Application of Hatch and Carry Generation 3.0 to Increase Fruit Set and Fruit-to-Bunch Ratio of Oil Palm (*Elaeis guineensis* Jacq.) at Rambutan Estate

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Abstract

Oil palm productivity is strongly influenced by pollination success, particularly under conditions of low male flower availability, which can limit pollen supply and pollinating insect populations. PT Perkebunan Nusantara IV Regional 1 Kebun Rambutan developed the Hatch and Carry Generasi 3.0 technique as an assisted-pollination technology to increase the population and distribution of the pollinating weevil Elaeidobius kamerunicus in Socfindo oil palm areas with a low male flower ratio. This study evaluated its effectiveness in increasing E. kamerunicus population, fruit set, fruit to bunch, and production components. The study was conducted in 14 mature oil palm blocks, comprising seven Hatch and Carry (HC) and seven non-Hatch and Carry (NHC) blocks, with the block as the experimental unit. Observed parameters included E. kamerunicus population, fruit set, fruit to bunch, bunch weight, bunch number, and production. Results showed that Hatch and Carry Generasi 3.0 increased the average E. kamerunicus population from 113,957 to 182,486 individuals (60.14%). Fruit set increased from 66.36% to 74.86% (12.88%), while fruit to bunch increased from 56.77% to 61.39% (8.14%). Bunch weight, bunch number, and production increased by 13.95%, 11.16%, and 27.02%, respectively. Statistical analysis showed significant differences between HC and NHC for all parameters. The correlation between E. kamerunicus population and fruit set was very strong (rs = 0.975). Therefore, Hatch and Carry Generasi 3.0 was effective in improving pollinator population, pollination success, and oil palm production components.

Keywords: *Elaeidobius kamerunicus, fruit set, fruit to bunch, hatch and carry, oil palm.*

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is one of the world's most important plantation crops and a major component of the global vegetable-oil economy. Indonesia is the world's leading producer of crude palm oil (CPO), with national CPO production reaching approximately 45.44 million tonnes in 2024, while more than three million households depend on the oil palm sector for their livelihoods (Direktorat Jenderal Perkebunan, 2026). Globally, oil palm supplies a substantial proportion of traded vegetable oil while producing more oil per unit of land than competing oilseed crops, making productivity improvement on existing plantations an important component of sustainable intensification (Murphy et al., 2021; Qaim et al., 2020). However, substantial yield gaps remain between actual and attainable production in commercial plantations and smallholder systems in Indonesia (Hoffmann et al., 2017; Monzon et al., 2023). These gaps are influenced by agronomic management, planting material, palm age, soil and climatic conditions, and biological processes affecting bunch formation. Therefore, improving plantation productivity while minimizing further land expansion remains an important objective for sustainable oil palm production (Abas et al., 2022; Darkwah & Ong-Abdullah, 2021). In addition to fertilization, harvesting, weed management, and pruning, reproductive processes, particularly pollination, play an important role in fruit formation and bunch development (Susanto et al., 2020; Yousefi et al., 2020).

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Successful pollination is essential for maximizing oil palm productivity because viable pollen transfer to receptive female inflorescences determines fertilization and fruit formation. *Elaeidobius kamerunicus* Faust is the principal insect pollinator of oil palm in Southeast Asia and is closely associated with male inflorescences, which provide food, pollen, and breeding sites (Tuo et al., 2011; Yue et al., 2015; Gintoron et al., 2023). Adult weevils subsequently visit anthesizing female inflorescences and transfer pollen between flowers. Studies in Indonesia and other oil palm-growing regions have demonstrated that *E. kamerunicus* abundance and activity are closely associated with pollination efficiency and fruit set (Siregar et al., 2010; Hulu et al., 2019; Lubis et al., 2017). Prasetyo and Susanto (2016) reported that introducing *E. kamerunicus* into an area with initially very low fruit set increased fruit set from approximately 11.27% to 75.56% within two months. More recent research has also demonstrated that *E. kamerunicus* population density and sex ratio are important factors associated with fruit set (Prasetyo et al., 2026).

Pollination effectiveness, however, is influenced by multiple biological, environmental, and management factors, including pollen availability and quality, male inflorescence abundance and distribution, palm age, planting material, weather, and surrounding landscape (Yousefi et al., 2020; Gintoron et al., 2023). Rainfall, temperature, humidity, and light conditions can affect weevil activity and visitation, while soil and plantation conditions may also influence pollinator populations and fruit set (Lubis et al., 2017; Gintoron et al., 2023). Landscape context may further affect pollination services. Field experiments in Sumatra showed that excluding floral visitors substantially reduced oil palm fruit set, while surrounding natural habitat influenced insect-mediated pollination (Li et al., 2022). A systematic review similarly concluded that oil palm pollination is controlled by interacting biotic, climatic, and management factors and that improving pollination services is an important opportunity for sustainable intensification (Li et al., 2019). Thus, maintaining adequate abundance and distribution of pollinating insects is an important component of biological management.

One strategy developed to address limitations in the abundance and distribution of *Elaeidobius kamerunicus* is the Hatch and Carry (H&C) technique. This biological pollination strategy involves collecting post-anthesis male inflorescences containing *E. kamerunicus* larvae and pupae and placing them in specially designed hatching containers to allow adult weevils to emerge. Post-anthesis inflorescences are selected because the florets have completed flowering, while the inflorescences may still contain developing immature stages of the pollinating weevil. Consequently, the purpose of using these inflorescences is not to obtain pollen from the male flowers, but to provide a source of *E. kamerunicus* for population augmentation. This is particularly relevant because male and female oil palm inflorescences differ in their flowering duration: male anthesis generally lasts approximately 6–7 days, whereas female anthesis lasts approximately 4–5 days. However, flowering duration should not be interpreted as equivalent to the precise period of female flower receptivity. Previous research has demonstrated that H&C can increase *E. kamerunicus* abundance and visitation to anthesising female inflorescences, thereby improving fruit set (Prasetyo et al., 2014).

The insects develop until adult emergence and are then released into targeted plantation areas to increase local pollinator populations and facilitate natural pollination (Prasetyo & Susanto, 2012). Prasetyo et al. (2014) demonstrated that Hatch and Carry increased *E. kamerunicus* population from 2,571 to 51,908 individuals per hectare and increased visitation to anthesizing female inflorescences from 32 to 604 weevils per bunch. Consequently, fruit set increased by 15.04–21.05% at distances of up to 200 m from Hatch and Carry boxes. Similar relationships between *E. kamerunicus* population density and fruit set have been reported under different plantation conditions (Lubis et al., 2017; Hulu et al., 2019).

The Hatch and Carry Generation 3.0 technique applied in this study represents a field application and refinement of the Hatch and Carry concept, primarily aimed at increasing the abundance and distribution of *E. kamerunicus* in plantation blocks where pollinator availability is inadequate. Its biological mechanism remains based on the development of immature *E. kamerunicus* from post-anthesis male inflorescences, followed by adult emergence and natural dispersal to receptive female inflorescences. Increased pollinator availability is therefore expected to enhance pollen transfer, fruit formation, and bunch development, consistent with previous findings linking *E. kamerunicus* abundance with pollination efficiency, fruit set, and fruit-to-bunch ratio (Susanto et al., 2020; Gintoron et al., 2023). However, production must also be interpreted within the broader reproductive and agronomic system because bunch development and yield are affected by nutrition, palm age, harvesting practices, environmental conditions, and other management factors (Hoffmann et al., 2017; Monzon et al., 2023).

Despite the implementation of Hatch and Carry technology in commercial plantations, scientific evidence regarding the effectiveness of Hatch and Carry Generation 3.0 under commercial field conditions remains limited. Previous studies have focused primarily on the biology, population dynamics, pollination

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activity, and ecological factors affecting *E. kamerunicus* (Siregar et al., 2010; Tuo et al., 2011; Yue et al., 2015; Li et al., 2019; Yousefi et al., 2020; Gintoron et al., 2023), while others evaluated conventional Hatch and Carry and its effects on pollinator abundance and fruit set (Prasetyo & Susanto, 2012; Prasetyo et al., 2014; Prasetyo & Susanto, 2016). Quantitative field evaluations simultaneously assessing *E. kamerunicus* population, fruit set, fruit-to-bunch ratio, bunch weight, bunch number, and fresh fruit bunch productivity following Hatch and Carry Gen 3.0 remain scarce. This gap is particularly relevant because improving management within existing plantation areas is increasingly important for sustainable productivity (Murphy et al., 2021; Monzon et al., 2023).

Therefore, this study evaluated the effectiveness of Hatch and Carry Generation 3.0 in increasing *Elaeidobius kamerunicus* population, improving *fruit set* and *fruit-to-bunch* ratio, and enhancing fresh fruit bunch productivity in mature oil palm plantations at PT Perkebunan Nusantara IV Regional I Rambutan Estate. The study also evaluated relationships among pollinator population, reproductive parameters, yield components, and production to provide comprehensive evidence of the biological response to the technology. The findings are expected to support biological pollination management and sustainable intensification of oil palm production without relying solely on cultivated-area expansion.

MATERIALS AND METHODS

Study Site and Experimental Period

The study was conducted at PTPN IV Regional I Rambutan Estate, Serdang Bedagai Regency, North Sumatra, Indonesia. The experimental area consisted of mature oil palm plantations with relatively uniform agronomic characteristics and planting years (2015, 2017, and 2018). The selected plantations were in the productive phase (mature palms), representing commercial production conditions suitable for evaluating the effectiveness of the Hatch and Carry Generation 3.0 technology. The study was conducted from January 2025 to April 2026.

Experimental Design

This field study was conducted in 14 oil palm plantation blocks distributed across four estate divisions (Divisions 02, 03, 04, and 05). The experimental unit was the plantation block, with seven blocks receiving the Hatch and Carry Generation 3.0 treatment (HC) and seven blocks serving as untreated controls (NHC). Each block represented one experimental unit and covered a uniform observation area of 10 ha, resulting in 14 experimental units and a total observation area of 140 ha. The blocks were selected based on comparability in planting year, agronomic conditions, and field management to reduce potential environmental variation between treatment groups. Treatment allocation was based on the field implementation of the H&C Gen 3.0 technique and the availability of comparable plantation blocks; therefore, the study should be interpreted as a comparative field study rather than a randomized experiment unless random allocation of treatments was performed. Data were collected within each 10-ha observation area to assess pollinator abundance, fruit set, fruit-to-bunch ratio, bunch weight, bunch number, and production. The plantation block, rather than each individual palm or bunch, was considered the experimental unit for treatment comparisons.

Hatch and Carry Generation 3.0 Technique

The Hatch and Carry Generation 3.0 technique was implemented by transferring post-anthesis male inflorescences containing eggs, larvae, and pupae of *Elaeidobius kamerunicus* from donor blocks to recipient blocks with relatively low pollinator populations. The transferred male inflorescences were evenly distributed throughout the treatment blocks according to the estate operational standard. Adult weevils emerging from the transferred inflorescences dispersed naturally and pollinated receptive female flowers during the flowering period.

Observed Variables

The variables observed in this study included fruit set (%), calculated as the percentage of fertile fruits relative to the total number of fruits per bunch; fruit-to-bunch ratio (FTB, %), determined as the percentage of fruit weight relative to the total fresh fruit bunch weight; average bunch weight (kg), measured using a calibrated digital scale with an accuracy of 0.1 kg; the number of harvested bunches, recorded from each observation block during the harvesting period; and the population of Elaeidobius

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kamerunicus, determined by counting adult weevils on male inflorescences at anthesis during peak activity between 08:00 and 11:00 a.m. and expressed as the number of weevils per spikelet.

Data Collection

Field observations were conducted at PTPN IV Regional 1, Kebun Rambutan, from January 2025 to April 2026. The study covered 14 plantation blocks, comprising seven blocks under the Hatch and Carry Generation 3.0 treatment (HC) and seven untreated control blocks (NHC), with an observation area of 10 ha per block. The sampled palms represented three planting-age groups: 8, 9, and 11 years. A total of 1,430 palms per block was reported for the observation area; however, whether this number represents the total stand population or the number of sampled palms requires confirmation. Fruit set, fruit-to-bunch ratio, bunch weight, and bunch number were assessed monthly, whereas *Elaeidobius kamerunicus* population observations were conducted every six months. For pollinator population assessment, three spikelets were sampled from each observed male inflorescence. The reported sampling procedure also included 10 bunches or inflorescences per sampling unit; the precise sampling level (per palm or per block) requires confirmation. Fruit set was determined from harvested bunch samples, while fruit-to-bunch ratio was assessed using the estate's standard bunch-analysis procedure. Bunch number, bunch weight, and production data were obtained from routine harvesting records and verified through field observations. The plantation block was considered the experimental unit, while individual palms, inflorescences, spikelets, and bunches served as sampling units, as applicable to each measured variable.

Statistical Analysis

The experimental block was considered the experimental unit, and the mean value of each block was used for statistical analysis. Data were first subjected to tests of normality and homogeneity of variance. Differences between Hatch and Carry and untreated blocks were evaluated using a paired t-test at a significance level of 5% ($P < 0.05$). Spearman correlation analysis was performed to determine the relationships among pollinator population, fruit set, fruit-to-bunch ratio, bunch weight, and fresh fruit bunch production. Linear regression analysis was subsequently applied to evaluate the contribution of pollinator population and fruit set to yield improvement. All statistical analyses were performed using IBM SPSS Statistics software.

RESULTS AND DISCUSSION

Table 1. Data Observation Results of Research Parameters under the Hatch and Carry (HC) Non-Hatch and Carry (NHC).

Treatment	Planting Year	Block	Wide (Ha)	Parameter				
				Fruit set (%)	Fruit to bunch (%)	Bunch Weight (Kg)	Number of Bunches (Tross)	Number Of Beetles (Individuals)
HC01	2017	308	10	73.89	59.97	8.81	238	167,686
HC02	2018	193	10	74.94	61.14	9.08	262	187,327
HC03	2018	203	10	75.22	61.65	7.69	241	187,020
HC04	2015	114	10	75.40	61.65	7.69	210	190,673
HC05	2015	121	10	76.71	62.26	9,66	212	207,526
HC06	2017	172C	10	74.55	61.77	8.80	265	174,527
HC07	2017	173	10	73.33	61.27	8.79	246	162,643
	Average			74.86	61.39	8.64	239	182,485
NHC01	2017	298	10	65.20	55.75	6.81	230	96,592
NHC02	2018	213	10	65.29	57.74	6.99	246	109,334
NHC03	2015	111	10	67.13	55.98	7.90	210	128,340
NHC04	2015	112	10	66.46	56.41	7.38	210	111,196
NHC05	2015	113A	10	66.25	57.27	8.32	152	111,547
NHC06	2015	124	10	66.92	57.23	8.82	210	125,369
NHC07	2017	174	10	67.29	57.05	7.95	248	115,324
	Average			66.36	56.77	7.74	215	113,957

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Based on observations from seven *Hatch and Carry* (HC) treatment samples and seven samples without *Hatch and Carry* (NHC), substantial differences were observed in the reproductive and production parameters of oil palm. The *Hatch and Carry* treatment resulted in *fruit set* values ranging from 73.33–76.71%, whereas the NHC treatment ranged from 65.20–67.29%. Overall, all blocks receiving the *Hatch and Carry* treatment exhibited higher *fruit set* values than the control blocks (NHC). This finding indicates that the introduction and distribution of pollinating beetles through the *Hatch and Carry* technique can improve pollination effectiveness and subsequently increase fruit set. This result is consistent with Prasetyo et al. (2014), who reported that the application of *Hatch and Carry* increased the population of *Elaeidobius kamerunicus* and its visitation frequency to anthesizing female inflorescences, resulting in a 15.04–21.05% increase in fruit set within a radius of 200 m from the *Hatch and Carry* boxes. The effectiveness of *E. kamerunicus* as the principal pollinator is also strongly associated with successful pollen transfer between male and female inflorescences, which determines the subsequent development of fertilized fruits (Yousefi et al., 2020; Gintoron et al., 2023).

The increase in *fruit set* was consistent with the higher population of *Elaeidobius kamerunicus* (EK) pollinating beetles observed under the *Hatch and Carry* treatment. The observed beetle population in the HC treatment ranged from 162,643 to 207,526 individuals, whereas the NHC treatment had a considerably lower population, ranging from 96,592 to 128,340 individuals. This substantial difference indicates that the *Hatch and Carry* technique was effective in increasing the availability of pollinating beetles within the observed plantation blocks. The higher abundance of *E. kamerunicus* provides greater opportunities for beetles to visit anthesizing inflorescences and transfer pollen to receptive female flowers. Pollination effectiveness is influenced by the abundance, mobility, and activity of *E. kamerunicus*, as well as by environmental conditions, planting material, inflorescence sex ratio, and the availability of male inflorescences (Yousefi et al., 2020; Gintoron et al., 2023). Prasetyo et al. (2014) similarly demonstrated that *Hatch and Carry* increased the population of *E. kamerunicus* from 2,571 to 51,908 individuals ha^{-1} and increased beetle visitation to female inflorescences from 32 to 604 individuals per bunch, which was followed by an increase in fruit set. More recent research in Indonesia also confirms that *E. kamerunicus* population density and sex composition are important factors affecting oil palm fruit set (Prasetyo et al., 2026).

The *Fruit to Bunch* (FTB) values showed a similar trend. Under the *Hatch and Carry* treatment, FTB values ranged from 59.97–62.26%, whereas the NHC treatment produced values ranging from only 55.75–57.74%. The higher FTB values observed under the HC treatment indicate that improved pollination was associated not only with a greater proportion of successfully developed fruits but also with a higher proportion of fruit mass relative to total bunch weight. This finding is consistent with earlier research by Chairani and Taniputra (1985), which demonstrated that the presence of *E. kamerunicus* increased fruit set, fruit-to-bunch ratio, and mean bunch weight in oil palm. The relationship between pollination and bunch composition is also supported by Harun and Md Noor (2002), who found that increasing fruit set was accompanied by an increase in bunch weight, reflecting the contribution of successful fertilization to bunch development. Therefore, the higher FTB values observed in the HC blocks may be interpreted as an indication of improved reproductive development resulting from more effective pollination.

In addition, the *Hatch and Carry* treatment had a positive effect on bunch weight. The average bunch weight under the HC treatment ranged from 7.69–9.66 kg, while that under the NHC treatment ranged from 6.81–8.82 kg. The highest bunch weight was recorded in the *Hatch and Carry* 05 (HC05) treatment, reaching 9.66 kg, which also had the highest pollinating beetle population at 207,526 individuals. This pattern suggests that improved pollination may contribute to greater bunch biomass accumulation. Harun and Md Noor (2002) demonstrated that bunch weight increased with increasing fruit set, with the highest bunch weight observed at approximately 90% fruit set. Similarly, Chairani and Taniputra (1985) reported increases in mean bunch weight and fruit-to-bunch ratio following the introduction of *E. kamerunicus*. More recently, Hartono et al. (2026) reported that *Hatch and Carry* distance affected both fruit set and bunch weight, with the highest values observed within an effective distribution range of approximately 200–300 m. These findings support the biological interpretation that effective pollination increases the number of fertilized flowers and subsequently contributes to bunch development and biomass accumulation.

The relatively high values observed in HC05 further provide an indication of the association between pollinator abundance and reproductive performance. However, the higher bunch weight in HC05 should not be interpreted solely as a direct consequence of beetle population, because bunch weight can also be influenced by palm age, genetic material, nutrient availability, environmental conditions, bunch development stage, and other agronomic factors. Nevertheless, the consistent pattern of higher *fruit set*,

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FTB, and bunch weight in the HC treatment, together with the substantially higher *E. kamerunicus* population, strengthens the biological explanation that improved pollinator availability contributed to better pollination performance. This interpretation is supported by the established role of *E. kamerunicus* as a major pollinator of oil palm and by evidence that pollinator abundance and pollination effectiveness are important determinants of fruit formation and bunch development (Yousefi et al., 2020; Gintoron et al., 2023; Prasetyo et al., 2026).

Tabel 2. Results of the Normality Test (Kolmogorov–Smirnov Test) for the Hatch and Carry (HC) and Non-Hatch and Carry (NHC) Treatments (140 Samples)

Variable	Statistic	df	Sig.	Interpretation
Fruit Set (%)	0.069	140	.200*	Normal
Fruit to Bunch (%)	0.047	140	.200*	Normal
Bunch Weight (kg)	0.074	140	0.057*	Normal
Number of Bunches (Bunches)	0.083	140	0.020	Not Normal
Number of Beetles (Individuals)	0.080	140	0.028	Not Normal
Production (Kg)	0.060	140	.200*	Normal
Square Root Transformation of Number of Beetles	0.084	140	0.018	Not Normal
Square Root Transformation of Number of Bunches	0.078	140	0.036	Not Normal
Inverse Transformation of Number of Bunches	0.112	140	0.000	Not Normal
Inverse Transformation of Number of Beetles	0.139	140	0.000	Not Normal
Log10 Transformation of Number of Bunches	0.096	140	0.003	Not Normal
Log10 Transformation of Number of Beetles	0.078	140	0.037	Not Normal

Test Criteria:
If Sig. > 0.05, the data are normally distributed.
If Sig. ≤ 0.05, the data are not normally distributed.

The Kolmogorov–Smirnov normality test showed that *fruit set*, *fruit to bunch*, bunch weight, and production had significance values greater than 0.05, indicating no statistically significant evidence of deviation from a normal distribution. In contrast, the number of bunches and *Elaeidobius kamerunicus* population showed significance values below 0.05. Data transformation using square root (√x), base-10 logarithm (log10), and inverse (1/x) methods did not improve the normality of these variables. The non-normal distribution of *E. kamerunicus* population may reflect substantial biological variation among plantation blocks and sampling periods, as its abundance and activity are influenced by the availability and flowering condition of male inflorescences, environmental conditions, and other ecological factors (Yousefi et al., 2020; Gintoron et al., 2023). Similarly, variation in the number of harvested bunches may be associated with differences in palm age, genetic characteristics, flowering intensity, physiological condition, nutrient availability, and environmental conditions during reproductive development. Recent research also confirms that *E. kamerunicus* population density and sex ratio are important factors associated with oil palm fruit set (Prasetyo et al., 2026).

Based on the normality assessment and experimental design, parametric and non-parametric statistical methods were selected accordingly. *Fruit set*, *fruit to bunch*, bunch weight, and production were analyzed using the paired *t*-test because they met the normality criterion applied in this study. The paired *t*-test is appropriate for comparing two related observations by testing whether the mean difference between paired observations differs significantly from zero; therefore, the normality assumption should principally be assessed for the distribution of the paired differences. Meanwhile, the number of bunches and *E. kamerunicus* population were analyzed using non-parametric methods because their distributions remained non-normal after transformation. This approach provides a more appropriate basis for statistical inference when the assumptions of parametric analysis are not adequately satisfied.

Tabel 3. Comparison of the Mean Values of the Research Parameters Based on the Paired t-Test between HC and NHC Treatments

Parameter	Mean Difference	t-value	df	Sig. (2-tailed)	Interpretation
Fruit Set (%)	8.544	13.512	69	<0.001	Significant difference

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Fruit to Bunch (%)	4.615	13.261	69	<0.001	Significant difference
Bunch Weight (kg)	1.081	8.087	69	<0.001	Significant difference
Production (kg)	44.83	8.789	69	<0.001	Significant difference

Note: A significance value of $p < 0.05$ indicates that there is a significant difference between the Hatch and Carry Gen 3.0 treatment and the Non-Hatch and Carry treatment.

The experimental unit in this study was the plantation block, comprising seven HC blocks and seven NHC blocks. The reported degrees of freedom (df = 69) require verification because they may reflect a different level of observation than the block-level experimental units. Therefore, the original dataset and statistical analysis must be reviewed to confirm the number of independent observations and ensure that the statistical test and degrees of freedom are appropriate for the experimental design.

Based on the results of the *Paired t-test* presented in Table 3, the application of the *Hatch and Carry* Gen 3.0 technique had a significant effect on all parameters that met the normality assumption, namely *fruit set*, *fruit to bunch*, bunch weight, and production. All parameters showed significance values (Sig. 2-tailed) of <0.001, which were lower than the 5% significance level ($\alpha = 0.05$). Therefore, the null hypothesis (H_0), which states that there is no difference between the *Hatch and Carry* Gen 3.0 and *Non-Hatch and Carry* treatments, was rejected, while the alternative hypothesis (H_1) was accepted. These results indicate that the application of *Hatch and Carry* Gen 3.0 significantly improved reproductive and production performance. This finding is consistent with Prasetyo et al. (2014), who reported that the *Hatch and Carry* technique increased the population and visitation activity of *Elaeidobius kamerunicus* and subsequently increased oil palm fruit set by 15.04–21.05%. The important role of *E. kamerunicus* in successful oil palm pollination has also been confirmed by Susanto et al. (2020) and Gintoron et al. (2023), who emphasized that adequate pollinator populations and effective pollen transfer are important factors determining fruit set and subsequent bunch development.

The *fruit set* parameter showed a mean difference of 8.544% with a calculated *t*-value of 13.512, representing the highest *t*-value among all parameters. This result indicates a strong and consistent difference in *fruit set* between the HC and NHC treatments. The higher *fruit set* in the HC treatment can be biologically associated with improved pollination resulting from increased availability and activity of *E. kamerunicus*. Prasetyo et al. (2014) demonstrated that the *Hatch and Carry* technique increased *E. kamerunicus* visitation to anthesizing female inflorescences from 32 to 604 weevils per bunch and was followed by a substantial increase in fruit set. Similarly, Hulu et al. (2019) reported that increasing the population of *E. kamerunicus* resulted in higher oil palm fruit set, supporting the importance of pollinator abundance in successful fertilization. The *fruit to bunch* parameter also showed a significant increase, with a mean difference of 4.615% and a calculated *t*-value of 13.261. The increase in *fruit to bunch* indicates that improved pollination not only increased the proportion of flowers developing into fruits but also contributed to a greater proportion of fruit within the harvested bunch. Susanto et al. (2020) reported that *fruit set* and *fruit to bunch* are closely related to pollination conditions, including the availability of viable pollen and adequate populations of *E. kamerunicus*. Therefore, the higher *fruit set* and *fruit to bunch* observed following the application of *Hatch and Carry* Gen 3.0 provide evidence that improved pollinator availability can enhance reproductive performance of oil palm.

Tabel 4. Wilcoxon Signed-Rank Test Results for Parameters That Were Not Normally Distributed

Parameter	Z-value	Asymp. Sig. (2-tailed)	Interpretation
Number of Bunches (Bunches)	-3.876	<0.001	Significant difference
Number of Elaeidobius kamerunicus Beetles (Individuals)	-6.083	<0.001	Significant difference

Note: Significance level (α) = 5%. A significance value of $p < 0.05$ indicates that there is a significant difference between the Hatch and Carry Gen 3.0 treatment and the Non-Hatch and Carry treatment.

Based on the Wilcoxon Signed-Rank Test presented in Table 4, bunch number and *Elaeidobius kamerunicus* population differed significantly between the Hatch and Carry (HC) Gen 3.0 and Non-Hatch and Carry (NHC) treatments (Asymp. Sig. 2-tailed, $p < 0.001$). The test requires paired observations, with

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each HC observation matched to a corresponding NHC observation based on a predefined pairing criterion, such as comparable plantation block characteristics or sampling periods. The paired differences are then ranked to assess whether the median difference between treatments differs significantly from zero. However, the specific HC–NHC pairing procedure and the number of valid pairs must be clarified based on the actual study design and dataset. If valid pairs were established, the results support rejecting the null hypothesis of no systematic difference between treatments. The Wilcoxon Signed-Rank Test is appropriate for paired data when the assumptions required for a parametric paired t-test are not satisfied, particularly when the distribution of paired differences is not approximately normal (Ghasemi & Zahediasl, 2012; Mishra et al., 2019).

The test statistic (Z) for the number of bunches was −3.876, whereas the test statistic for the *E. kamerunicus* population was −6.083. The larger absolute Z-value for *E. kamerunicus* population indicates a stronger and more consistent statistical difference between the paired HC and NHC observations than that observed for bunch number. The highly significant difference in *E. kamerunicus* population is biologically consistent with the objective of the *Hatch and Carry* technique, which is to increase the availability and distribution of pollinating weevils within plantation blocks. Prasetyo et al. (2014) demonstrated that *Hatch and Carry* substantially increased *E. kamerunicus* population and visitation to female inflorescences, while Gintoron et al. (2023) emphasized that pollinator abundance and activity are influenced by the availability of male inflorescences, environmental conditions, and other ecological factors. Thus, the significant increase in *E. kamerunicus* population observed in the present study provides quantitative evidence that *Hatch and Carry* Gen 3.0 was effective in increasing the availability of the principal oil palm pollinator under the studied plantation conditions. In contrast, changes in bunch number are likely to be less immediate because bunch production is determined by reproductive processes occurring over a longer developmental period and is affected by multiple agronomic, physiological, genetic, and environmental factors.

Tabel 5. Spearman Correlation Analysis Results among Research Parameters in the Application of Hatch and Carry Gen 3.0 Technique

Variable	Fruit Set	Fruit to Bunch	Bunch Weight	Number of Bunches	Number of Beetles	Production
Fruit Set	1	0.558	0.484	0.226	0.975	0.460
Fruit to Bunch		1	0.476	0.161	0.444	0.394
Bunch Weight			1	0.061	0.419	0.555
Number of Bunches				1	0.205	0.852
Number of Beetles					1	0.413
Production						1

Note:
Correlation coefficient range
0.00–0.199 Very weak
0.20–0.399 Weak
0.40–0.599 Moderate
0.60–0.799 Strong
0.80–1.000 Very strong

Based on the Spearman correlation analysis presented in Table 5, all research parameters showed positive relationships, although their strength varied. The strongest relationship was observed between the population of *Elaeidobius kamerunicus* and *fruit set* (r_s = 0.975), which was categorized as a very strong correlation. This finding indicates that higher pollinating beetle populations were closely associated with higher *fruit set*, reflecting the important role of *E. kamerunicus* in oil palm pollination. The strong association is consistent with previous studies showing that the abundance and activity of *E. kamerunicus* are important factors influencing pollen transfer and fruit set in oil palm (Yousefi et al., 2020; Gintoron et al., 2023; Prasetyo et al., 2026). In addition, *fruit set* showed moderate correlations with *fruit to bunch* (r_s = 0.558), bunch weight (r_s = 0.484), and production (r_s = 0.460), indicating that better pollination performance was associated with improved bunch development and production components. In contrast, the relationship between *fruit set* and bunch number was weak (r_s = 0.226), suggesting that bunch number may be influenced more strongly by other reproductive, physiological, genetic, and environmental factors rather than by pollination success alone (Gintoron et al., 2023).

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Among the other parameters, *fruit to bunch* showed moderate correlations with bunch weight (r_s = 0.476), *E. kamerunicus* population (r_s = 0.444), and production (r_s = 0.394), while its relationship with bunch number was very weak (r_s = 0.161). This pattern indicates that *fruit to bunch* was more closely associated with bunch development and quality than with the number of harvested bunches. Bunch weight also showed moderate correlations with *E. kamerunicus* population (r_s = 0.419) and production (r_s = 0.555), but only a very weak correlation with bunch number (r_s = 0.061). The strong correlation between bunch number and production (r_s = 0.852) indicates that the number of harvested bunches was an important component contributing to total production. Meanwhile, the moderate correlation between *E. kamerunicus* population and production (r_s = 0.413) suggests that pollinator abundance is more closely associated with production through intermediate reproductive processes, particularly successful pollination and fruit formation, rather than directly determining yield. This interpretation is consistent with previous studies emphasizing that *E. kamerunicus* primarily contributes to oil palm productivity through effective pollen transfer, which subsequently affects *fruit set*, bunch development, and yield components (Yousefi et al., 2020; Gintoron et al., 2023; Prasetyo et al., 2026).

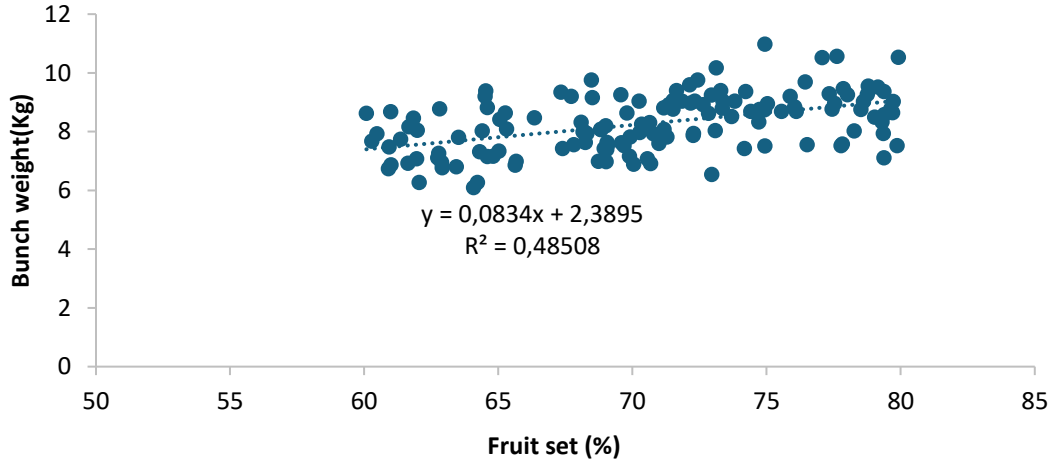


Figure 1. Correlation Between Fruit Set and Bunch Weight.

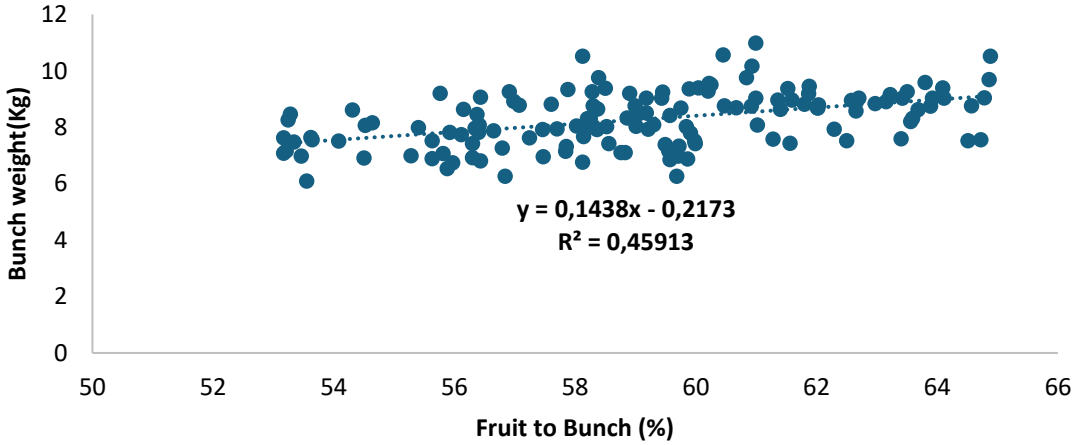


Figure 2. Correlation Between Fruit to Bunch and Bunch Weight.

A positive relationship was found between fruit set and bunch weight on figure 1, (r = 0.485), as well as fruit to bunch and bunch weight on figure 2, (r = 0.459). All two relationships were categorized as moderate, indicating that an improvement in pollination success was followed by an increase in the proportion of fruit within the bunch and an increase in bunch weight. Therefore, the higher the fruit set achieved, the better the quality and development of the bunches produced by oil palm plants.

In addition, fruit set and fruit to bunch also showed positive relationships with production, with correlation coefficients of r = 0.441 and r = 0.369, respectively. The beetle population also showed a positive correlation with fruit to bunch (r = 0.425). Although the strength of these relationships ranged

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from low to moderate, all relationships were statistically significant. Overall, the correlation analysis indicates that an increase in the E. kamerunicus population plays an important role in improving fruit set, which subsequently contributes to increases in fruit to bunch, bunch weight, and oil palm production. These findings further support the conclusion that successful pollination is one of the key factors determining oil palm productivity.

Tabel 6. Effectiveness of the Hatch and Carry Gen 3.0 Technique Application on Research Parameters

Parameter	HC	NHC	Effectiveness (%)
Fruit Set (%)	74.86	66.36	12.88
Fruit to Bunch (%)	61.39	56.77	8.14
Bunch Weight(kg)	8.64	7.74	13.95
Number of Bunches (bunches)	239	215	11.16
Number of *Elaeidobius kamerunicus* Beetles (Individuals)	182.484	113.957	60.13
Production (kg/ha)	210.74	165.91	27.02

Based on the effectiveness calculation presented in Table 4.16, the application of the *Hatch and Carry* Gen 3.0 technique showed higher values across all research parameters compared with the Non-Hatch and Carry (NHC) treatment. The highest effectiveness value was observed for the population of Elaeidobius kamerunicus, at 60.13%, indicating that the application of Hatch and Carry Gen 3.0 was associated with a substantial increase in the population of pollinating beetles compared with the untreated area. This finding is consistent with Prasetyo et al. (2014), who demonstrated that the Hatch and Carry technique substantially increased the population of E. kamerunicus and its visitation to female inflorescences. The increase in pollinator abundance is important because the population and activity of E. kamerunicus are closely related to the effectiveness of pollen transfer and successful pollination in oil palm (Yousefi et al., 2020; Gintoron et al., 2023).

In addition to increasing the population of pollinating beetles, the application of Hatch and Carry Gen 3.0 was associated with improvements in reproductive parameters. Fruit set showed an effectiveness increase of 12.88%, while fruit to bunch increased by 8.14% compared with the NHC treatment. These results indicate that increased availability of pollinating beetles was accompanied by improved reproductive performance of oil palm. Previous research has shown that increasing the abundance and activity of E. kamerunicus can enhance pollen transfer to receptive female inflorescences and subsequently increase fruit set (Prasetyo et al., 2014; Hulu et al., 2019). Recent evidence from Indonesia also demonstrates that E. kamerunicus population density is an important factor associated with oil palm fruit set (Prasetyo et al., 2026). Furthermore, effective pollination contributes to the development of fruits within the bunch and consequently influences fruit-to-bunch ratio (Susanto et al., 2020).

The improvement in reproductive parameters was followed by increases in yield components. Bunch weight showed an effectiveness increase of 13.95%, while the number of bunches increased by 11.16%. Consequently, oil palm production showed an effectiveness increase of 27.02% compared with the NHC treatment. The increase in bunch weight is biologically consistent with the contribution of successful pollination to fruit formation and bunch development, although bunch weight is also influenced by other factors such as genetic characteristics, palm age, nutrient availability, and environmental conditions (Yousefi et al., 2020; Gintoron et al., 2023). The higher production observed in the HC treatment therefore reflects the combined improvement of reproductive and yield components. Overall, the effectiveness calculation demonstrates a consistent positive response to the application of Hatch and Carry Gen 3.0, beginning with an increase in pollinator population, followed by improved pollination performance, reproductive parameters, yield components, and ultimately oil palm production. This sequential pattern is consistent with the established biological role of E. kamerunicus in oil palm pollination and the previously reported effectiveness of the Hatch and Carry technique (Prasetyo et al., 2014; Gintoron et al., 2023; Prasetyo et al., 2026).

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CONCLUSION

The results of this study demonstrate that the implementation of the Hatch and Carry (HC) Gen 3.0 technique effectively increased the population of the pollinating weevil *Elaeidobius kamerunicus*, leading to improved pollination success in oil palm plantations. The increased pollinator population was followed by significant improvements in fruit set, fruit-to-bunch (FTB), average bunch weight, bunch number, and overall productivity compared with the non-Hatch and Carry (NHC) treatment. Paired *t*-test analysis confirmed significant differences ($P < 0.05$) for all observed parameters, while correlation analysis revealed positive relationships among fruit set, fruit-to-bunch, bunch weight, and productivity. Therefore, the Hatch and Carry Gen 3.0 technique can be considered an effective and practical biological pollination management strategy to enhance fruit formation and increase oil palm productivity, particularly in plantations with low pollinator populations or limited male inflorescences.

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to the Management of PT Perkebunan Nusantara IV for granting permission to conduct this research and for providing the necessary support and facilities during the implementation of this study. The authors also appreciate all individuals who contributed, directly or indirectly, to the successful completion of this research.

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