

# THE IMPACT OF *Elaeidobius kamerunicus* FAUST POPULATION DENSITY AND SEX RATIO ON OIL PALM FRUIT SET IN INDONESIA

AGUS EKO PRASETYO<sup>1,2\*</sup>; EDHI MARTONO<sup>2</sup>; ANDI TRISYONO<sup>2</sup>; ALAN SOFFAN<sup>2</sup>  
and ROCH DESMIER DE CHENON<sup>3</sup>

## ABSTRACT

The persistent issue of low fruit set has remained a significant challenge in oil palm plantations in Indonesia for over 1.5 decades. One of the major causes of low fruit set is imperfect pollination due to *Elaeidobius kamerunicus* being the main oil palm pollinator. This study, conducted in Central Kalimantan, examined the role of weevils in pollinating nine fruiting positions within bunches of DxP Simalungun. The fruiting positions included the tip, middle and base spikelet, for each fruit location in the spikelet, the outside, middle and inside were considered. The artificial pollination test used 60 and 120 individual weevils/inflorescence, with the sex ratio of weevils including each of only male weevils, only female weevils and male/female weevil ratios of 1:2 and 1:4. Each treatment was trailed on 20 bunches, with approximately 1,100 fruits in each bunch. The results showed that male weevil treatment produced better fruit set only on the tip and outer sides. On the other hand, with female weevils, the fruit set of the spikelet at the base and the inner fruit was still relatively high. This was likely attributed to the smaller body size of female weevils, which enhanced their mobility and penetration into the inner parts of the spikelet.

**Keywords:** entomophilous pollination, fruiting position analysis, weevil mobility.

**Received:** 2 October 2024; **Accepted:** 10 October 2025; **Published online:** 8 January 2026.

## INTRODUCTION

Pollination plays an important role in determining the productivity of oil palm. The pollinating insect *Elaeidobius kamerunicus* is still a mainstay in ensuring the continuity of natural pollination in oil palm plantations, especially in the Southeast Asia (Desmier de Chenon, 2016; Fijen et al., 2018; Li et al., 2019; Mohamad et al., 2023; Norman et al., 2018), the world's largest producer of palm oil (Oil World, 2020). Although Dislich

et al. (2016) stated that the oil palm industry's trust in one pollinator species like *E. kamerunicus* was risky, it seems that *E. kamerunicus* can coexist with local insect pollinators and even synergise in increasing pollination efficiency, as is the case in Southeast Asia with the pollinator *Thrips hawaiiensis* (Anggraeni et al., 2013; Lubis & Sipayung, 1987; Rahayu, 2009; Wahid & Kamarudin, 1997). In several countries, such as Benin, Brazil and Ecuador, studies have documented positive interspecific interactions between *E. kamerunicus* and other pollinating species including *E. subvittatus* and *E. plagiatus* in Benin, and both *E. subvittatus* and *Grasidius hybridus* in Brazil and Ecuador (Beaudoin-Ollivier et al., 2017).

However, several decades after it was first introduced in the early 1980s, this pollinating weevil began to attract criticism, both for its low population (Kahono et al., 2012; Li et al., 2019; Lubis et al., 2014; Mohd-Rizuan et al., 2013; Prasetyo & Susanto, 2012a) and its aggressiveness as a slightly

<sup>1</sup> Department of Crop Protection, Indonesian Oil Palm Research Institute (IOPRI), Medan, Indonesia.

<sup>2</sup> Department of Plant Protection, Faculty of Agriculture, Universitas Gadjah Mada (UGM), Yogyakarta, Indonesia.

<sup>3</sup> Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia.

\* Corresponding author e-mail: [prasetyo.marihat@gmail.com](mailto:prasetyo.marihat@gmail.com)

weakened pollinator due to a reduced frequency of visits to female flowers (Dumont et al., 2018; Haran et al., 2020a; Prasetyo & Susanto, 2012b; Rahardjo et al., 2018). The results of a study on the dynamics of oil palm fruit set in various regions in Indonesia showed that oil palm plantations in the Sumatra Region tended to have oil palm bunches with a fairly high fruit set. Meanwhile, in the Kalimantan Area, including in the Malaysian section of Sarawak (Idris et al., 2016), many regions reported problems with lower fruit set (Lubis et al., 2014; Prasetyo & Susanto, 2012a; Purba et al., 2016). Makhdzir (2016) states that the concept of pollinator syndrome related to its role in transferring pollen from male flowers to female flowers is closely related to the rewards that will be received, such as pollen and nectar as separate considerations for this type of obligate pollinator.

According to Desmier de Chenon (2016), the female *E. kamerunicus* weevil visiting a female flower is likely looking for a location beneficial for its breeding. It has been suggested that the male *E. kamerunicus* weevil acts more effectively as a pollinator than the female weevil because it has a larger body size and can carry more pollen (Abd Latip et al., 2019; Desmier de Chenon, 1982; Malanno et al., 2018; Norman et al., 2018; Permana et al., 2017; Susanto et al., 2007; Syed, 1979). The weevil *E. kamerunicus* is thought to come to female flowers because female flowers bloom and emit attractive odour similar to male flowers' anthesis (Auffray et al., 2017; Barcelos et al., 2015; Dhileepan, 1994; Mayfield & Margaret, 2005; Sambathkumar & Ranjith, 2011; Tandon et al., 2001). Yue et al. (2015) stated that female flowers produce nectar as a food source for *E. kamerunicus* weevils but did not specifically mention the sex of the weevils. However, the specific contributions of male and female weevils to pollination efficiency have not yet been thoroughly investigated.

Therefore, a study of the sex composition and population density of the *E. kamerunicus* weevil was conducted to obtain information on the role of female flowers in insect breeding and as a basis for oil palm plant breeders to create plant materials that are in accordance with the behavioural characteristics of the *E. kamerunicus* weevil. This article discusses the role of male and female *E. kamerunicus* weevils, as well as their relative proportions, in determining the fruit set of oil palm under field conditions.

## MATERIALS AND METHODS

### Samples and Location of Study

The study was conducted on five-year-old commercial oil palm (*dura* × *pisifera*) Simalungun in East Kotawaringin, Central Kalimantan. The

selected test block has homogeneous planting conditions with standard planting practice. The randomly selected samples were plants with prospective female inflorescences, which would bloom at least seven days later and had a total of around 1,100 flowers/bunch. Each selected bunch was then covered using a pollination bag (Agrivex®) as in the procedure for pollination in the breeding program (Bonneau et al., 2017; Durran-Gasselin et al., 1999; Lubis, 1993).

### Artificial Pollination Process

The pollination process was carried out artificially using a number of weevils (60 and 120 weevils/bunch) with different sex compositions. Weevils were collected immediately after emerging from post anthesis of male inflorescences, before they began carrying pollen, as part of the breeding process. Weevils were collected in gauze bags with treatment numbers. The collection was conducted in the morning, before 6:00 am, when the weevils were inactive, to facilitate easier counting. The weevils were then sprayed with pure oil palm pollen with a moisture content (MC) of 4%-6%, using the protocol established by Widiastuti and Palupi (2008). Finally, the weevils were immediately put into the pollination bag when the female flowers bloomed on the first day and left for at least 15 days. After that, the pollination was opened, and the bunches were labelled.

### Experimental Design

The experiment was conducted using a completely randomised design (CRD) with treatments comprising two weevil population levels: 60 and 120 weevils/inflorescence. Each population level was tested with four different sex ratio compositions: 1:0 (all-male), 0:1 (all-female), 1:2 and 1:4 (male-to-female). Each treatment was replicated 20 times. Control treatments included: (1) Female inflorescences enclosed and left unopened until anthesis had fully passed, (2) female inflorescences enclosed and subsequently opened at the onset of anthesis and (3) female inflorescences left uncovered and untrimmed, representing natural open pollination conditions. During both artificial pollination treatments and open pollination controls, weather conditions were dry, with daytime temperatures ranging from 21°C-34°C and relative humidity between 50% and 80%.

### Fruit Bunch Analysis

The artificial pollination treatments were carried out during August-September 2022. After 5-6 months of the treatment of pollination, bunch analysis was carried out using the 9-Quadrant

Method (Purba *et al.*, 2016). After the bunches were weighed, each spikelet was cut from the bunch from the base to the tip and placed sequentially. The first one-third is the spikelet group from the base of the bunch, the one-third in the middle is the spikelet group from the centre of the bunch and the remaining one-third is the spikelet group from the tip of the bunch (Figure 1). Each spikelet was then divided into three parts based on its position: Outer, middle and inner fruit. The fruit set was calculated from the percentage of fruit that develops due to pollination (indicated by the presence of kernels and nuts) compared to the total fruit potential. Thus, the value of the fruit set was obtained from nine quadrants, including the spikelet/fruit parts of outer tip, middle tip, inner tip, outer centre, middle centre, inner centre, outer base, middle base and inner base. In addition, the weight of developed fruits was compared to the bunch weight to obtain the fruit-to-bunch value.

### Data Analysis

The data were analysed using Multivariate Analysis of Variance (MANOVA) in R Studio to assess the significance of differences in treatment effects. Post-hoc comparisons were conducted using Tukey's HSD test to identify specific differences between groups. To evaluate the effect of *E. kamerunicus* population and sex ratio on fruit, a multiple linear regression analysis was performed. The model was analysed using the Ordinary Least Squares (OLS) method with the statsmodels package in Python. Significance of individual predictors was tested at a 95% confidence level ( $\alpha = 0.05$ ), and the overall model fit was assessed using the F-test to determine whether the predictors jointly explain significant variance in fruit set.

## RESULTS AND DISCUSSION

Generally, the oil palm fruit set from the treatment of 60 female weevils/female inflorescence on the outside was higher than the fruit set on the inside (Table 1). Likewise, the fruit set of the spikelet at the tip was higher than at the middle and the base. The highest fruit set value was achieved in the weevil treatment with a sex ratio of 1:4 at the outermost fruit position of the spikelet tip of 71.30% followed by the weevil treatment with a sex ratio of 0:1, 1:0 and 1:2 which produced fruit set values of 69.57%, 68.40% and 62.85% in the same position, respectively, although not significantly different by Tukey's test. Statistically significant differences among treatments were observed at the base section of the spikelet across all fruit positions (outer, middle and inner). The lowest fruit set at the base was recorded in the 1:0 (all male weevils) treatment, at 33.19%, which was significantly lower compared to the 1:2, 1:4 and 0:1 treatment, which had fruit set 42.88%, 48.91% and 54.84%, respectively. Within this section, the 1:2 treatment was statistically different from the 1:4 and 0:1 treatment, whereas no significant difference was observed between the latter two. This pattern was also seen in the middle fruit position of the spikelet base. In contrast, at the outer fruit position of the spikelet base, the 1:2 treatment yielded a fruit set value of 59.78%, which was not significantly different from the 1:4 and 0:1 treatments. However, it remained significantly higher than the 1:0 treatment. This finding suggests that female weevils play a substantial role particularly in pollinating the innermost fruit positions, suggesting that female weevils possess enhanced mobility and efficiency in accessing deeper floral structures. Therefore, optimising the sex ratio of pollinator populations may serve

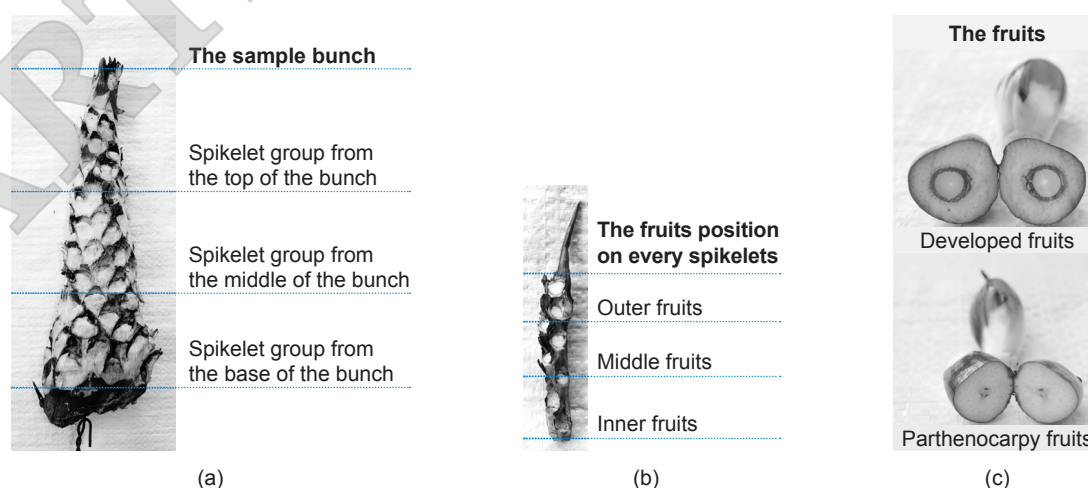


Figure 1. (a) The sample bunch divided into three spikelet groups (top, middle and base); (b) the fruits position on every spikelet divided into three groups (outer, middle, inner) and (c) the developed and parthenocarp fruits in every spikelet.

as a strategic approach to improving pollination efficiency and enhancing fruit set in oil palm plantations.

A similar pattern was observed in treatments of 120 weevils/inflorescence, the highest fruit set value was consistently recorded at the spikelet tip, followed by the middle and base sections. Furthermore, the outer fruit position demonstrated the highest fruit set, followed by the middle and inner positions (Table 2). Notably, the fruit set value exceeded the typical range, reaching 79.91% in the 0:1 (all-female) weevil sex ratio treatment. Although this value was not statistically different from those recorded in the 1:4, 1:2 and 1:0 treatments, which achieved fruit set values of 76.48%, 74.99% and 71.95%, respectively, at the spikelet tip and outer fruit position, it remained significantly higher compared to the open-pollinated control treatments. The control treatments, involving inflorescences with and without prior sheath removal, yielded fruit set values of 66.18% and 65.40%, respectively. Significant differences among weevil sex ratio treatments, particularly in the 1:0 (all-male weevils) group, were evident at the spikelet base across all fruit positions (outer, middle and inner). Despite these differences, the fruit set values in the 1:0 treatment remained higher than those in the open-pollinated control treatments. Moreover, no statistically significant differences were observed among the 1:2, 1:4 and 0:1 treatments, indicating that variations in sex ratio within these ranges did not substantially affect fruit set outcomes. These findings highlight the critical influence of weevil population density on pollination success. The consistently higher fruit set values in treatments with 120 weevils/inflorescence, regardless of sex ratio, suggest that an increased number of pollinators enhances pollen distribution and fertilisation efficiency. This observation underscores the importance of optimising both weevil population size and sex ratio to maximise pollination effectiveness and improve fruit set in oil palm cultivation.

A multiple linear regression analysis was conducted to determine the effect of weevil population and sex ratio on fruit set in oil palm. The regression model was statistically significant [ $F(2, 1077) = 105.7, p < 0.001$ ], indicating that the predictors collectively explain a significant proportion of variance in fruit set. The model yielded an  $R^2$  value of 0.164, meaning that approximately 16.4% of the variability in fruit set can be explained by the combined effect of the number of weevils and sex ratio. Regression coefficients and their significance levels are presented in Table 3. The regression results indicate that the number of weevils has a positive and statistically significant effect on fruit set, with each additional weevil associated with an increase of 0.195% in fruit set. Conversely, sex ratio shows a negative and significant relationship

with fruit set, suggesting that a higher proportion of male weevils corresponds to a lower fruit set percentage.

The higher value of oil palm fruit set on the outside is due to the ease with which the weevil visits flowers, beginning at the outer or tip and working its way inward. *Elaeidobius kamerunicus* weevils are known to visit female flowers to the fennel scent that is released (Anggraeni et al., 2013; Fahmi et al., 2016; Filho et al., 2019; Hussein et al., 1989; Rahayu, 2009; Syed, 1979). Although, in one bunch, female flowers bloom on the first day from the base position or at random (Adam et al., 2005), and some researchers suspect that the arrival of weevils carrying pollen is a coincidence (Auffray et al., 2017; Li et al., 2019; Mayfield & Margaret, 2005; Norman et al., 2018; Sambathkumar & Ranjith, 2011; Syed, 1979). As a result, the distribution of pollen attached to the weevil's body to be dropped onto the flower pistil is greater on the tip and outer sides than on the innermost side. The spikelet at the base has a narrower angle than the spikelet in the centre and tip. Meanwhile, the position of the flower on the inside may also be pinched, making it difficult for the weevil to move in that position.

Table 1 and 2 consistently show that treatment with female *E. kamerunicus* weevils produced better fruit set values compared to treatment with only male weevils. This result indicates that female weevils that have smaller body sizes than male weevils (Abd Latip et al., 2019; Haran et al., 2020b; Lumentut & Hosang, 2016; Syed, 1979) actually have a bigger role as pollinator insects for oil palm. Female weevils also carry less pollen than male weevils but still much more than the indigenous *T. hawaiiensis*. The study conducted by Permana et al. (2017) showed that the number of pollen grains in the bodies of male and female weevils visiting the female oil palm flowers was 3,357 grains/weevil and 277 grains/weevil, respectively. Meanwhile, according to Syed (1979), 235 and 56 grains were stored in the elytra, thorax and abdomen of male and female weevils. Rahayu's study (2009) showed that fruit set values were higher in flowers visited by *E. kamerunicus* and *T. hawaiiensis* than those visited by *E. kamerunicus* weevils only. The relatively small size could be a factor causing the *T. hawaiiensis* insect to be able to enter the deepest corners of the fruit. According to Anggraeni et al. (2013), the arrival of *T. hawaiiensis* tended to occur when the sun was not shining (very early in the morning or late in the evening); hence, its job as a pollinating insect became less important because it could only carry a few pollen grains. Therefore, it is necessary to consider an insect species that is small but capable of acting as a good oil palm pollinator. Desmier de Chenon (2016) mentions that this opportunity exists

TABLE 1. FRUIT SET VALUE IN EACH QUADRANT OF BUNCHES AS AFFECTED BY TREATMENTS OF 60 *E. kamerunicus* WEEVILS/FEMALE INFLORESCENCE

| Quadrant         |                | Average fruit set value (%)     |                    |                    |                    |                    |                    |                    |
|------------------|----------------|---------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|                  |                | Weevil sex ratio (male: female) |                    |                    |                    | Control treatments |                    |                    |
| Part of spikelet | Fruit position | 1:0                             | 0:1                | 1:2                | 1:4                | A                  | B                  | C                  |
| Tip              | Outer          | 68.40 <sup>a</sup>              | 69.57 <sup>a</sup> | 62.85 <sup>a</sup> | 71.30 <sup>a</sup> | 0.16 <sup>b</sup>  | 66.18 <sup>a</sup> | 65.40 <sup>a</sup> |
|                  | Middle         | 59.29 <sup>a</sup>              | 66.05 <sup>a</sup> | 61.96 <sup>a</sup> | 61.92 <sup>a</sup> | 0.05 <sup>b</sup>  | 59.51 <sup>a</sup> | 59.79 <sup>a</sup> |
|                  | Inner          | 48.59 <sup>a</sup>              | 54.65 <sup>a</sup> | 51.10 <sup>a</sup> | 53.90 <sup>a</sup> | 0.06 <sup>b</sup>  | 52.83 <sup>a</sup> | 54.26 <sup>a</sup> |
| Middle           | Outer          | 64.38 <sup>a</sup>              | 69.33 <sup>a</sup> | 62.14 <sup>a</sup> | 68.92 <sup>a</sup> | 0.22 <sup>b</sup>  | 69.45 <sup>a</sup> | 59.10 <sup>a</sup> |
|                  | Middle         | 56.59 <sup>a</sup>              | 67.64 <sup>a</sup> | 54.23 <sup>a</sup> | 59.24 <sup>a</sup> | 0.14 <sup>b</sup>  | 58.84 <sup>a</sup> | 57.71 <sup>a</sup> |
|                  | Inner          | 45.56 <sup>a</sup>              | 54.38 <sup>a</sup> | 50.42 <sup>a</sup> | 49.26 <sup>a</sup> | 0.12 <sup>b</sup>  | 52.58 <sup>a</sup> | 46.63 <sup>a</sup> |
| Base             | Outer          | 54.98 <sup>b</sup>              | 64.18 <sup>a</sup> | 59.78 <sup>a</sup> | 62.04 <sup>a</sup> | 0.14 <sup>d</sup>  | 56.02 <sup>b</sup> | 45.02 <sup>c</sup> |
|                  | Middle         | 44.46 <sup>c</sup>              | 59.82 <sup>a</sup> | 50.93 <sup>b</sup> | 54.30 <sup>a</sup> | 0.06 <sup>d</sup>  | 49.26 <sup>b</sup> | 39.75 <sup>c</sup> |
|                  | Inner          | 33.19 <sup>c</sup>              | 54.84 <sup>a</sup> | 42.88 <sup>b</sup> | 48.91 <sup>a</sup> | 0.00 <sup>d</sup>  | 42.90 <sup>b</sup> | 29.31 <sup>c</sup> |

Note: Means followed by the same letters in each row show no significant difference based on Tukey's test at a significance level of 95%. A - Covered before and opened two weeks after anthesis; B - Covered before and opened when the flowers started to bloom; C - Without being covered nor the sheath being cleaned.

TABLE 2. FRUIT SET VALUE IN EACH QUADRANT OF BUNCHES AS AFFECTED BY TREATMENTS OF 120 *E. kamerunicus* WEEVILS/FEMALE INFLORESCENCE

| Quadrant         |                | Average fruit set value (%)     |                    |                    |                    |                    |                    |                    |
|------------------|----------------|---------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|                  |                | Weevil sex ratio (male: female) |                    |                    |                    | Control treatments |                    |                    |
| Part of spikelet | Fruit position | 1:0                             | 0:1                | 1:2                | 1:4                | A                  | B                  | C                  |
| Tip              | Outer          | 71.95 <sup>a</sup>              | 79.91 <sup>a</sup> | 74.99 <sup>a</sup> | 76.48 <sup>a</sup> | 0.16 <sup>c</sup>  | 66.18 <sup>b</sup> | 65.40 <sup>b</sup> |
|                  | Middle         | 71.49 <sup>a</sup>              | 71.84 <sup>a</sup> | 70.05 <sup>a</sup> | 72.54 <sup>a</sup> | 0.05 <sup>c</sup>  | 59.51 <sup>b</sup> | 59.79 <sup>b</sup> |
|                  | Inner          | 60.60 <sup>a</sup>              | 66.68 <sup>a</sup> | 66.07 <sup>a</sup> | 64.29 <sup>a</sup> | 0.06 <sup>c</sup>  | 52.83 <sup>b</sup> | 54.26 <sup>a</sup> |
| Middle           | Outer          | 70.09 <sup>a</sup>              | 77.55 <sup>a</sup> | 73.72 <sup>a</sup> | 73.90 <sup>a</sup> | 0.22 <sup>c</sup>  | 69.45 <sup>a</sup> | 59.10 <sup>b</sup> |
|                  | Middle         | 66.94 <sup>a</sup>              | 72.29 <sup>a</sup> | 64.03 <sup>a</sup> | 69.76 <sup>a</sup> | 0.14 <sup>c</sup>  | 58.84 <sup>b</sup> | 57.71 <sup>b</sup> |
|                  | Inner          | 58.14 <sup>a</sup>              | 62.73 <sup>a</sup> | 61.84 <sup>a</sup> | 61.57 <sup>a</sup> | 0.12 <sup>c</sup>  | 52.58 <sup>a</sup> | 46.63 <sup>b</sup> |
| Base             | Outer          | 68.91 <sup>b</sup>              | 72.94 <sup>a</sup> | 72.09 <sup>a</sup> | 72.85 <sup>a</sup> | 0.14 <sup>d</sup>  | 56.02 <sup>b</sup> | 45.02 <sup>c</sup> |
|                  | Middle         | 59.97 <sup>b</sup>              | 69.07 <sup>a</sup> | 63.72 <sup>a</sup> | 61.11 <sup>a</sup> | 0.06 <sup>d</sup>  | 49.26 <sup>b</sup> | 39.75 <sup>c</sup> |
|                  | Inner          | 50.53 <sup>b</sup>              | 60.48 <sup>a</sup> | 59.28 <sup>a</sup> | 55.34 <sup>a</sup> | 0.00 <sup>d</sup>  | 42.90 <sup>b</sup> | 29.31 <sup>c</sup> |

Note: Means followed by the same letters in each row show no significant difference based on Tukey's test at a significance level of 95%. A - Covered before and opened two weeks after anthesis; B - Covered before and opened when the flowers started to bloom; C - Without being covered nor the sheath being cleaned.

TABLE 3. REGRESSION COEFFICIENTS FOR PREDICTORS OF FRUIT SET

| Predictor        | Coefficient ( $\beta$ ) | Std. error | t-value | p-value |
|------------------|-------------------------|------------|---------|---------|
| Intercept        | 50.560                  | 1.534      | 32.96   | <0.001  |
| Number of weevil | 0.195                   | 0.015      | 12.92   | <0.001  |
| Sex ratio (M/F)  | -14.805                 | 2.216      | -6.68   | <0.001  |

for *E. subvittatus*, which is more than half the size of *E. kamerunicus* and acts as a pollinator for oil palm. Previous studies even concluded that there was a dominance of *E. subvittatus* as a pollinator insect in areas with low rainfall (Desmier de Chenon, 1982), thereby offering a great opportunity as a good pollinator complex for oil palm plantations in Indonesia.

Compared to the control treatment, the treatment of weevils with 60 and 120 weevils/inflorescence produced higher fruit set values (Table 1, 2 and 4). This indicates that the population of weevils that naturally visit female flowers bloom is insufficient for pollination in the field, or the amount and availability of pollen carried are still lacking, although field observations

during the treatments indicated an *E. kamerunicus* population density of 35,442 weevils/ha and the availability of male inflorescences at anthesis was 5 inflorescences/ha. In the weevil treatment, before infesting the female flowers bloom, the weevils were first sprayed with pure oil palm pollen with a viability of above 80% in dry conditions with a MC of 4%-6% so that the pollen could easily fall on the flower stigmas. This causes the pollen falling on the pistils of female flowers to be in good conditions for pollination. This also occurs in the hatch and carry method, which produces better pollination (Prasetyo *et al.*, 2019). While in natural conditions, weevils from the field that land on female flowers bloom come from male flowers bloom so that the pollen conditions are still wet or sticky. They may also carry pollen that has just germinated, making it difficult to fall on the stigma. On top of that, the weevils might not carry pollen or have just hatched from male flowers after blooming and immediately visited female flowers in bloom so that flower pollination did not occur. Recent findings also confirmed that the female weevil population is generally much higher than males at both male and female inflorescences, and that visitation intensity varies according to anthesis day, which further influences pollination efficiency (Zulkefli *et al.*, 2024).

In greater detail, the fruit set values from the three control treatments (*Table 1, 2 and 4*) are different. In the negative control treatment (female inflorescences were covered before blooming and opened two weeks after the flowers bloomed), almost no flowers developed into fruit and the fruit set only 0.11%. In contrast, the control treatment involving sheath removal before flowering recorded a higher fruit set value of 56.40%, compared to 50.88% in the control treatment without sheath

removal. However, the difference between these two control treatments was not statistically significant. Normally, female flowers will start to bloom when the sheath is broken by 25.00%-50.00% (Tandon *et al.*, 2001). This condition causes some of the flowers from the outermost part not to be seen visually. Nonetheless, the weevils still have the potential to visit these flowers because of the smell of volatile compounds produced by these flowers (Anggraeni *et al.*, 2013; Rahayu, 2009; Susanto *et al.*, 2007; Syed, 1979). This also demonstrates that, in addition to the fruit's relatively narrow angle, its location covered with a sheath also creates problems for the range of the weevil's movement to visit all the flowers in the inflorescence.

*Table 1, 2, 3 and 4* also show that the more weevils infest the female oil palm flowers bloom, the higher the fruit set value is formed. Various observations regarding the higher population of weevils will increase the fruit set of oil palm have also been made before (Dhileepan, 1994; Lubis *et al.*, 2017; Prasetyo *et al.*, 2019; Rahardjo *et al.*, 2018; Syed & Saleh, 1987). A higher population of weevils carrying a lot of pollen leads to better mobility of insects, thereby optimising pollen distribution. A population of 120 weevils/inflorescence could produce fruit set above normal (>75%) at the tip of the flower spikelet and the outer flower and tended not to be reached from other positions. *Table 3* shows that, on average, the highest fruit set value (only 70.39%) was achieved in the 0:1 treatment (only female weevils).

On the other hand, the value of a fruit bunch was higher with the increasing fruit set value. *Table 3* shows that the tendency for a high fruit set will result in a higher fruit-to-bunch value, although some data show that different fruit sets produce fruit-to-bunch values that are not significantly different. Corley and Tinker (2016) stated that in the

TABLE 4. FRUIT SET, FRUIT TO BUNCH AND POTENTIAL OF OIL CONTENT OF BUNCHES AS AFFECTED BY TREATMENTS

| Treatments | Number of weevils/ inflorescence   | Sex ratio | Average fruit set value (%) | Average value of fruit to bunch (%) | Oil potential (%)* |
|------------|--|-----------|-----------------------------|-------------------------------------|--------------------|
| Weevil     | 60   | 1:0       | 52.83 <sup>c</sup>          | 56.30 <sup>b</sup>                  | 22.58 <sup>c</sup> |
|            |  | 0:1       | 62.27 <sup>b</sup>          | 64.25 <sup>a</sup>                  | 24.07 <sup>b</sup> |
|            |  | 1:2       | 55.14 <sup>bc</sup>         | 56.68 <sup>b</sup>                  | 22.60 <sup>c</sup> |
|            |  | 1:4       | 58.87 <sup>b</sup>          | 62.71 <sup>a</sup>                  | 23.43 <sup>b</sup> |
|            | 120  | 1:0       | 64.29 <sup>b</sup>          | 63.83 <sup>a</sup>                  | 24.01 <sup>b</sup> |
|            |  | 0:1       | 70.39 <sup>a</sup>          | 69.37 <sup>a</sup>                  | 25.42 <sup>a</sup> |
|            |  | 1:2       | 67.31 <sup>a</sup>          | 65.49 <sup>a</sup>                  | 24.84 <sup>a</sup> |
|            |  | 1:4       | 67.54 <sup>a</sup>          | 65.15 <sup>a</sup>                  | 24.89 <sup>a</sup> |
| Control    | Inflorescences were covered and opened two weeks after anthesis          |           | 0.11 <sup>d</sup>           | 0.75 <sup>c</sup>                   | 10.51 <sup>d</sup> |
|            | Inflorescences were covered and opened when the flowers started to bloom |           | 56.40 <sup>bc</sup>         | 63.82 <sup>a</sup>                  | 23.45 <sup>b</sup> |
|            | Inflorescences were uncovered and the sheath were not cleaned            |           | 50.88 <sup>c</sup>          | 59.84 <sup>ab</sup>                 | 22.60 <sup>c</sup> |

Note: Means followed by the same letters in the same column show no significant difference based on Tukey's test at a significance level of 95%. \* - Calculated using the Rendemenmeter formula (Susanto *et al.*, 2014).

case of a lower fruit set, the size of loose fruit could be heavier if the nutrients given were the same in one planting area. A high value of fruit-to-bunch will result in a greater oil yield.

## CONCLUSION

The number and sex of *E. kamerunicus* weevil that comes to the anthesis female inflorescence blooms determine the value of the fruit set formed. Pollination using 120 weevils/inflorescence resulted in a higher pollination rate compared to a lower density treatment of 60 weevils/inflorescence. Greater use of female weevils gives higher fruit set values, because female weevils with a size of about 2-3 mm can reach flowers to the base of the bunch and the deepest spikelet.

## ACKNOWLEDGEMENT

The authors would like to thank the management of Indonesian Oil Palm Research Institute for all funding for this study and the Plant Protection research group that assisted in field activities. Thanks also go to PT Bumitama Gunajaya Agro, especially the Research and Development Department, for the permit for the testing location and all assistance regarding the implementation of activities.

## REFERENCES

- Abd Latip, N. F., Ghani, I. A., Hazmi, I. R., Zainal Abidin, C. M. R., Sartiami, D., Yacob, S., & Nasir, D. M. (2019). Morphometric comparison of the oil palm pollinator *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae) from Malaysia, Indonesia, and Liberia. *The Coleopterists Bulletin*, 73(3), 746–756. <https://doi.org/10.1649/0010-065X-73.3.746>
- Adam, H., Jouannic, S., Escoute, J., Duval, Y., Verdeil, J., & Tregear, J. W. (2005). Reproductive developmental complexity in the African oil palm (*Elaeis guineensis*, Arecaceae). *American Journal of Botany*, 92(11), 1836–1852. <https://doi.org/10.3732/ajb.92.11.1836>
- Anggraeni, T., Rahayu, S., Ahmad, I., Esyanti, R., & Putra, R. E. (2013). Resources partitioning and different foraging behavior is the basis for the coexistence of *Thrips hawaiiensis* (Thysanoptera: Thripidae) and *Elaeidobius kamerunicus* (Coleoptera: Curculionidae) on oil palm (*Elaeis guineensis* Jacq.) flower. *Journal of Entomology & Nematology*, 5(5), 59–63. <https://doi.org/10.5897/JEN12.008>
- Auffray, T., Frérot, B., Poveda, R., Louise, C., & Beaudoin-Ollivier, L. (2017). Diel patterns of activity for insect pollinators of two oil palm species (Arecaceae). *Journal of Insect Science*, 17(2), 1–6. <https://doi.org/10.1093/jisesa/iex018>
- Barcelos, E., Rios, S. de A., Cunha, R. N. V., Lopes, R., Motoike, S. Y., Babiychuk, E., Skirycz, A., & Kushnir, S. (2015). Oil palm natural diversity and the potential for yield improvement. *Frontier Plant Science*, 6, 190. <https://doi.org/10.3389/fpls.2015.00190>
- Beaudoin-Ollivier, L., Flori, A., Syahputra, I., Nodichao, L., Poveda, R., & Louise, C. (2017). Study of *Elaeidobius* spp. and *Grasidius hybridus* population activity using a new trapping method during oil palm anthesis (Coleoptera, Curculionidae). *Bulletin de la Société entomologique de France*, 122(2), 151–160.
- Corley, R. H. V., & Tinker, P. B. (2016). *The Oil Palm* (5th ed.). John Wiley and Son. <http://dx.doi.org/10.1002/9781118953297>
- Desmier de Chenon, R. D. (2016). Keynote speech: The current and future challenges of pests, disease, weeds and biodiversity in oil palm. In *Proceedings of the Sixth IOPRI–MPOB International Seminar on Pests and Diseases*. IOPRI–MPOB.
- Desmier de Chenon, R. D. (1982). *Entomophil pollination of oil palm in West Africa: Preliminary research*. In *The oil palm in the eighties: In Proceedings of the International Conference on Oil Palm in Agriculture in the Eighties* (Vol. 1, pp. 291–319). Incorporated Society of Planters.
- Dhileepan, K. (1994). Variation in populations of the introduced pollinating weevil (*Elaeidobius kamerunicus*) (Coleoptera: Curculionidae) and its impact on fruitset of oil palm (*Elaeis guineensis*) in India. *Bulletin of Entomological Research*, 84(4), 477–485. <https://doi.org/10.1017/S0007485300032703>
- Dislich, C., Keyel, A. C., Salecker, J., Kisel, Y., Meyer, K. M., Auliya, M., Barnes, A. D., Corre, M. D., Darras, K., Faust, H., Hess, B., Klasen, S., Knohl, A., Kreft, H., Meijide, A., Nurdiansyah, F., Otten, F., Pe'er, G., Steinebach, S., . . . Wiegand, K. (2016). A review of the ecosystem functions in oil palm plantations, using forests as a reference system. *Biological Reviews/Biological Reviews of the Cambridge Philosophical Society*, 92(3), 1539–1569. <https://doi.org/10.1111/brv.12295>

- Dumont, Y., Soulie, J. C., & Michel, F. (2018). Modelling oil palm pollinator dynamics using deterministic and agent-based approaches. Applications on fruit set estimates. Some preliminary results. *Mathematical Methods in the Applied Sciences*, 41(18), 8545–8564. <https://doi.org/10.1002/mma.4858>
- Fahmi, M. H. M., Ahmad Bukhary, A. K., Norma, H., & Idris, A. B. (2016). Analysis of volatile organic compound from *Elaeis guineensis* inflorescences planted on different soil types in Malaysia. *AIP Conference Proceedings*, 1784, 060020. <https://doi.org/10.1063/1.4966858>
- Fijen, T. P. M., Scheper, J. A., Boom, T. M., Janssen, N., Raemakers, I., & Kleijn, D. (2018). Insect pollination is at least as important for marketable crop yield as plant quality in a seed. *Crop Ecology Letters*, 21, 1704–1713. <https://doi.org/10.1111/ele.13150>
- Filho, E. G. A., Brito, R. S., Rodrigues, T. H. S., Silva, L. M. A., De Brito, E. S., Canuto, K. M., Krug, C., & Zocolo, G. J. (2019). Association of pollinators of different species of oil palm with the metabolic profiling of volatile organic compounds. *Chemistry & Biodiversity*, 16(6), e1900050. <https://doi.org/10.1002/cbdv.201900050>
- Haran, J. M., Abanda, R. F. X. N., Benoit, L., Bakoume, C., & Beaudoin-Ollivier, L. (2020a). Multilocus phylogeography of the world populations of *Elaeidobius kamerunicus* (Coleoptera, Curculionidae), pollinator of the palm *Elaeis guineensis*. *Bulletin of Entomological Research*, 110(5), 654–662. <https://doi.org/10.1017/S0007485320000218>
- Haran, J. M., Beaudoin-Ollivier, L., Benoit, L., & Kuschel, G. (2020b). Revision of the palm-pollinating weevil genus *Elaeidobius* Kuschel, 1952 (Curculionidae, Curculioninae, Derelomini) with descriptions of two new species. *European Journal of Taxonomy*, 684, 1–32. <https://doi.org/10.5852/ejt.2020.684>
- Hussein, M., Lajis, N., Kinson, A., & Teo, C. (1989). Laboratory and field evaluation on the attractancy of *Elaeidobius kamerunicus* Faust to 4-allylanisole. *PORIM Bulletin*, 18, 20–26.
- Idris, A. B., Ramle, M., Norman, K., SyarifahNadia, S. M. D., NoorHisham, H., Fatihah, N. A. L., Hakim, A. M. L., Fahmi, M. H., & Teo, T. M. (2016). Oil palm pollinators in Malaysia: Implication to oil palm industry and Malaysia economy. In *Proceedings of the Sixth IOPRI-MPOB International Seminar of Pests and Diseases*. IOPRI-MPOB.
- Kahono, S., Lupiyaningdyah, P., Erniwati, & Nugroho, H. (2012). Potensi dan pemanfaatan serangga penyerbuk untuk meningkatkan produksi kelapa sawit di perkebunan kelapa sawit Desa Api-Api, Kecamatan Waru, Kabupaten Penajam Paser Utara, Kalimantan Timur [Potential and utilization of pollinating insects to increase oil palm production in oil palm plantations in Desa Api-Api, Waru Subdistrict, Penajam Paser Utara Regency, East Kalimantan]. *Zoo Indonesia*, 21(2), 23–34.
- Li, K., Tschardt, T., Saintes, B., Buchori, D., & Grassa, I. (2019). Critical factors limiting pollination success in oil palm: A systematic review. *Agriculture, Ecosystems and Environment*, 280, 152–160. <https://doi.org/10.1016/j.agee.2019.05.001>
- Lubis, A. U., & Sipayung, A. (1987). Serangga penyerbuk kelapa sawit, *E. kamerunicus* di Indonesia 1983–1987 [Pollinating insects of oil palm, *E. kamerunicus* in Indonesia 1983–1987]. Makalah Pertemuan Balai Penelitian dan Direksi PTP, April 1987, Tanjung Morawa.
- Lubis, F. I., Agustin, I., Riana, I., Kurniawan, L., & Latif, S. (2014). The occurrence of poor fruit set at Central Kalimantan. In *Proceedings of the International Oil Palm Conference*.
- Lubis, F. I., Sudrajat, & Dono, D. (2017). Populasi serangga penyerbuk kelapa sawit *Elaeidobius kamerunicus* Faust dan pengaruhnya terhadap nilai fruit set pada tanah berliat, berpasir dan gambut di Kalimantan Tengah, Indonesia [Population of oil palm pollinating insects *Elaeidobius kamerunicus* Faust and their effect on fruit set value on clay, sandy, and peat soils in Central Kalimantan, Indonesia]. *Jurnal Agrikultura*, 28(1), 39–46.
- Lumentut, N., & Hosang, M. L. A. (2016). Demografi kumbang *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae) sebagai serangga polinator pada tanaman kelapa sawit [Demography of *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae) as a pollinator insect on oil palm plants]. *Buletin Palma*, 17(1), 89–95.
- Makhdzir, M. (2016). Issues related to low fruit set in oil palm. In *Proceeding of the Sixth IOPRI-MPOB International Seminar of Pests and Diseases*. IOPRI-MPOB.

- Malanno, K., Adelophe, H. K., N'klo, H., & Mamadou, D. (2018). *Efficacité de la pollinisation entomophile du palmier à huile dans les plantations du sud-ouest et du sud-est de la Côte d'Ivoire* [Effectiveness of entomophilous pollination of oil palm in plantations of the southwest and southeast of Côte d'Ivoire]. *European Scientific Journal*, 14(12), 392–406. <https://doi.org/10.19044/esj.2018.v14n12p392>
- Mayfield, T., & Margaret, M. (2005). The importance of nearby forest to known and potential pollinators of oil palm (*Elaeis guineensis* Jacq.) (Arecaceae) in Southern Costa Rica. *Economic Botany*, 59(2), 190–196.
- Mohd-Rizuan, Z. A., Noor-Hisham, H., & Samsudin, A. (2013). Role of pollinating weevil (*Elaeidobius kamerunicus*), seasonal effect and its relation to fruit set in oil palm area of FELDA. In *Proceeding of International Palm Oil Congress (PIPOC) 2013 Conference*, MPOB.
- Mohamad, S. A., Mohd Masri, M. M., Kamarudin, N., Sulaiman, M. R., Costa, A., Ong-Abdullah, M., Othman, H., Ahmad, S. N., Syarif, M. N. Y., Abdul Karim, Z., Abdul Ghani, I., Amit, S., Zakaria, A., Su, C. M., Siaw, T. C., Jalinas, J., Yap, Y. K., Sairi, A. A., Syed Ali, S. M. F., ... Parveez, G. K. A. (2023). Impact of *Elaeidobius kamerunicus* (Faust) introduction on oil palm fruit formation in Malaysia and factors affecting its pollination efficiency: A review. *Journal of Oil Palm Research*, 35(1), 1–22. <https://doi.org/10.21894/jopr.2022.0021>
- Norman, K., Ramle, M., Rosman, S. A., Costa, A., & Sivapragasam, R. (2018). Fruit set and weevil pollination issues in oil palm. *Planter*, 94, 565–578.
- Oil World (2020). *Palm oil: World production, yield, and mature area*. ISTA Mielke GmbH. <http://www.oilworld.biz>
- Permana, A. D., Permana, B., Sahari, B., Putra, R. E., & Kinasih, I. (2017). Estimating numbers of oil palm (*Elaeis guineensis*) pollen grains using image analysis and processing. *Journal of Oil Palm Research*, 29(3), 311–317.
- Prasetyo, A. E., Rozziansha, T. A. P., Priwiratama, H., Wening, S., Susanto, A., & Desmier De Chenon, R. D. (2019). *Perspectiva bioecológica de Elaeidobius kamerunicus en relación con el llenado de frutos de palma de aceite en Indonesia* [Bioecological perspective of *Elaeidobius kamerunicus* in relation to oil palm fruit filling in Indonesia]. *PALMAS*, 40(Especial Tomo I), 94–110.
- Prasetyo, A. E., & Susanto, A. (2012a). *Meningkatkan fruit set kelapa sawit dengan teknik hatch and carry Elaeidobius kamerunicus* [Improving oil palm fruit set using the hatch and carry technique for *Elaeidobius kamerunicus*]. *Seri Kelapa Sawit Populer 11*, Pusat Penelitian Kelapa Sawit, Medan, Indonesia. 61 pp.
- Prasetyo, A. E., & Susanto, A. (2012b). *Serangga penyerbuk kelapa sawit Elaeidobius kamerunicus Faust: Agresivitas dan dinamika populasi di Kalimantan Tengah* [Oil palm pollinating insect *Elaeidobius kamerunicus* Faust: Aggressiveness and population dynamics in Central Kalimantan]. *Jurnal Penelitian Kelapa Sawit*, 20(3), 103–113.
- Purba, A. R., Prasetyo, A. E., Kurniawan, A., Supena, N., Siregar, H. A., Sujadi, Hasibuan, H. A., Arif, M. A., & Suprianto, E. (2016). Oil Palm Pollinator Weevil *Elaeidobius kamerunicus* and the fruit set in Indonesia. In *Proceeding of the Sixth IOPRI-MPOB International Seminar of Pests and Diseases*. IOPRI-MPOB.
- Rahardjo, B. T., Rizali, A., Utami, I. K., Karindah, S., Puspitarini, R. D., & Sahari, B. (2018). Populasi *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae) pada beberapa umur tanaman kelapa sawit. *Jurnal Entomologi Indonesia*, 15(1), 31–39. <https://doi.org/10.5994/jei.15.1.31>
- Rahayu, S. (2009). Peranan senyawa volatile kelapa sawit (*Elaeis guineensis* Jacq.) bagi serangga penyerbuk *Elaeidobius kamerunicus* Faust dan *Thrips hawaiiensis* Morgan [disertasi]. Bandung: Institut Teknologi Bandung.
- Sambathkumar, S., & Ranjith, A. M. (2011). Insect pollinators of oil palm in Kerala with special reference to African weevil, *Elaeidobius kamerunicus* Faust. *Pest Management in Horticultural Ecosystems*, 17(1), 14–18.
- Susanto, A., Purba, R. Y., & Prasetyo, A. E. (2007). *Elaeidobius kamerunicus: Serangga penyerbuk kelapa sawit* [*Elaeidobius kamerunicus*: The oil palm pollinating insect]. *Seri Buku Saku 28*, Pusat Penelitian Kelapa Sawit.
- Syed, R. A., & Saleh, A. (1987). Population of *Elaeidobius kamerunicus* Fst. in Relation to fruit Set. In *Proceedings of the International Oil Palm Conference*. Kuala Lumpur, Malaysia.
- Syed, R. A. (1979). Studies on oil palm pollination by insects. *Bulletin of Entomological Research*, 69(2), 213–224. <https://doi.org/10.1017/s0007485300017673>

- Tandon, R., Manohara, T. N., Nijalingappa, B. H. M., & Shivanna, K. R. (2001). Pollination and pollen-pistil interaction in oil palm, *Elaeis guineensis*. *Annals of Botany*, 87(6), 831–838. <https://doi.org/10.1006/anbo.2001.1421>
- Wahid, M.B., & Kamarudin, N. (1997). Role and effectiveness of *Elaeidobius kamerunicus*, Thrips *hawaiiensis* and *Pyroderces* sp. in pollination of mature oil palm in Peninsular Malaysia. *Elaeis*, 9(1), 1–16.
- Yue, J., Yan, Z., Bai, C., Chen, Z., Lin, W., & Jiao, F. (2015). Pollination activity of *Elaeidobius kamerunicus* (Coleoptera: Curculionoidea) on oil palm on Hainan Island. *Florida Entomologist*, 98(2), 499–505.
- Zulkefli, M. H. H., Jamian, S., Adam, N. A., Abdullah, S., Masri, M. M. M., Moslim, R., & Saharul, A. M. (2024). Population density of *Elaeidobius kamerunicus* (Faust) and abiotic factors effect within anthesising inflorescences of Malaysian oil palm. *Serangga*, 29(2), 79–95. <https://doi.org/10.17576/serangga-2024-2902-07>

ARTICLE IN PRESS