectarium with 75% paranet layer			T4	<i>Nephrolepis biserrata</i> (Sw.) Desv.

Duration of adults mortality = Copulation date – date of total adults death (i)  
 Duration of male mortality = Copulation date – date of male death (ii)  
 Duration of female mortality = Copulation date – date of female death (iii)  
 Oviposition periode = Copulation date – date of laying egg (iv)  

$$Fertility = \frac{\sum Hatched\ Eggs}{\sum Laid\ Eggs} \times 100\%$$
 (vi)

Data was analysed using the three-way ANOVA to identify significant variable at a 5% significance level, followed by multivariate testing to deepen the analysis. Before conducting ANOVA, normality and homogeneity of variances were tested using the Shapiro-Wilk test and Levene's test, respectively. Non-normal data were transformed using logarithmic or square root or non-parametric alternatives such as the Kruskal-Wallis test. Morphological characteristic analysis was performed

descriptively, based on observations using a microscope.

RESULTS AND DISCUSSION

Characteristics of *Sycanus dichotomus* Stål, 1866 at the study area

*Sycanus dichotomus* detected at the research location exhibited two distinct colour variations: (1) a deep black colour across the entire abdomen with wings that are black-brown fading towards the tips (Figure 2.A and B), and (2) a golden-brown body with black patterns and wings that are black-gold to brown and fading towards the tips (Figure 2.C). The adults of *S. dichotomus* generally have an elongated, thickened body divided into three main sections: head, thorax, and distinctive abdomen. The head (hd) of *S. dichotomus* is very slim and long, equipped with two long and smooth antennae, usually longer than the dorsal pronotum (pn, Figure 2.D).

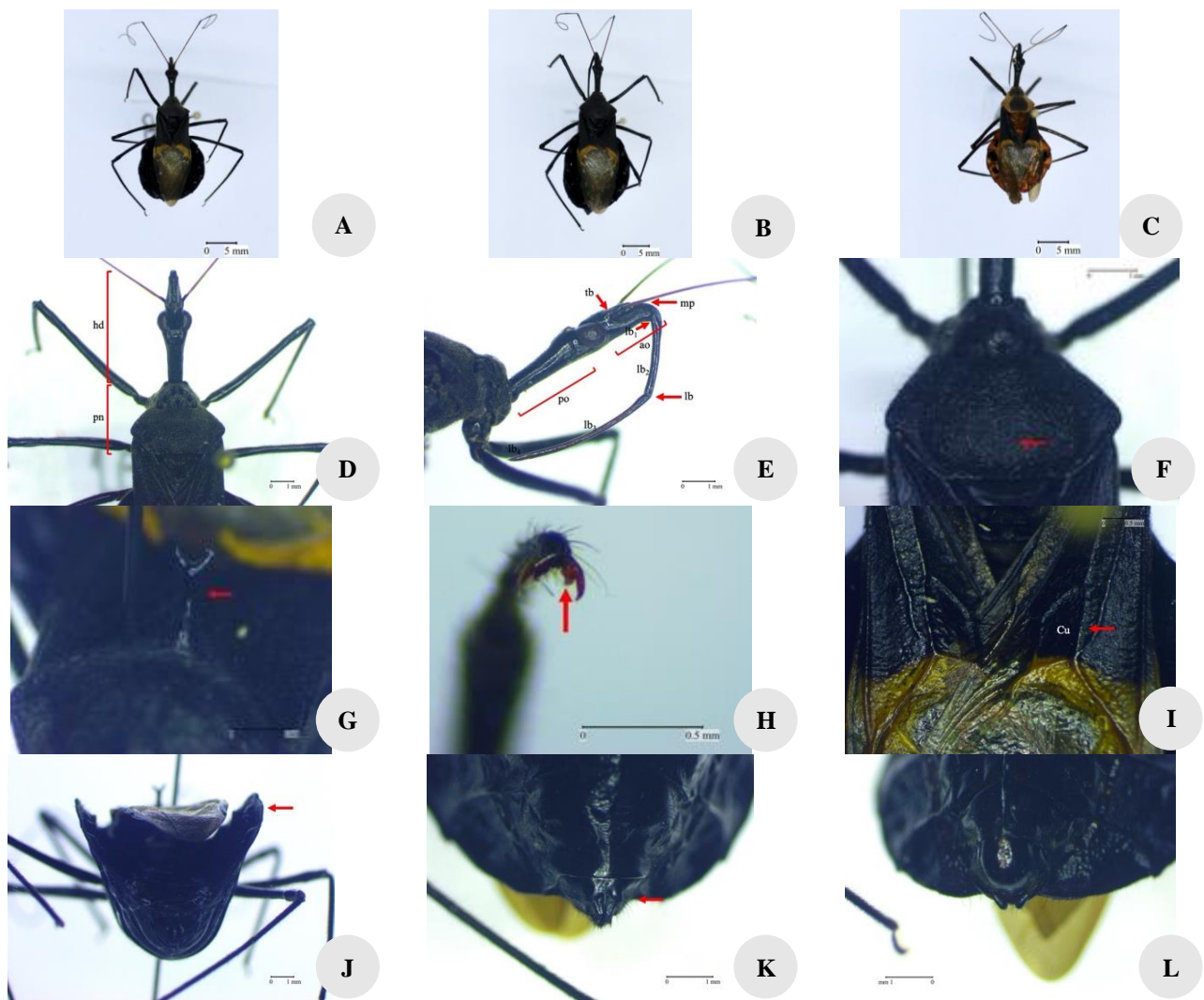


Figure 2. Identification results of *Sycanus dichotomus* insects at an oil palm plantation in Central Kalimantan, Indonesia. A; B; C. Abdomen and colour patterns of *S. dichotomus*; D. Head; E. Labium; F. Discus pronotum; G. Pine structure in scutellum; H. Ventral base of the claw; I. Cubitus vein; J. Laterotergite; K. Abdomen for female; L. Abdomen for male

The head features three clearly visible labium segments, with the first segment reduced and black in colour, a small mandibular plate (mp), and a labium (lb) that curves and tapers from the base to the tip. The tibia (tb) lacks spurs or tubercles behind the base of the antennae, and the anterior area (ao) is shorter than the postocular area (po) (lateral, Figure 2.E). The pronotum disc of *S. dichotomus* lacks spurs but has indentations on the pronotum surface resembling dots and wrinkles (dorsal) and is equipped with erect spurs on its scutellum (Figure 2.F). A tooth-like structure was observed at the base of the ventral claw (Figure 2.G). The cubitus vein (Cu) of *S. dichotomus* formed a square cell (dorsal), as shown in Figure 2.I. The laterotergite on its abdomen was somewhat elongated dorsally or dorsolaterally, making the abdomen appear boat-like or caudal (Figure 2.J). Differences between male and female adults of *S. dichotomus* lie in the tips of the abdomen (Figure 2.K and L) and their sizes, with female adults being larger than males. According to Davis (1966) and Ishikawa et al. (2007), the genital organs of *S. dichotomus* can be distinguished by the characteristics of the abdominal tip, with female adults marked by a slenderer and more pointed abdominal tip (Figure 2.K), while male adults are characterised by a blunt tip with a male external organ on the ventral side (Figure 2.L). Morphological species identification can be based on the colour and pattern of the first labium segment; *S. dichotomus* has a black or black-brown patterned first labium segment. This contrasts with *Sycanus aurantiacus* Ishikawa & Okajima, 2007, which is characterised by an orange colour on the first labium segment, distinguishing it from other species (Yuliadhi et al. 2021).

### Optimisation of *Sycanus dichotomus* productivity in the insectarium

The results in Tables 2 and 3 reveal that the type of insectarium manifested as paranet density significantly affected the mortality of male and female *S. dichotomus*, the day of laying eggs, the total number of egg clusters, and total number of eggs produced after infestation in the rearing box. The adult sex ratio of copulated *S. dichotomus* significantly affected the total number of egg clusters produced, fecundity, and total eggs. Type of refugia/host plants significantly influenced total adult mortality and female adult mortality, and the egg-laying duration after infestation and copulation in the rearing box. The interaction between insectarium type, sex ratio, and different plant types significantly affected the duration of egg laying and the total number of eggs produced by *S. dichotomus* after being infested in the rearing box.

Based on the above parameters, the total number of eggs was the main indicator for determining rearing success. This is because the average number of eggs directly measures the fertility and reproductive effectiveness of *S. dichotomus* under the given conditions. The results revealed that the treatment of J1K3T2 (i.e. the combination of a shadeless insectarium, an adult count of two males and four females, and the host plant *C. cobanensis*) provided the best results in term of the highest average total number of eggs with 372.3 eggs from 4.3 egg clusters with an average fecundity of 4.3 units. The results of the study indicate that a female-to-male imago ratio of 4:2 enhances egg productivity. However, when the number of males is higher, it may increase stress and competition among the adults, negatively affecting egg productivity. This indicates that the insectarium environment, including factors such as the microclimate, number of adults, and the presence of host plants in the J1K3T2 treatment, can support the life cycle of the insect. Conversely, treatment J2K2T2 (A 25% paranet-covered insectarium with a 2:4 male-to-female imago ratio and *C. cobanensis* as the host plant), J3K1T1, J3K1T2, (A 50% paranet-covered insectarium with a 2:2 male to female with *A. leptopus*, and *C. cobanensis*), and J3K2T2 (A 50% paranet-covered insectarium with a 4:2 male to female with *C. cobanensis*) showed the lowest number of eggs, with eggs that did not hatch and an average fecundity of only 0.3 days, indicating that this treatment has limitations in supporting the reproduction of *S. dichotomus*.

The variation in the number of eggs produced by *S. dichotomus* among the different treatments indicates that several factors affect the reproductive capability of the insect (Figure 3). The results showed that regression analysis between egg clusters significantly affected the number of eggs of *S. dichotomus*, with a determination coefficient ( $R^2$ ) of 0.87 (Figure 4). This indicates that the greater the number of egg clusters, the higher the potential egg production. The duration of female adult mortality and the time required for females to lay eggs after infestation in the insectarium (DLE) showed a very low correlation with the number of eggs, with an  $R^2$  of 0.03; therefore, these factors do not significantly affect the number of eggs produced. Similarly, no relationship was observed between the duration of adult death and egg productivity ( $R^2 = 0.00$ ), indicating that the duration of adult death (total and male) did not significantly affect egg productivity. Although fecundity had a positive relationship with the number of eggs, its correlation was low ( $R^2 = 0.07$ ), indicating that other unidentified factors may influence productivity.

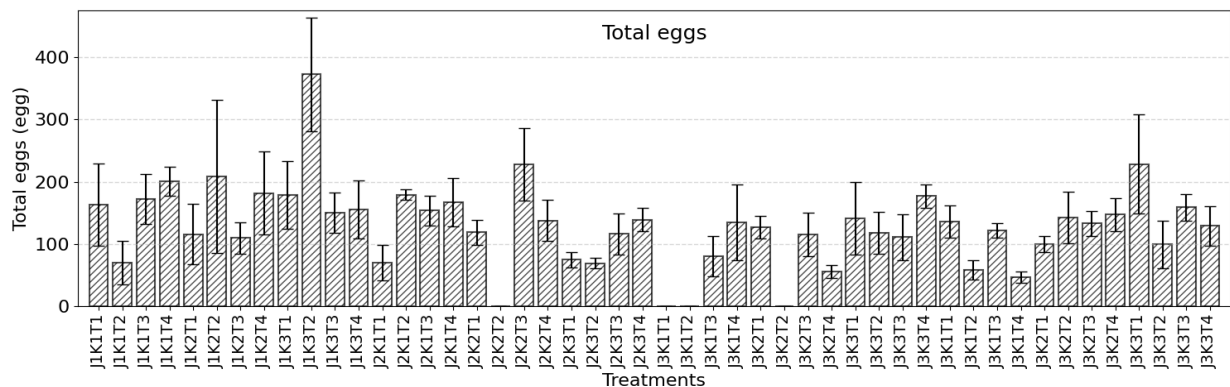
**Table 2.** Analysis results of the influence of treatment factor interactions on the development parameters of mortality, laying eggs, and their productivity of *Sycanus dichotomus*

Parameter	Result of three-way ANOVA						
	Paranet (J)	Adults sex ratio (K)	Host plant (T)	J*K	J*T	K*T	J*K*T
Mortality of male adults	0.036 *	0.174 <sup>ns</sup>	0.726 <sup>ns</sup>	0.713 <sup>ns</sup>	0.726 <sup>ns</sup>	0.397 <sup>ns</sup>	0.445 <sup>ns</sup>
Mortality of female adults	0.122 <sup>ns</sup>	0.085 <sup>ns</sup>	0.003 *	0.459 <sup>ns</sup>	0.575 <sup>ns</sup>	0.745 <sup>ns</sup>	0.087 <sup>ns</sup>
Day of laying eggs	0.122 <sup>ns</sup>	0.563 <sup>ns</sup>	0.000 *	0.143 <sup>ns</sup>	0.052 <sup>ns</sup>	0.726 <sup>ns</sup>	0.003 *
Number of egg groups	0.001 *	0.002 *	0.310 <sup>ns</sup>	0.072 <sup>ns</sup>	0.057 <sup>ns</sup>	0.658 <sup>ns</sup>	0.106 <sup>ns</sup>
Fecundity	0.000 <sup>ns</sup>	0.043 *	0.067 <sup>ns</sup>	0.051 <sup>ns</sup>	0.704 <sup>ns</sup>	0.964 <sup>ns</sup>	0.630 <sup>ns</sup>
Total eggs	0.436 *	0.026 *	0.559 <sup>ns</sup>	0.138 <sup>ns</sup>	<b>0.063 <sup>ns</sup></b>	0.545 <sup>ns</sup>	0.011 *

**Table 3.** Analysis results of factors affecting the productivity of *Sycanus dichotomus* in the insectarium

Code	Mortality		Day of laying eggs	Number of egg clusters	Fecundity
	Male	Female	Mean ± SE		Mean ± SE
J1K1T1	12.3 <sup>abcde</sup>	9.2 <sup>abcd</sup>	6.9 ± 0.7 <sup>abcde</sup>	2.0 <sup>abc</sup>	81.7 ± 33.2 <sup>bcde</sup>
J1K1T2	6.5 <sup>abcde</sup>	8.0 <sup>abc</sup>	5.0 ± 3.6 <sup>abcde</sup>	1.3 <sup>abc</sup>	34.8 ± 17.5 <sup>bcde</sup>
J1K1T3	<b>15.3<sup>e</sup></b>	<b>19.0<sup>de</sup></b>	19.0 ± 4.0 <sup>j</sup>	2.0 <sup>abc</sup>	86.2 ± 20.3 <sup>bcde</sup>
J1K1T4	5.0 <sup>a</sup>	9.3 <sup>abcd</sup>	11.0 ± 0.9 <sup>abcdej</sup>	2.3 <sup>bc</sup>	100.2 ± 11.7 <sup>bcde</sup>
J1K2T1	10.1 <sup>abcde</sup>	10.8 <sup>abcd</sup>	13.3 ± 3.4 <sup>cdej</sup>	1.3 <sup>abc</sup>	58.0 ± 24.4 <sup>a</sup>
J1K2T2	8.4 <sup>abcde</sup>	10.3 <sup>abcd</sup>	6.8 ± 4.1 <sup>abcde</sup>	2.0 <sup>abc</sup>	104.5 ± 61.4 <sup>bcde</sup>
J1K2T3	7.8 <sup>abcde</sup>	14.8 <sup>abcd</sup>	15.7 ± 3.0 <sup>ej</sup>	1.3 <sup>abc</sup>	54.8 ± 12.3 <sup>ab</sup>
J1K2T4	11.5 <sup>abcde</sup>	12.8 <sup>abcd</sup>	12.6 ± 1.7 <sup>bcdej</sup>	2.0 <sup>abc</sup>	91.0 ± 33.4 <sup>abcd</sup>
J1K3T1	5.3 <sup>abc</sup>	8.0 <sup>abc</sup>	10.6 ± 1.3 <sup>abcdej</sup>	2.3 <sup>bc</sup>	50.5 ± 7.8 <sup>abcde</sup>
J1K3T2	8.7 <sup>abcde</sup>	12.8 <sup>abcd</sup>	13.2 ± 0.8 <sup>cdej</sup>	<b>4.3<sup>d</sup></b>	93.1 ± 22.8 <sup>bcde</sup>
J1K3T3	9.3 <sup>abcde</sup>	9.4 <sup>abcd</sup>	8.2 ± 1.9 <sup>abcde</sup>	2.0 <sup>abc</sup>	37.5 ± 8.1 <sup>bcde</sup>
J1K3T4	8.2 <sup>abcde</sup>	5.3 <sup>ab</sup>	3.8 ± 1.6 <sup>abcd</sup>	2.0 <sup>abc</sup>	38.9 ± 11.6 <sup>bcde</sup>
J2K1T1	11.2 <sup>abcde</sup>	8.3 <sup>abcd</sup>	7.8 ± 2.7 <sup>abcde</sup>	1.3 <sup>abc</sup>	34.2 ± 14.4 <sup>bcde</sup>
J2K1T2	9.3 <sup>abcde</sup>	11.7 <sup>abcd</sup>	9.6 ± 3.6 <sup>abcdej</sup>	2.0 <sup>abc</sup>	89.7 ± 4.4 <sup>bcde</sup>
J2K1T3	9.7 <sup>abcde</sup>	8.5 <sup>abcd</sup>	7.0 ± 1.0 <sup>abcde</sup>	1.7 <sup>abc</sup>	78.2 ± 13.2 <sup>de</sup>
J2K1T4	13.8 <sup>abcde</sup>	15.8 <sup>bcde</sup>	12.2 ± 3.8 <sup>bcdej</sup>	2.0 <sup>abc</sup>	83.5 ± 19.5 <sup>bcde</sup>
J2K2T1	7.5 <sup>abcde</sup>	9.0 <sup>abcd</sup>	6.0 ± 0.0 <sup>abcde</sup>	1.3 <sup>abc</sup>	59.3 ± 10.3 <sup>bcde</sup>
J2K2T2	11.2 <sup>abcde</sup>	12.3 <sup>abcd</sup>	<b>0.0 ± 0.0<sup>a</sup></b>	0.3 <sup>a</sup>	0.0 ± 0.0 <sup>a</sup>
J2K2T3	14.2 <sup>cde</sup>	25.2 <sup>e</sup>	20.7 ± 4.0 <sup>j</sup>	2.3 <sup>bc</sup>	114.2 ± 29.0 <sup>de</sup>
J2K2T4	8.0 <sup>abcde</sup>	13.7 <sup>abcd</sup>	10.3 ± 2.6 <sup>abcdej</sup>	1.3 <sup>abc</sup>	68.8 ± 16.5 <sup>de</sup>
J2K3T1	8.5 <sup>abcde</sup>	9.4 <sup>abcd</sup>	4.0 ± 0.6 <sup>abcde</sup>	1.0 <sup>ab</sup>	18.8 ± 3.1 <sup>bcde</sup>
J2K3T2	7.5 <sup>abcde</sup>	9.2 <sup>abcd</sup>	5.0 ± 2.6 <sup>abcde</sup>	1.0 <sup>ab</sup>	28.4 ± 10.8 <sup>abcde</sup>
J2K3T3	5.5 <sup>abc</sup>	9.4 <sup>abcd</sup>	7.5 ± 2.1 <sup>abcde</sup>	1.7 <sup>abc</sup>	44.2 ± 23.2 <sup>bcde</sup>
J2K3T4	7.5 <sup>abcde</sup>	12.7 <sup>abcd</sup>	18.0 ± 3.1 <sup>j</sup>	1.7 <sup>abc</sup>	34.8 ± 4.7 <sup>de</sup>
J3K1T1	9.0 <sup>abcde</sup>	5.6 <sup>ab</sup>	<b>0.8 ± 0.8<sup>ab</sup></b>	1.3 <sup>abc</sup>	34.8 ± 19.0 <sup>abcde</sup>
J3K1T2	7.2 <sup>abcde</sup>	11.2 <sup>abcd</sup>	7.3 ± 7.3 <sup>abcde</sup>	0.3 <sup>a</sup>	22.2 ± 22.2 <sup>abc</sup>
J3K1T3	10.5 <sup>abcde</sup>	11.2 <sup>abcd</sup>	9.3 ± 2.3 <sup>abcdej</sup>	1.3 <sup>abc</sup>	40.3 ± 16.1 <sup>e</sup>
J3K1T4	14.0 <sup>bcde</sup>	15.3 <sup>abcd</sup>	14.8 ± 4.1 <sup>dej</sup>	1.7 <sup>abc</sup>	67.3 ± 30.6 <sup>bcde</sup>
J3K2T1	10.8 <sup>abcde</sup>	10.0 <sup>abcd</sup>	11.8 ± 2.9 <sup>bcdej</sup>	1.7 <sup>abc</sup>	63.5 ± 9.1 <sup>de</sup>
J3K2T2	11.3 <sup>abcde</sup>	13.8 <sup>abcd</sup>	1.7 ± 1.7 <sup>abc</sup>	0.3 <sup>a</sup>	15.8 ± 15.8 <sup>ab</sup>
J3K2T3	10.0 <sup>abcde</sup>	14.2 <sup>abcd</sup>	9.8 ± 2.7 <sup>abcdej</sup>	1.3 <sup>abc</sup>	57.8 ± 17.5 <sup>de</sup>
J3K2T4	14.8 <sup>de</sup>	16.3 <sup>cde</sup>	16.0 ± 4.2 <sup>j</sup>	1.0 <sup>ab</sup>	28.2 ± 5.1 <sup>de</sup>
J3K3T1	11.0 <sup>abcde</sup>	9.3 <sup>abcd</sup>	9.3 ± 0.9 <sup>abcdej</sup>	1.7 <sup>abc</sup>	44.2 ± 14.6 <sup>cde</sup>
J3K3T2	12.8 <sup>abcde</sup>	9.3 <sup>abcd</sup>	8.7 ± 4.2 <sup>abcde</sup>	1.3 <sup>abc</sup>	36.2 ± 7.4 <sup>cde</sup>
J3K3T3	9.0 <sup>abcde</sup>	16.8 <sup>cde</sup>	24.2 ± 10.4 <sup>j</sup>	1.3 <sup>abc</sup>	<b>27.8 ± 9.1<sup>e</sup></b>
J3K3T4	11.3 <sup>abcde</sup>	11.8 <sup>abcd</sup>	17.6 ± 2.2 <sup>j</sup>	2.3 <sup>bc</sup>	44.3 ± 4.7 <sup>bcde</sup>
J4K1T1	9.2 <sup>abcde</sup>	10.0 <sup>abcd</sup>	7.7 ± 1.5 <sup>abcde</sup>	1.3 <sup>abc</sup>	43.3 ± 11.4 <sup>cde</sup>
J4K1T2	6.8 <sup>abcde</sup>	8.0 <sup>abc</sup>	6.7 ± 2.4 <sup>abcde</sup>	1.0 <sup>ab</sup>	15.5 ± 8.9 <sup>cde</sup>
J4K1T3	9.7 <sup>abcde</sup>	13.5 <sup>abcd</sup>	8.2 ± 1.6 <sup>abcde</sup>	1.7 <sup>abc</sup>	25.7 ± 16.7 <sup>bcde</sup>
J4K1T4	7.3 <sup>abcde</sup>	9.3 <sup>abcd</sup>	9.3 ± 3.3 <sup>abcdej</sup>	1.0 <sup>ab</sup>	17.3 ± 9.3 <sup>bcde</sup>
J4K2T1	6.3 <sup>abcd</sup>	5.0 <sup>a</sup>	4.7 ± 3.3 <sup>abcde</sup>	1.0 <sup>ab</sup>	20.7 ± 20.7 <sup>de</sup>
J4K2T2	10.6 <sup>abcde</sup>	14.7 <sup>abcd</sup>	13.2 ± 7.4 <sup>cdej</sup>	1.7 <sup>abc</sup>	61.8 ± 26.6 <sup>bcde</sup>
J4K2T3	8.4 <sup>abcde</sup>	7.3 <sup>abc</sup>	6.5 ± 2.3 <sup>abcde</sup>	2.0 <sup>abc</sup>	63.0 ± 13.0 <sup>de</sup>
J4K2T4	7.5 <sup>abcde</sup>	8.5 <sup>abcd</sup>	7.7 ± 3.7 <sup>abcde</sup>	1.7 <sup>abc</sup>	65.8 ± 20.9 <sup>bcde</sup>
J4K3T1	5.2 <sup>ab</sup>	8.6 <sup>abcd</sup>	5.1 ± 0.9 <sup>abcde</sup>	3.0 <sup>cd</sup>	<b>45.2 ± 40.2<sup>e</sup></b>
J4K3T2	8.2 <sup>abcde</sup>	10.3 <sup>abcd</sup>	7.7 ± 3.1 <sup>abcde</sup>	1.7 <sup>abc</sup>	<b>33.6 ± 8.5<sup>e</sup></b>
J4K3T3	8.2 <sup>abcde</sup>	10.6 <sup>abcd</sup>	11.5 ± 2.9 <sup>abcdej</sup>	2.7 <sup>bc</sup>	47.8 ± 27.2 <sup>de</sup>
J4K3T4	8.2 <sup>abcde</sup>	8.7 <sup>abcd</sup>	8.1 ± 2.3 <sup>abcde</sup>	2.0 <sup>abc</sup>	16.3 ± 8.1 <sup>bcde</sup>

Note: Different letters indicate significant differences between treatments



**Figure 3.** Comparison of *Sycanus dichotomus* productivity of egg production in each treatment combination

### Optimisation of *Sycanus dichotomus* instar development

Table 4 presents the results of the three-way ANOVA test showing the significance level of the interaction between three factors: parant density (J), adults sex ratio (K), and refugia/host plants (T) on several measured parameters. Based on fertility parameters, parant density, adult sex ratio, and host plant type showed significant results for egg fertility ( $P < 0.05$ ), with p-values of 0.000, 0.032, and 0.025, respectively. Additionally, the combination of parant density and host plant types also provided significant results with a p-value of 0.025. The analysis showed that the interaction between the two factors (J\*K) and three factors (J\*K\*T) had no significant effect on fertility. In terms of the developmental stage of the 1<sup>st</sup> instar, only the adult sex ratio had a significant influence ( $p = 0.020$ ), but a deeper understanding is needed to analyse this factor. Meanwhile, at the 3<sup>rd</sup> instar stage, no individual or combinations of factors showed a significant influence. However, at the developmental stage of the 5<sup>th</sup> instar adults, parant density showed a very significant influence ( $p = 0.000$ ), indicating that physical environmental conditions such as parant density affect certain developmental stages. This confirms that although some factors significantly influence certain developmental stages,

not all factors or their combinations have a consistent effect on all developmental stages.

The purpose of rearing activities of *S. dichotomus* in the insectarium is to multiply its population for subsequent release in oil palm plantations, with release at the 3<sup>rd</sup> instar developmental stage. Based on this, the main parameter in assessing the success of this propagation was the highest number of *S. dichotomus* at the 3<sup>rd</sup> instar. The data visualisation results in Figure 5 show significant variation in the development of the 3<sup>rd</sup> instar between different treatments. The results show that J4K3T1 (the combination of 75% parant insectarium, a ratio of two males to four females and *A. leptopus* as host plant) is the best treatment with a count of 120 adult individuals at the 3<sup>rd</sup> instar per rearing box. The success of this treatment indicates that the specific combination of male and female adult ratio, along with the choice of the host plant, creates ideal conditions to support larval development up to the 3<sup>rd</sup> instar. Significant variation in the number of 3<sup>rd</sup> instar larvae indicates that some factors in that treatment may provide conditions that are more supportive for larvae to reach this stage, which may include better nutrition, more suitable habitat conditions, or other factors relevant to the life cycle and development of the insect.

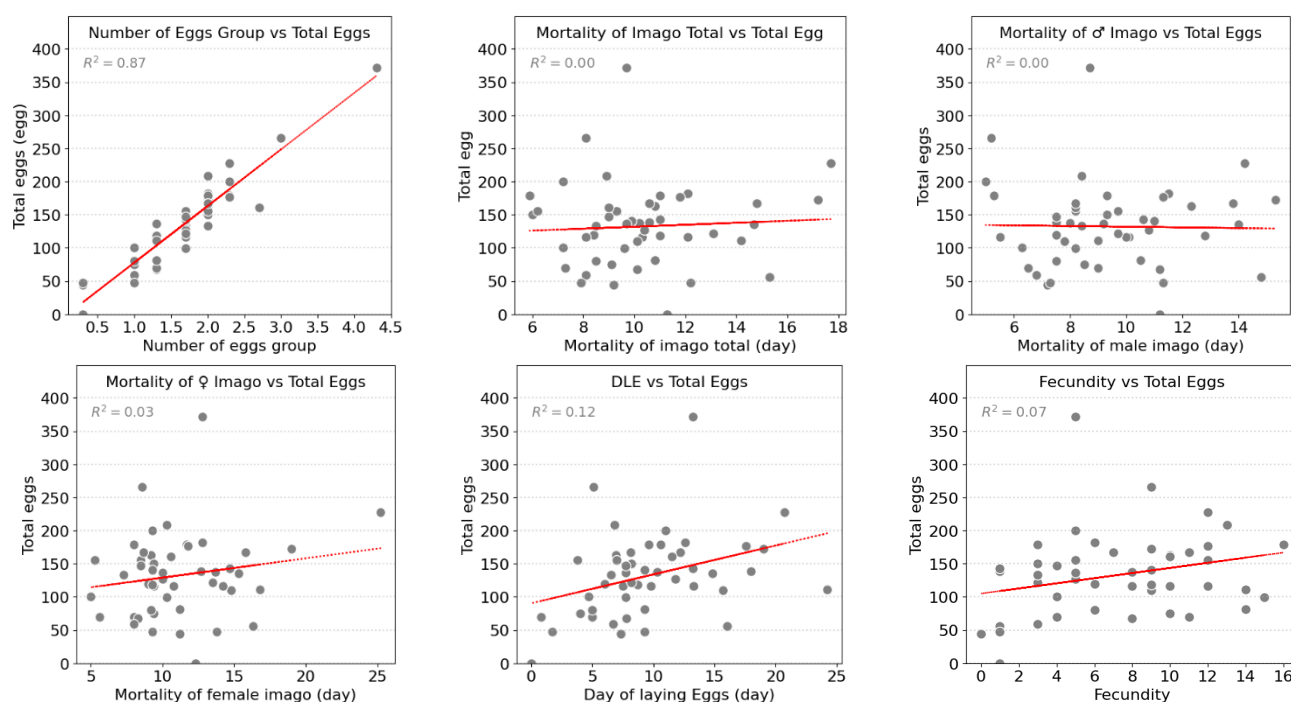


Figure 4. Interaction between factors affecting the productivity of *Sycanus dichotomus*

Table 4. Analysis results of the influence of treatment factor interactions on the development parameters of instar stages of *Sycanus dichotomus*

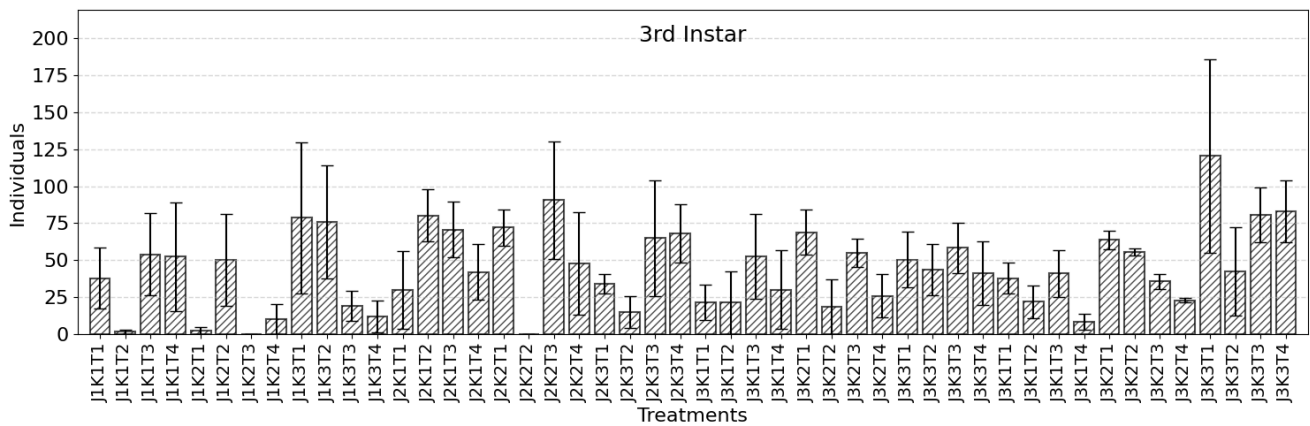
Parameter	Result of Three-Way ANOVA Test						
	Parant (J)	Adults sex ratio (K)	Host plant (T)	J*K	J*T	K*T	J*K*T
Fertility	0.000 *	0.032 *	0.025 *	0.068 ns	0.007 *	0.291 ns	0.288 ns
1st instar	0.241 ns	0.020 *	0.570 ns	0.075 ns	0.006 *	0.528 ns	0.146 ns
3rd instar	0.153 ns	0.054 ns	0.152 ns	0.107 ns	0.430 ns	0.749 ns	0.159 ns
5th instar	0.000 *	0.132 ns	0.051 ns	0.770 ns	0.641 ns	0.242 ns	0.083 ns

High egg productivity plays a critical role in determining the number of larvae that successfully reach the 1<sup>st</sup> instar stage, which subsequently affects their ability to progress to the 3<sup>rd</sup> instar and subsequent stages (Table 5). The analysis showed a positive relationship between the number of eggs and the number of individuals at the 1<sup>st</sup> instar, with a determination coefficient ( $R^2$ ) of 0.42, indicating that an increase in the number of eggs potentially increases the number of individuals reaching the 1<sup>st</sup> instar. This relationship became more significant when examining the transition from the 1<sup>st</sup> to the 3<sup>rd</sup> instar, with a sufficiently strong  $R^2$  of 0.66 (Figure 6). This finding indicates that the success of the 1<sup>st</sup> instar larvae in growing and developing is closely correlated with their ability to reach the 3<sup>rd</sup> instar. Fertility has a weak relationship with the number of eggs ( $R^2$  0.14) and with the number of 1<sup>st</sup> instar individuals produced ( $R^2$  0.21). This observation indicates that fertility is not determined by the number of eggs. Eggs of lower quality have a reduced chance of developing into 1st instar *S. dichotomus*. Environmental conditions, particularly the extreme fluctuations in temperature between day and night, are primary influencing factors. Consistency in development from the 1<sup>st</sup> to the 3<sup>rd</sup> instar emphasises the importance of the early phase in the life cycle of *S. dichotomus* as a critical factor determining the population's success in reaching further developmental stages, highlighting the importance of ensuring conditions that support increased egg numbers and larval survival. The lack of a relationship

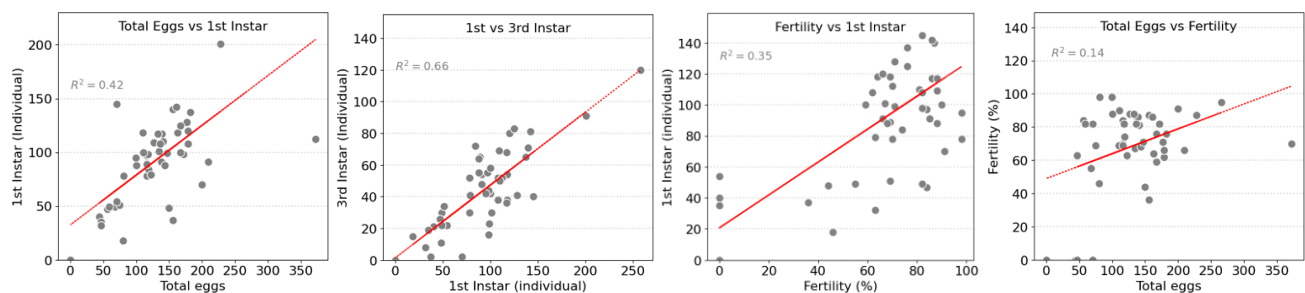
between fertility and the number of eggs may be directly related to the food source and internal factors of *S. dichotomus*, but a positive correlation means that the greater the number of eggs, the greater the chances of eggs emerging with fertility.

**Discussion**

*Sycanus dichotomus* insects identified at an oil palm plantation in Central Kalimantan exhibit two distinct morphotypes: one with a deep black abdomen and fading black-brown elytra, and the other with a golden-brown abdomen with black patterns and fading black-gold to brown elytra. This study highlights the optimal rearing conditions for *S. dichotomus* from Central Kalimantan, achieved by combining an insectarium with 100% light intensity, a 2:4 male-to-female ratio, and *C. cobanensis* as the host plant, which significantly enhances egg productivity during rearing. High light intensity promotes more active reproductive behavior, as reported by Shimoda and Honda (2013), who stated that bright light enhances mating behavior in nocturnal insects. This finding aligns with Desouhant et al. (2019), who demonstrated that optimal lighting conditions stimulate reproductive hormones in predatory insects. Additionally, Juddin et al. (2023) confirmed that intensive lighting influences insect behavior, including increased mating and oviposition rates.



**Figure 5.** Comparison of the development of 3<sup>rd</sup> instar adults of *Sycanus dichotomus* in each treatment combination



**Figure 6.** Interaction between factors affecting the development of *Sycanus dichotomus*

**Table 5.** The influence of treatment factor interactions on the development parameters of instar stages of *Sycanus dichotomus*

Code	Fertility (%) Mean ± SE	1 <sup>st</sup> Instar	3 <sup>rd</sup> Instar	5 <sup>th</sup> Instar
J1K1T1	60% ± 12% bcde	118.3 abc	38.0 abc	3.3 a
J1K1T2	60% ± 31% bcde	145.0 abc	39.7 ab	5.3 a
J1K1T3	70% ± 6% bcde	98.0 abc	16.3 abcd	2.0 a
J1K1T4	70% ± 21% bcde	69.7 abc	1.7 abcd	2.0 ab
J1K2T1	3% ± 3% a	77.7 ab	30.3 ab	3.7 a
J1K2T2	53% ± 27% bcde	91.0 bcd	54.0 abcd	3.7 abcd
J1K2T3	23% ± 12% ab	117.7 abc	54.0 abcd	3.7 abcd
J1K2T4	37% ± 7% abcd	136.7 abc	64.7 abc	4.7 a
J1K3T1	47% ± 26% abcde	108.3 abcd	52.3 abcd	5.0 a
J1K3T2	70% ± 15% bcde	112.0 e	52.3 abcd	5.0 abcd
J1K3T3	67% ± 17% bcde	48.3 abc	11.3 abc	0.3 ab
J1K3T4	53% ± 3% bcde	37.0 abc	2.3 abc	2.0 a
J2K1T1	57% ± 28% bcde	49.0 ab	30.0 abc	3.3 a
J2K1T2	67% ± 12% bcde	120.3 abc	80.3 abcd	47.7 d
J2K1T3	87% ± 9% de	140.3 abcd	70.7 abcd	26.0 abcd
J2K1T4	60% ± 17% bcde	100.3 abc	42.0 abcd	7.7 ab
J2K2T1	73% ± 12% bcde	84.3 abc	72.0 abcd	38.7 bcd
J2K2T2	0% ± 0%	0.0	0.0	0.0
J2K2T3	87% ± 7% de	201.3 cde	90.7 cd	46.7 cd
J2K2T4	87% ± 3% de	90.5 abc	47.7 abcd	4.7 a
J2K3T1	67% ± 3% bcde	51.3 ab	34.0 abc	21.7 abcd
J2K3T2	47% ± 26% abcde	18.3 ab	15.0 abc	8.7 ab
J2K3T3	70% ± 15% bcde	89.3 abc	65.0 abcd	29.0 abcd
J2K3T4	87% ± 9% de	117.0 abc	68.3 abcd	27.3 abcd
J3K1T1	47% ± 29% abcde	53.7 ab	21.7 abc	6.3 ab
J3K1T2	30% ± 30% abc	40.3 ab	21.3 abc	0.3 a
J3K1T3	97% ± 3% e	78.3 abc	52.3 abcd	21.0 abcd
J3K1T4	67% ± 15% bcde	101.3 abc	30.0 abc	3.3 a
J3K2T1	87% ± 9% de	108.7 abc	69.0 abcd	18.0 abcd
J3K2T2	27% ± 27% ab	35.3 ab	18.7 abc	10.3 ab
J3K2T3	83% ± 3% de	97.0 abc	55.0 abcd	26.7 abcd
J3K2T4	87% ± 9% de	47.0 ab	26.0 abc	0.3 a
J3K3T1	80% ± 6% cde	109.7 abc	50.3 abcd	17.7 abcd
J3K3T2	83% ± 7% cde	98.3 abc	43.7 abcd	10.3 ab
J3K3T3	90% ± 6% e	100.3 abc	58.3 abcd	17.0 abcd
J3K3T4	70% ± 12% bcde	128.3 abcd	41.3 abcd	20.0 abcd
J4K1T1	80% ± 10% cde	108.0 abc	38.0 abc	14.3 abcd
J4K1T2	83% ± 9% cde	49.3 ab	22.0 abc	8.7 ab
J4K1T3	63% ± 12% bcde	79.0 abc	41.0 abcd	8.7 ab
J4K1T4	63% ± 32% bcde	32.3 ab	8.3 ab	8.3 ab
J4K2T1	90% ± 0% de	87.7 abc	63.7 abcd	30.3 abcd
J4K2T2	70% ± 15% bcde	88.0 abc	55.3 abcd	32.3 abcd
J4K2T3	90% ± 6% de	117.0 abc	35.7 abc	24.7 abcd
J4K2T4	70% ± 12% bcde	99.0 abc	23.0 abc	13.3 abc
J4K3T1	97% ± 3% e	258.3 de	120.3 d	21.0 abcd
J4K3T2	97% ± 3% e	95.3 abc	42.3 abcd	7.7 ab
J4K3T3	83% ± 9% de	142.3 abcd	80.7 abcd	32.3 abcd
J4K3T4	77% ± 9% bcde	125.0 abc	83.0 bcd	23.3 abcd

Note: Different letters indicate significant differences between treatments

A 2:4 male-to-female ratio enhances copulation success and egg productivity compared to a 1:1 ratio (Vitta and Lorenzo 2009). Parker (2006) demonstrated that unbalanced sex ratios maximise reproductive outcomes due to male competition, while Ekrem and Kokko (2023) noted that excessive competition in high-male populations reduces reproductive efficiency. Córdoba-Aguilar (2009) added that female stress from frequent male pursuits negatively affects egg production. Meanwhile, Colin et al. (2017) emphasised

that a higher proportion of females improves colony-level reproductive performance under controlled conditions.

The host plant *C. cobanensis* can enhance the egg productivity of *S. dichotomus* during rearing. Host plants such as *A. leptopus* and *C. cobanensis* influence insect behavior and improve their ability to adapt from natural environments to insectarium conditions. The findings of this study indicate that the physical attributes of plants, particularly the leaf surface of *C. cobanensis*, significantly influence insect behavior. This outcome is evident from the

shorter oviposition duration, likely due to the leaf surface providing an ideal site for egg deposition. Jamian and Adam (2018) noted that nutrient-rich host plants support reproductive success. Similarly, Giles et al. (2002) revealed that suitable host plants play a dual role as both a nutritional source and a suitable habitat for reproduction. Groenteman et al. (2006) further emphasised that specific host plant characteristics, such as leaf texture and nutrient content, influence insect oviposition preferences.

During the incubation phase, findings indicate that dim light conditions (25%) combined with *A. leptopus* as the host plant support optimal egg fertility and nymph survival, emphasising the importance of low light intensity during early developmental stages. Johansen et al. (2011) observed that dim light reduces environmental stress, promoting embryonic development in predatory insects. King (2011) supported this observation, stating that low-light conditions create a stable microclimate conducive to embryogenesis. Furthermore, Raju et al. (2024) highlighted that host plants with complex structures, such as *A. leptopus*, protect additionally during the early stages of the insect life cycle. The productivity of *S. dichotomus*, measured by the total number of eggs from copulation, is not always influenced by adult female mortality. Some insects can maintain sperm competition levels released by males, allowing males to utilise chemical compounds stored in the female body to influence subsequent copulation processes (Danielsson 1998).

The low correlation between total egg count or fertility and the number of first-instar nymphs in *S. dichotomus* may be attributed to biological and environmental factors during the study. The insectarium employed UV plastic covers, which indirectly depended on weather conditions that can affect temperature, humidity, and light quality, potentially impacting the development, reproduction, and behavior of *S. dichotomus* during rearing. Ody et al. (2017) support this, showing that consistent temperature, humidity, and light conditions can enhance *S. dichotomus* development.

This experiment demonstrates that light intensity has a greater impact on later instar stages compared to earlier ones. Early nymphs are less sensitive to external stimuli, such as light, because their primary focus is survival rather than activity. At this stage, nymphs exhibit minimal movement to conserve energy and reduce predation risks. Conversely, later instars exhibit higher metabolic rates and energy demands, requiring increased activity for feeding and growth, which is stimulated by light intensity (Raubenheimer 2007). Additionally, sensory systems, including photoreceptors, develop progressively as nymphs grow. Early stages may have underdeveloped photoreceptors, making them less responsive to light, while later instars rely on these systems to regulate circadian rhythms.

As a generalist predator, *S. dichotomus* can alter food chain dynamics in certain ecosystems. Over-predation of prey species can impact the availability of food sources for other predators, ultimately disrupting ecosystem balance (Exéllis et al. 2022). *Sycanus dichotomus* may also prey on non-target insects, potentially causing a decline in populations of ecologically significant species, such as

pollinators, decomposers, or other natural enemies (Ambrose and Kumar 2016). Disruption of non-target species may trigger cascading effects, such as reduced biodiversity or the emergence of secondary pests previously controlled by local natural enemies.

Based on these findings, the propagation techniques for *S. dichotomus* as a biological control agent can be optimised through practical field strategies. First, insectariums should be designed using UV plastic covers to regulate light intensity and protect against temperature fluctuations and rainfall, with ventilation systems to create a suitable microclimate (25–30°C, 50–70% humidity). A 2:4 male-to-female ratio can enhance egg productivity, while regular population monitoring is crucial to maintain balance. *C. cobanensis* and *A. leptopus* are recommended as host plants to support oviposition and nymph development. Additionally, dim light conditions (~25%) are essential for egg and nymph development, necessitating temporary shading or protective covers in the field. Monitoring tools, such as data loggers, to track temperature, humidity, and light intensity will help optimise field conditions and ensure successful implementation. Production can begin on a small scale and gradually expand, with careful monitoring to minimise risks. These strategies ensure the effective and sustainable implementation of *S. dichotomus* as a biological control agent in the field.

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