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INCREASING THE POPULATION OF OIL PALM WEEVIL (*Elaeidobius kamerunicus*) USING HATCH AND CARRY BOX TECHNIQUE IN OIL PALM CULTIVATION ON TROPICAL PEAT SOIL

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ABSTRACT

The decline in the oil palm weevil, Elaeidobius kamerunicus *population has led to inadequate pollination, posing a significant challenge in oil palm production. The decrease in population may be linked to the widespread application of cypermethrin insecticide, which is commonly used to control the bunch moth,* Tirathaba rufivena. *This could be due to the insecticide's impact on the behavioural and physiological traits of the moth population, potentially reducing their ability to thrive and exhibit aggressive tendencies. Consequently, low fruit setting rates (≤65.0%) and bunch failures have been observed in these estates. This study was conducted in a private oil palm plantation in Kota Samarahan, Sarawak, Malaysia aimed to assess the impact of* E. kamerunicus *on oil palm productivity. To address this issue, a hatch and carry box technique was devised. This technique involved hatching adult* E. kamerunicus *and then dispersing them in targeted areas of the oil palm plantation after coating them with highly viable pollen (≥85.0%). Following two months of application, there was a significant increase* (p<0.05) *in the population of* E. kamerunicus *within male inflorescences, rising from 8 to 19 weevils spikelet^{-1}. Additionally, the oil palm fruit set increased from 43.5% to 50.0% to 75.0% after 4–5 months of employing the hatch and carry box technique. Consequently, the estates experienced an increase in fresh fruit bunch (FFB) yield by 2–3 t ha^{-1} compared to the previous 1–2 years.*

Keywords: *Elaeidobius kamerunicus*, hatch and carry box, oil palm, peat soil.

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INTRODUCTION

The African oil palm (*Elaeis guineensis* Jacq.) is the world's most significant contributor and source of vegetable oil (Murphy et al., 2021). It is widely grown in the tropical humid climate of Malaysia, with regular rainfall. Malaysia is the second largest producer of crude palm oil (CPO) in the world after Indonesia, with a total of 15.13 million tonnes, accounting for 25% of global CPO production in 2023 (Malaysian Palm Oil Board [MPOB], 2024).

The fresh fruit bunch (FFB) yield has been shown to correlate with the meteorological conditions including rainfall, temperature and humidity (Adhi et al., 2021; Hermanto et al., 2023; Monzon et al., 2022). However, previous studies have been constrained by limitations in the methods and data used to identify causal relationships between FFB yield data and *Elaeidobius kamerunicus*. One of the key determinants of an oil palm plantation's performance is the management of pollinators (Henson et al., 2008; Melling et al., 2009).

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Palm oil production relies on effective pollination, mainly carried out by the weevil called *E. kamerunicus* (Meijaard et al., 2020). *Elaeidobius kamerunicus* was introduced to Southeast Asia in the 1980s to pollinate oil palm trees. However, recent reports have shown a decline in the population of these *E. kamerunicus*, which has led to poor FFB fruit set formation (Prasetyo et al., 2014; Su, 2016). In Sarawak, Malaysia, the low population of *E. kamerunicus* is linked to the infestation of another pest, the oil palm bunch moth *Tirathaba rufivena*, which has become a major pest in estates grown on peat soil (Su, 2016). The larvae of *T. rufivena,* feed on the oil palm inflorescences (Wood & Ng, 1974) and can bore through oil palm fruitlets to access the juicy embryo-containing kernel (Su, 2016). As a result, insecticide application is necessary to prevent economic loss (Su, 2016). However, the use of broad-spectrum insecticides such as cypermethrin to control *T. rufivena* has also been reported to kill *E. kamerunicus* (Norman et al., 2018). In addition to the effects of excessive insecticide application (Asib & Musli, 2020; Ismail et al., 2020; Ming & Bong, 2017; Prasetyo & Susanto, 2019; Yusdayati & Hamid, 2015), *E. kamerunicus* populations were also influenced by factors such as predation by natural enemies like rodents (Wahyuni et al., 2021). In addition, climate and weather factors such as temperature and humidity significantly influence *E. kamerunicus* reproduction and survival rates (Wahid & Kamarudin, 1997). The low population of *E. kamerunicus* has been attributed to incomplete pollination, resulting in a high number of parthenocarpic fruits (Norman et al., 2018).

This study is essential for assessing the efficacy of the hatch and carry box technique in optimising the oil palm fruit set, thereby enhancing overall productivity in plantation operations. Furthermore, the findings will provide critical insights into the variables influencing *E. kamerunicus* pollination efficiency and fruit set dynamics, which are pivotal for maximising the FFB yield. Therefore, estate management must revamp and apply Good Agricultural Practices (GAP) to ensure the establishment and sustainability of *E. kamerunicus* populations, which are vital for effective pollination and optimal FFB yield. For example, GAP practices could include the elimination of pests such as *T. rufivena*, which negatively affect *E. kamerunicus* populations, alongside other strategies that support the overall 'health' of the plantation (Suib et al., 2023). This study specifically investigated three key aspects. Firstly, the effectiveness of employing hatch-and-carry boxes within peat environments, focusing on their success rate in augmenting the population of *E. kamerunicus*. Secondly, the impact of this technique on the development of fruit set in oil palms cultivated in peat soils, and thirdly, the subsequent increase in FFB yield observed after the application of the hatch and carry box technique in the peat areas. By examining these factors comprehensively, we aim to provide a thorough understanding of how this method influences both pollinator efficacy and overall productivity in the oil palm plantations.

MATERIALS AND METHODS

Site Description

The trial was conducted on seven-year-old palms (*Figure 1*), in a 100-ha block, within a private estate near Samarahan Province, Sarawak (1°27'35.64"N, 110°29'17.88"E) between March and December 2017. From the beginning until the end of the study, the average temperature was 25.3°C in Samarahan (max, 27.0°C; min, 22.5°C). with an annual rainfall of 3,500 mm (Sa'adi et al., 2017). The oil palm plantation is situated on the low-lying and flat terrains of Kota Samarahan-Asajaya. This area is primarily utilised for the commodity sector.

The palm density was 148 stands ha^{-1}, on very deep peat, identified as the Anderson series. The field trial, covering approximately 25 ha, was established using a grouped-strip layout consisting of three treatments (T1, T2 and T3). To minimise potential cross-contamination and prevent *E. kamerunicus* movement between plots, buffer zones with a radius of approximately 2 km were maintained between T1 and T2 and between T2 and T3 (*Figure 2*). This spatial separation ensured that each treatment plot remained independent. Each treatment included four replicates (R1–R4), arranged in vertical columns within their respective treatment zones. Prasetyo et al. (2014) suggested that *E. kamerunicus* can disperse up to a 200 m radius under certain conditions. This study establishes a 2 km buffer zone as a precautionary measure to prevent the mixing of treatments in the plot.

Treatment and Experimental Design

A pre-observation was conducted before the application of the hatch and carry box technique. This covered fruit set analysis, the number of anthesising male inflorescences ha^{-1} and the *E. kamerunicus* population. These pre-observations were needed to determine the effectiveness of using the hatch and carry box technique proposed by Prasetyo et al. (2014) to improve the *E. kamerunicus* population and thus also to increase the fruit set and FFB yield. This study area has fully recovered from the *T. rufivena* infestation but still faced substantial challenges regarding the

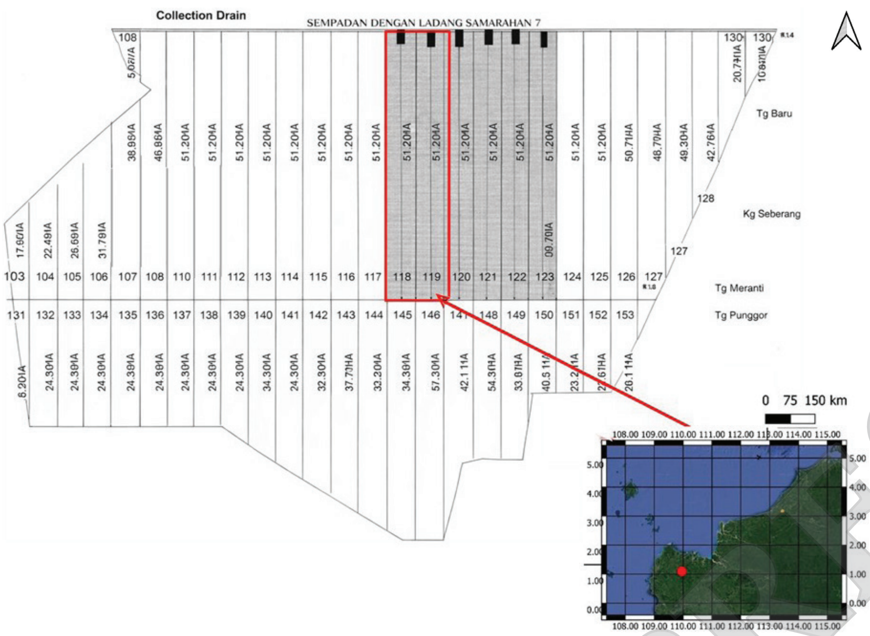


Figure 1. The map shows a trial plot map of 100 ha at an oil palm estate using ArcGIS.

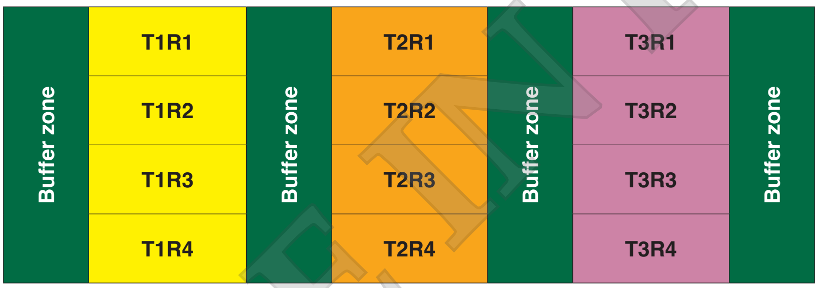


Figure 2. Treatment plot diagram.

fruit set formation. There were three treatment plots, hatch and carry box technique (T1), untreated (T2) and assisted pollination (T3). In the T1 treatment, a controlled environment was created to facilitate pollination, whereby the introduction of pollen to the pollinators was conducted inside a box, before releasing them onto the palms. The T2 treatment served as the control group, where no external pollination methods were applied, relying solely on natural or self-pollination. The T3 treatment involved transferring pollen to the female flowers. First, the pollen was collected from the male flowers, using a brush. The pollen was then carefully applied to the female flowers, using a burst pump. The best time for pollination is just before or during the opening of the female flowers. Pollination may be repeated if needed and the palms were monitored to ensure that the fruit developed properly. To prevent cross-contamination between treatments, buffer zones were established between the plots. These buffer zones served as neutral areas to minimise unintended pollen transfer, ensuring the accuracy and reliability of the experimental results.

The experimental design is shown in *Table 1*. The different mean values for pre- and post-trial were tested and the hypothesis testing using Duncan's Multiple Range Test (DMRT) was used to observe the effectiveness and comparison of each treatment for the *E. kamerunicus* population. The mean fruit set values for T1, T2 and T3 were further evaluated through DMRT at a 95% significance level.

TABLE 1. EXPERIMENTAL DESIGN

Treatment	Description	Replicates
T1	Hatch and carry box technique	4 (Consists of 4 palms with anthesising flower)
T2	Untreated	4 (Consists of 4 palms with anthesising flower)
T3	Assisted pollination	4 (Consists of 4 palms with anthesising flower)

Analysis of Oil Palm Fruit Set

The oil palm fruit set was assessed using the method from Susanto et al. (2007). This method was chosen because it provides a thorough process to assess the fruit set and understand its formation and distribution within the bunch. Fifteen spikelets were taken from each fruit bunch sample. Each bunch was segmented into three distinct sections: The base, the middle and the top, each representing one-third of the total. The number of developed fruits and the parthenocarpic fruits were determined from each spikelet. Fruit set value is calculated by dividing the number of developed fruits by the total number of fruitlets segment^{-1} and multiplying by 100 (Hartmann et al., 2011). The Equation (1) is widely used and a standard method in plant science and horticulture for evaluating the success of pollination and fruit development, as follows:

$$\text{Fruit set value} = \frac{\text{Number of developed fruits}}{\text{Number of developed fruits} + \text{Parthenocarpic fruits}} \times 100\% \quad (1)$$

Statistical analysis was carried out to assess variations in fruit set values across the treatments. The analysis spans three critical timeframes relative to the treatment application: Six months prior, during and six months post-application. It includes a comparative evaluation of oil palm production across treatments, with a clear distinction made between the pre-treatment period (2015–2016) and the post-treatment period (2017–2019).

Observation of Anthesising Male Flowers

The anthesising male flowers were divided and only considered into two groups based on the percentage of anthesis: 25%–50% and 75%–100% as shown in *Figure 3*.

(a) (b)

Figure 3. Percentage of anthesising males: (a) 75–100% and (b) 25–50%. This illustration courtesy by Muhammad Idrus Shukor from AARSB

Observation on *Elaeidobius kamerunicus* population

From each anthesising male flower sample, the total number of spikelets was determined by counting as described by Gurr et al. (2000). The male flowers were randomly selected for the counting of the *E. kamerunicus* for each spikelet present at the anthesis stage. Three spikelets were then selected from different positions of each flower: Three from the top, three from the middle and three from the bottom. The individual spikelets were then covered with transparent plastic (5 × 15 cm) to prevent *E. kamerunicus* from escaping. In the laboratory, the spikelet bases were cut, and the inactive *E. kamerunicus* were collected and counted. The average number of *E. kamerunicus* in those selected spikelets was assumed to be the average *E. kamerunicus* population per spikelet. This approach ensures a representative sample by distribution across the entire flower. The number of *E. kamerunicus* per inflorescence was then calculated by multiplying the average *E. kamerunicus* per spikelet by the total spikelets in each anthesising male sample [Equation (2)]. Then, the population of *E. kamerunicus* per ha was calculated from the total number of *E. kamerunicus* in the anthesising male samples of 48 palms, as in Equation (3):

$$\textit{Elaeidobius kamerunicus} \text{ per inflorescence} = \frac{\text{Number of individuals } \textit{E. kamerunicus} \text{ at spikelet}}{\text{Total number of samples (spikelet)}} \times 100\% \quad (2)$$

$$\textit{Elaeidobius kamerunicus} \text{ population per hectare} = \textit{E. kamerunicus} \text{ per inflorescence} \times \text{Total number of spikelets} \quad (3)$$

The observations were conducted from 09:00 to 11:00 am due to optimal conditions and aligning with the peak *E. kamerunicus* activity, thus ensuring more accurate counts (Susanto et al., 2007). The number of *E. kamerunicus* visiting the anthesising female inflorescences was counted pre- and post-application of the hatch and carry box technique using sticky traps and was marked between bunches of pre- and post-application (Susanto et al., 2007).

Hatch and Carry Box Technique

The hatch and carry box technique, developed by Susanto et al. (2007), involves constructing a durable box from weather-resistant materials, with internal compartments and ventilation to facilitate egg hatching. *Elaeidobius kamerunicus* eggs present in post-anthesis spikelets of the male inflorescences are collected from the plantation and placed in the box, which was then kept in a controlled environment to optimise hatching conditions. The hatch and carry box technique used in this study consisted of two steps. The first step involved the hatching in boxes of larvae and pupae of *E. kamerunicus* present on the male inflorescences. The second step was the release of *E. kamerunicus* into the treatment plot.

The release of *E. kamerunicus* was carried out after the current *E. kamerunicus* population has been assessed to ensure that the introduction of these techniques is effective. By doing so, the actions taken will be more precise in addressing the *E. kamerunicus* problem and enhancing the effectiveness of the management strategy. The second step involved releasing *E. kamerunicus* into the treatment field. Each hatch and carry box (measuring 60 x 60 x 120 cm) contained six inflorescences, each at 4–5 days post-anthesis. To accommodate the 9–12 day life cycle of the *E. kamerunicus*, the inflorescences were systematically replaced every 9-12 days. This practice ensured a continuous supply of fresh inflorescences, maintaining optimal conditions for *E. kamerunicus* development and enabling accurate population assessments. Before release, the *E. kamerunicus* were treated with 1.00 g of high-viability pure pollen. The high-viability pollen was obtained through viability tests, in which oil palm pollen was germinated in a liquid medium containing 8% sucrose and 15 mg of boric acid (H_3BO_3) (Lubis, 1993).

Pollens with a percentage of germination above 70%–80% are considered high viability pollen (Dafni & Firmage, 2000) and were used for the hatch and carry box technique. The pollen is considered germinated when the pollen tube has reached an equal length or more than the length of the pollen diameter. The T1 was installed in the trial plot of approximately 25 ha and required careful planning and execution. Regular maintenance and checks are necessary to ensure that the box remains functional and free of damage.

As the observation in pre-application, parameters used after the application of the hatch and carry box technique also covered fruit set analysis, the number of anthesising males ha^{-1}, *E. kamerunicus* population and monthly FFB yield ha^{-1}. The *E. kamerunicus* population was counted every two months starting from the beginning of the application (Prasetyo et al., 2014).

RESULTS AND DISCUSSION

Development of the *Elaeidobius kamerunicus* Population

Before implementing the T1 treatment, the presence of *E. kamerunicus* on male flowers seems limited, where the mean population was only 8 individuals spikelet^{-1} or 2,127 individuals ha^{-1} during anthesis. This suggests that the experimental area initially has a low population level. According to Lee and Mohd Ridzuan (2013), the population density of *E. kamerunicus* in oil palm plantations can significantly influence pollination, with densities of approximately 5,000 weevils ha^{-1} reported to be effective for optimal fruit set in Southeast Asia.

However, two months after the release, there was a rapid escalation in the *E. kamerunicus* population, with the mean population reaching 13,089 *E. kamerunicus* ha^{-1} in the treatment block, where the T1 application was employed, representing a six-fold increase. This increase was statistically significant, as confirmed by a paired sample t-test ($t = 4.36$, $df = 47$, $p<0.05$). *Figures 5a* and *5b* illustrate the substantial presence of *E. kamerunicus* on the inflorescences.

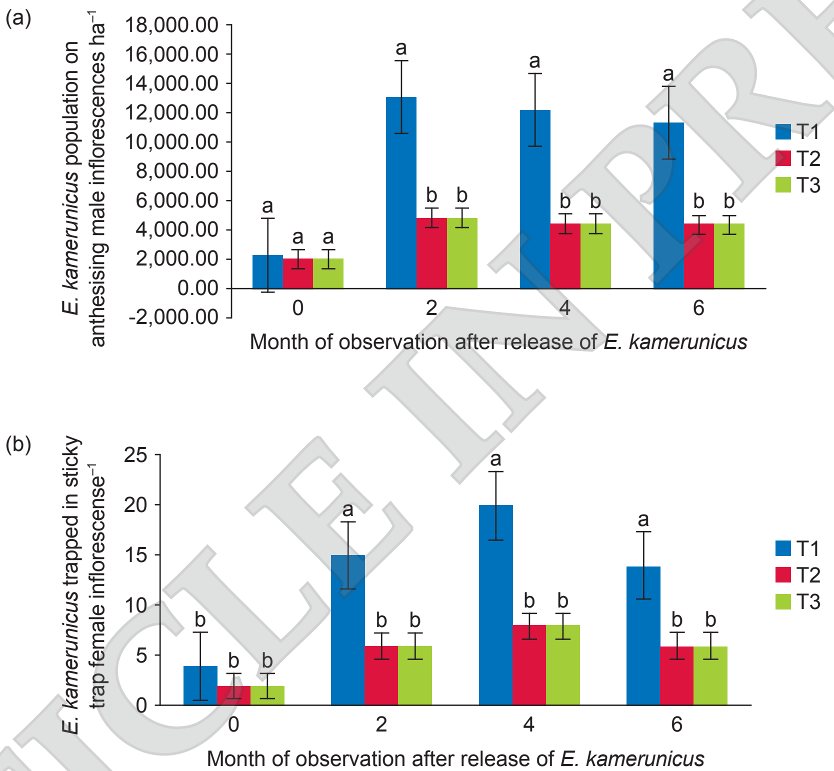
The continuous increase in the *E. kamerunicus* population in T1 compared to T2 and T3 suggests that the regular release of *E. kamerunicus* from the breeding box boosted their numbers. However, after four and six months, the population growth slowed down compared to the first two months. This could be due to limited breeding sites, as high concentrations of *E. kamerunicus* gather on male inflorescences post-anthesis, where the full life cycle of *E. kamerunicus*, from eggs to pupae, takes place (Hutauruk et al., 1982; Syed, 1981). A study by Smith and Brown (2022) found a significant positive correlation between the abundance of *E. kamerunicus* and the number of inflorescences in oil palm. This suggests that increased inflorescence production leads to a higher *E. kamerunicus* population, as more inflorescences provide more opportunities for pollination. A study by Lee and Chen (2021) found that a decrease in the population of *E. kamerunicus* is generally linked to a reduction in the number of inflorescences in oil palm. Fewer inflorescences could reduce pollination activity, leading to a lower *E. kamerunicus* population.

A similar trend was observed in the capture of *E. kamerunicus* on sticky traps placed on female inflorescences at anthesis. T1 had a significantly higher capture rate of approximately 13 weevils month^{-1} post-release, compared to T2 and T3, which captured only eight weevils month^{-1} (*Figure 5b*).

Oil Palm Fruit Set Development

Table 2 summarises the comparative analysis of mean fruit set values (%) and mean bunch weight (kg) across three treatment groups: T1, T2 and T3. The analysis covers three distinct periods: Six months before application, during application and six months post-application. The results indicated that there was no significant difference in mean fruit set values between six months before and during hatch and carry box technique in all treatments. However, after the six-month application period, there was a significant difference between the treatments. Statistical analysis using DMRT (p<0.05) confirmed that the differences observed after the application were significant, particularly T1 and T3 against T2, which was Untreated. T1 and T3's mean fruit set values increased significantly to 78.1% and 81.0%, while T2 was only 57.8% respectively. Similarly, bunch weight analysis revealed a significant difference between treatments after four months of application. T1 and T3 exhibited a mean bunch weight of 12.11 kg and 12.50 kg compared to 9.65 kg for T2.

Statistical analysis using DMRT (p<0.05) confirmed significant differences after the application period, particularly favouring treatments against untreated plots in several instances. These results demonstrate the effectiveness of the T1 in enhancing fruit set and bunch weight compared to other treatments. *Figure 6* illustrates the physical appearance of fruit set across different treatments, with a clearer comparison of fruit size pre- and post-treatment for T1.



Note: T1 - Hatch and carry box technique; T2 - Untreated and T3 - Assisted pollination. Means with the same letter in the figure for treatments are not significantly different at p<0.05.

Figure 5. Occurrence of Elaeidobius kamerunicus *on (a) male and (b) female flowers during anthesis.*

TABLE 2. THE MEAN FRUIT SET VALUES BETWEEN THE TREATMENT, CONTROL AND ASSISTED POLLINATION

Treatment Block	Mean fruit set values (%)			Mean bunch weight (kg), four months after the Hatch and carry application
	Six months before Hatch and carry application	During Hatch and carry application	Six months after Hatch and carry application	
T1	43.9a	55.3a	78.1a	12.11a
T2	43.2a	47.3a	57.8b	9.65ab
T3	44.2a	58.2a	81.0a	12.50a
Means	**43.5**	**50.0**	**70.0**	**11.34**

Note: T1 - Hatch and carry box technique; T2 - Untreated and T3 - Assisted pollination. The same letter in the same column does not show a significant difference by Duncan's Multiple Range Test at a 95% significance level.

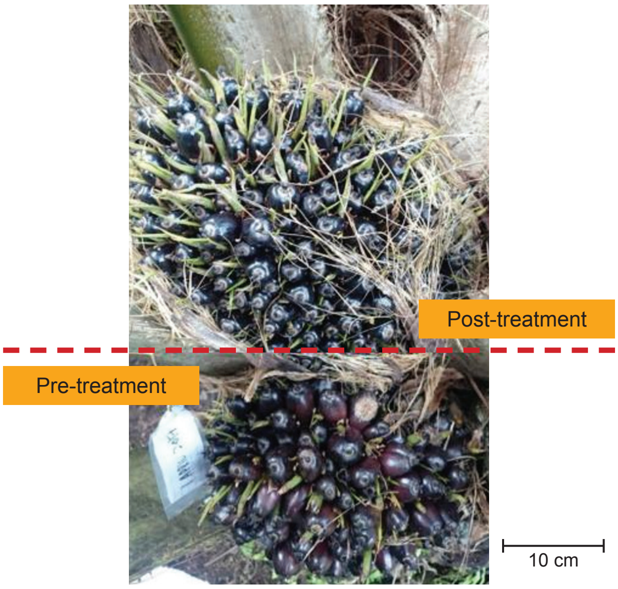


Figure 6. Differentiation of fruit set during pre- and post-treatment on palm.

Comparison of Oil Palm Production

Figure 7 presents a comparative analysis of annual FFB yield ha^{-1}, for three different treatments (T1, T2 and T3) over five years from 2015-2019. The data is divided into two distinct phases: The "pre-treatment" phase which was between 2015–2016 and the "post-treatment" phase which was between 2017–2019, enabling an assessment of the treatments' effectiveness over time. During the pre-treatment phase, analysis revealed no significant differences in yields across the treatment group. This lack of variation provided a consistent baseline for comparing the effects of the treatments.

However, in the post-treatment phase, significant differences emerged. Specifically, T1 consistently resulted in higher FFB yield compared to T2 and T3. Statistical analyses confirmed that these differences were significant (p<0.05) and T1 yielded significantly more than both T2 and T3. This consistent superior performance of T1 suggests it has a more effective impact of using the hatch and carry box technique on crop yields than the other treatments. The significantly higher yield observed in T1 compared to T2 and T3 suggests that the hatch and carry box technique enhances pollination efficiency and fruit set, leading to superior FFB yield outcomes. This improvement can be attributed to the controlled release of *E. kamerunicus*, ensuring a higher concentration of active pollinators at the critical pollination phase, unlike the Assisted method, which may rely on external conditions for optimal *E. kamerunicus* activity. Additionally, the hatch and carry box technique likely reduces *E. kamerunicus* mortality and improves retention near the target crop, maximising their role in pollination, whereas untreated conditions may result in lower *E. kamerunicus* density and the assisted method may not provide an optimal release environment. Moreover, the synchronisation of *E. kamerunicus* emergence with the plant's reproductive cycle ensures a higher fruit set percentage, reducing the risk of pollination gaps that may contribute to lower yields in T2 and T3. The structured introduction of *E. kamerunicus* in T1 also minimises dispersal inefficiencies, leading to higher *E. kamerunicus* retention within the crop area, unlike the assisted method, which may cause uncontrolled movement. These factors collectively demonstrate the superior effectiveness of the hatch and carry box technique in improving FFB yield compared to the other treatments. No significant difference in annual yield was detected between T2 and T3, likely due to the single pollen application conducted at the initial stage of the pollination setup. This intervention aimed to evaluate differences in fruit set development during the six-month application period across three approaches: Hatch and carry box introduction, assisted pollination and no intervention (untreated). The results indicate that yield improvement depends on a consistent and sustained pollination process facilitated by *E. kamerunicus*, initiated through the deployment of hatch-and-carry boxes. This suggests that enhancing oil palm yield requires regular and continuous pollination efforts rather than one-off applications.

Impact of Treatment on the *Elaeidobius kamerunicus* Population

The application of the hatch and carry box led to a significant increase in the *E. kamerunicus* population in male flowers at anthesis ha^{-1}, supported by a previous study by Johnson et al. (2019). This result indicates that the use of the hatch and carry box effectively enhanced the density of the *E. kamerunicus* population on male flowers during the flowering stage. It follows the previous study by Smith and Brown (2022), which demonstrated its effectiveness in improving the *E. kamerunicus* population. This increase suggests that the hatch and carry box technique positively influences pollination activities in oil palm flowers, potentially improving FFB yield.

However, the plateau in *E. kamerunicus* population growth in the trial plot as shown in *Figure 5a* is due to the limited availability of post-anthesis male inflorescences, which serve as essential breeding sites. As these inflorescences wither, *E. kamerunicus* face reduced reproductive opportunities, increased competition and restricted larval development, ultimately stabilising their population. Environmental factors and fluctuations

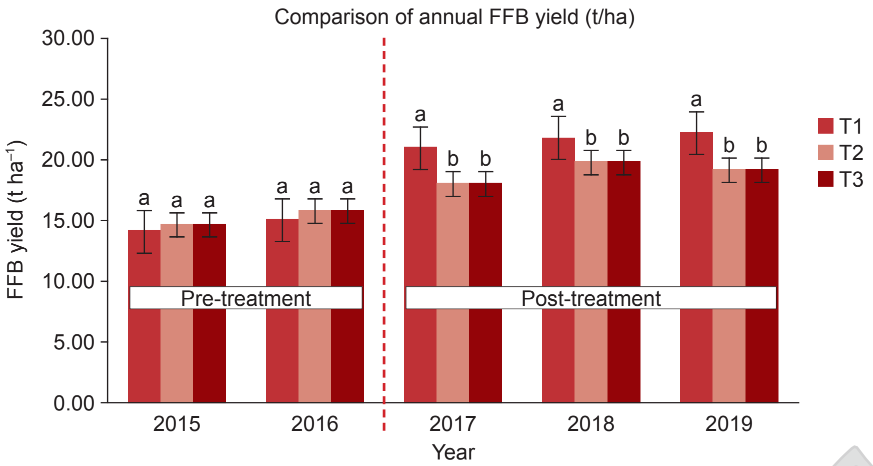


Figure 7. Comparison of pre- and post-treatment of yearly FFB yield (t ha^{-1}) between, Hatch and carry box technique (T1), Untreated 00 (T2) and Assisted pollination (T3). Means sharing the same letter in the figure for treatments are not significantly different at $p<0.05$.

in male inflorescence production further contribute to this limitation (Nguyen et al., 2017). Given that the *E. kamerunicus* life cycle progresses through distinct stages-from eggs to larvae and pupae-the presence of adequate host plants is essential for sustaining continuous population growth (Doe et al., 2018; Smith & Brown, 2022). Adhi et al. (2021) investigated the impact of different stages of male inflorescences on the population dynamics of *E. kamerunicus* in oil palm plantations. They found that post-anthesis stages resulted in high *E. kamerunicus* concentrations, which led to overcrowding and resource competition, ultimately limiting further population growth. Hermanto et al. (2023) studied the behavioural ecology of *E. kamerunicus* in oil palm plantations, focusing on how overcrowding at post-anthesis male inflorescences leads to intense competition for breeding sites and resources. Their study showed that this competition significantly restricts the potential for population expansion. Findings by Monzon et al. (2022) explored the effects of breeding site limitations on the population growth of *E. kamerunicus* in oil palm plantations. They concluded that when *E. kamerunicus* concentrated in certain inflorescence stages, resource competition becomes severe, preventing further population increase even in otherwise favourable conditions.

Interestingly, this study also found that the increase in the *E. kamerunicus* population is closely linked to enhanced pollination activity as shown in *Figure 5b*. This correlation is supported by the higher number of *E. kamerunicus* captured on sticky traps that were attached to anthesising female inflorescences within the treatment plot. The presence of more *E. kamerunicus* during the anthesis stage suggests that as the *E. kamerunicus* population grows, their pollination activity intensifies, leading to greater interaction with female inflorescences. This observation aligns with findings from Johnson et al. (2019), who demonstrated that a rise in *E. kamerunicus* populations directly contributes to more effective pollination in oil palm plantations, as evidenced by increased trap catches during peak flowering periods.

Prasetyo et al. (2014) discuss the balance between *E. kamerunicus* population management and maximising fruit set. They highlight that while *E. kamerunicus* is highly effective in pollination, its population can fluctuate due to various factors, such as environmental conditions, availability of breeding sites and competition for resources on male inflorescences. The study suggests that managing these factors, including the strategic release of *E. kamerunicus* during critical flowering periods, can significantly enhance pollination success.

Generally, the study highlights the importance of understanding the population fluctuations of key pollinators like *E. kamerunicus* and the potential interventions, such as the hatch and carry box technique, to enhance their populations for improved pollination outcomes.

Improvement in Fruit Set After the Treatment

The data indicate a notable increase in fruit set across treatments compared to the initial phase of the study. Particularly, T1, where *E. kamerunicus* populations were bolstered through the hatch and carry box technique, exhibited the most substantial increase. This suggests the efficacy of the hatch and carry box technique in promoting the proliferation of *E. kamerunicus*, subsequently enhancing pollination rates in oil palm plantations (Pinnamaneni & Potineni, 2022; Prasetyo et al., 2014). While T2, the untreated block, also demonstrated an increase in fruit set, it is hypothesised that this may be due to various factors. Notably, the rise could be attributed to the resurgence of *E. kamerunicus* populations in the block following an extensive treatment with cypermethrin insecticide for *T. rufivena* infestation.

Furthermore, the fruit set analysis at T1 indicated no statistically significant difference between the oil palm fruit sets with T3, assisted-pollinated bunches and those subjected to natural pollination (T2). However, a notable disparity was observed in T2, where the untreated block exhibited a significantly lower fruit set compared to the other treatments. This underscores the importance of effective pollination, whether through assisted means or natural mechanisms, in optimising fruit sets and ultimately improving FFB yield in oil palm plantations (Cik Mohd Rizuan et al., 2013).

A visual examination of the fruit set's physical appearance across different treatments provides valuable insights into the impact of *E. kamerunicus* population increases on FFB yield. Observations of fruit size pre- and post-treatment (*Figure 6*), particularly in T1, emphasise the significant benefits of enhanced pollination on fruit development and maturation. Moreover, the study demonstrates a direct correlation between increased oil palm fruit set and corresponding FFB yield improvements. In summary, T1 and T3 demonstrated a significantly higher average bunch weight compared to T2. This suggests that T3, assisted pollination remains a viable method for enhancing FFB yield, the hatch and carry box technique involving *E. kamerunicus* shows greater promise in achieving substantial yield improvements (Pinnamaneni & Potineni, 2022). Furthermore, assisted pollination is effective in improving fruit set, but its application can be limited by high costs and practical difficulties on a large scale (Wu et al., 2020). It is also supported by Smith and Brown (2022) where assisted pollination techniques can increase fruit sets, however their widespread use is constrained by the associated high costs and practical challenges in large-scale applications.

Furthermore, the findings underscore the pivotal role of *E. kamerunicus* in oil palm pollination and yield enhancement. The hatch and carry box technique present a promising strategy for augmenting *E. kamerunicus* populations, consequently improving fruit set and yield in oil palm plantations.

Increase in FFB Yield After Application of The Hatch and Carry Box Technique

The analysis of FFB yield in relation to the hatch and carry box technique reveals significant insights into the effectiveness of this technique in enhancing FFB yield. Post-treatment analysis revealed a statistically significant increase and revealed positive responses to hatch and carry box techniques in contrast to the untreated. The study demonstrates a significant increase in FFB yield following the application of the hatch and carry box technique. This improvement highlights a positive correlation between fruit set and FFB yield, consistent with a previous study, as reported by Popet et al. (2022). The hatch and carry box technique efficiency in harvesting appears to enhance fruit set, thereby increasing overall FFB yield (Prasetyo et al., 2014). This correlation underscores the potential for such innovative tools to optimise FFB yield in oil palm plantations and supports further adoption and research into similar agricultural technologies.

The use of the hatch and carry box technique has been associated with an increase in FFB yield in oil palm plantations. However, the extent of this increase has been moderated by environmental factors such as soil quality and climatic conditions. According to a study by Hidayat et al. (2021), environmental factors can significantly impact the performance of agricultural technologies including harvesting tools like the Hatch and Carry Box Technique. Their study highlights that while such tools can improve FFB yield, their effectiveness is often influenced by local environmental conditions, necessitating adjustments to maximise their benefits.

In general, the findings suggest that the hatch and carry box technique has a significant positive impact on FFB yield, primarily driven by improvements in average bunch weight (ABW). Despite these gains, the increase has been moderated by environmental factors such as soil quality and climate variability. Research by Lim et al. (2020) highlights how environmental conditions can impact the effectiveness of agricultural technologies, including harvesting tools. Additionally, ongoing monitoring and management are crucial to sustain yield improvements over the long term.

Altieri et al. (2015) emphasise that addressing challenges such as declining bunch numbers and environmental variability is essential for maintaining yield gains. This underscores the need for continuous adaptation of practices and technologies to evolving environmental conditions. Future research efforts should focus on refining techniques for enhancing pollination efficiency and optimising yield performance in oil palm cultivation.

CONCLUSION

Overall, the technique effectively enhances FFB yield by optimising the pollinator population. The utilisation of the hatch and carry box technique appears to be the most effective tool in bolstering the *E. kamerunicus* population, improving fruit sets and increasing FFB yield ha^{-1}. These findings hold potential significance for forthcoming studies, particularly in relation to correlating them with the fruit-to-bunch ratio factor to evaluate the performance of both *E. kamerunicus* and the plantation itself. Two months following the implementation of the hatch and carry box technique, the population of *E. kamerunicus* surged from 2,127–13,089 ha^{-1}. With such a density, *E. kamerunicus* could fulfil a more substantial role as pollinators, resulting in more frequent visits to the female inflorescences during anthesis. Moreover, boasting over 60% pollen viability, the augmented population of *E. kamerunicus* through the hatch and carry box technique contributed to enhancing fruit set from 50%–70% for oil palm within a radius of 25 ha^{-1} for each box.

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