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Impact of *Elaeidobius kamerunicus* population in F1 hybrid-single generation families of oil palm on Malaysia profound peat-soil

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Abstract— *Elaedobius kamerunicus (EK) is the most effective oil palm pollinator, and has positively improved the rate of pollination and oil yield. However, the decline in the oil palm fruit set and oil yield is alarming in oil palm industries. Therefore, this study investigated the EK population abundance and its impact on the oil palm fruit set. A significant variation in EK population was observed among the biparental families and a decline in its population abundance. The highest mean number of EK per palm was recorded on Day-three and family ECPHP500 recorded the highest (2367.94 ± 140.74). The total population means of EK was 36830.14 ± 851.68 per hectare and ECPHP550 recorded the highest at 52,189.64 weevils per hectare.A simple linear regression and correlation coefficient (r) analysis indicated declines in the efficiency of the weevil and it accounted for 31% of the variation in fruit to bunch, 25% in average bunch weight, 37% infertile fruit, and 33% of the total variation in oil palm fruit set ratio. The oil palm traits analysed, had a positive and highly significant moderate correlation with the weevil effectiveness. A strong perfect relationship was established between Day-three anthesis with EK population per inflorescence (r = 0.99, df = 3, 23, P<0.0001). Moderate evaporation rate, rainfall, wind velocity, and sunshine duration with temperature (29°C) will increase the weevil population and efficiency. Future research and good management practices should be considered to improve the population and pollination effectiveness of EK, enhancing the livelihoods of farmers.*

Keywords— ***Elaeis guineensis, pollinator, Efficiency, Fertile fruit, Biparental, yield traits.***

I. INTRODUCTION

The African oil palm (*Elaeis guineensis*Jacq.) is one of the extensively cultivated perennial crops and the most significant industrial crop in Malaysia. It produces unisexual inflorescences of males and females separately (Adam et al., 2011) and is entomophilous, or pollinated by insects (Syed, 1979;Daud and Ghani, 2016). For many crops, insect pollination is vital (Jalloh et al., 2018; Fatihah et al., 2019). Souza et al. (2017) reported that, for every pollination process affected in flowering plants, more than 80% are done by biotic pollinators. Among biotic pollinators, the African oil palm weevil commonly known as *Elaeidobius kamerunicus* (EK) from the order Coleoptera of Curculionidae family,has been considered as the most efficient oil palm pollinator (Meléndez and Ponce 2016, Meijaard et al., 2018) and it has been introduced globally. However, fluctuating populations in oil palm plantations have led to anxieties on yield and resilience (Li *et al*., 2019). Weevils significantly determine the yield of palm oil for industrial oil palm producers in which adequate weevils, 30% to 60% of flowers grow into fruit and fresh fruit bunch weight of 60% to 70% (Yousefi et al., 2020).

Oil palm is well known as a specific host plant for the weevil EK, and this weevil is incapable to carry out its normal life on any other kind of plant (Syed, 1984). *Elaeidobius. kamerunicus*, is extremely dependent on spikelets of the male inflorescence where they breed, feed, and animate. Its visitation depended on the aroma produced by the male inflorescence ascribed as estragole or P-methoxyally benzene (Muhammad et al., 2016). The female and male inflorescences of oil palm emit sequentially in the form of a cycle and two dissimilar inflorescences do not overlap at the time of sexual maturity and therefore transfer of male pollen grains is required for pollination. The proportion of oil palm fruit sets is strongly associated with the population density of the pollinating weevils (Kouakou et al., 2018).

In the 1980s, *E. kamerunicus* was introduced into Malaysia from Cameroon at Pamol estates in Kluang Johor and Ladang, Pamol in Sabah. This increased the rate of pollination and fruit set from 20 to 30% thereby resulting in the lower fresh fruit bunches abortion and greatly reduced the need for hand pollination or assisted pollination (Syed, 1982). Moreover, a 30% reduction in production cost (Basri et al., 1983) and approximately 43% of the kernel to bunch ratio were attained (Dhileepan, 1994). Similarly, Ponnamma (1999) revealed that a 36.9 to 78.3% bunch fruit set was achieved while Basri et al. (1987) reported a higher yield of fresh fruit bunches after the introduction of *E. kamerunicus* in oil palm plantations. This indicated a strong relationship between oil palm production and *E. kamerunicus* population as compared with several other crop species (Atibita et al., 2016, Posho-Ndola et al., 2017).

However, continuous decline in the oil palm fruit set has been reported and it has been constantly associated with the decline in *E.kamerunicus* population and efficiency (Swaray et al., 2021). Prasetyo et al. (2014) reported that the oil palm bunch fruit set has recently declined as a result of a decrease in *E. kamerunicus* population. Also, according to Fatihah et al. (2019), it is confirmed that the fruit set has recently decreased. For Malaysia's oil palm industry, the most challenging year was 2018 with a record of low fresh fruit bunch (FFB) production at 19.52 tons/ha resulting in low export earnings (Kushairi et al., 2019). The decline in EK population has been associated with several contributing factors which is not limited to its natural enemies and use of chemicals for the control of pest and diseases. According to Prasetyo et al. (2014), Yue et al. (2015), and Li et al. (2019), Predators such as rats, birds, ants, mites, and spiders have all been identifiedto feed on EK population levels at all life stages.

Despite the efforts of the Malaysia Palm Oil Board (MPOB) in the expansion of oil palm plantations across the country, poor fruit set due to the inadequate pollinator insects has been a major drawback (Frimpong and Adjaloo, 2012; Sisye, 2018). According to Latip et al. (2018), the yield output of oil palm has declined recently with several contributing factors, and perhaps a decline in the population and effectiveness of *E. kamerunicus* could be no exception. Fatihah et al. (2019) reported a low population abundance of EK in *dura* × *pisifera* (D×P) palms, and they suggested that to determine the relationship of various planting materials of oil palm and the EK population for fruit set, further study is required. Accordingly, we hypothesised that there is a decline in EK population abundance and its efficiency in oil palm D×P families. Therefore, this current study aims to assess the EK population abundance and its effectiveness in oil palm D×P biparental F1 hybrid-single generation families on oil palm fruit set yield.

II. MATERIALS AND METHODS

2.1.Planting materials

A total of 24 F1 hybrid-single generation (D×P415, D×P618, D×P4118, D×P4841, D×P4679, D×P4465, D×P550, D×P500, D×P4674, D×P4651, D×P4648, D×P4621, D×P4504, D×P4482, D×P4474, D×P4591, D×P4570, D×P4550, D×P4535, D×P4529, D×P4505, D×P4548, D×P4540, D×P4539) oil palm biparental families of the genus *Elaeis*derived from closed pollinated hybridization of four male *pisiferas* (Nigeria, Cameroon, Yangambi and AVROS) and six female *duras* (Angola, Deli-Banting, Tanzania, Deli-Johor Labis, Deli-Ulu Remis, Deli-Serdang) parental origins were utilized in this study. The current planting materials were planted in 2008 at Field 6B1-Trial 0.502,Teluk-Intan (3.49˚N, 101.06˚E), Malaysiaby MPOB.

2.2. Experimental design and data collection

The oil palm D×P derivative families were laid down in an Independent completely randomized design (ICRD) in four replications, 16 palms/family/replicate (16×4 = 64 palms/family) of 24 families, planted in 8.5 meters equi-lateral tri-angular design.Experimental sample palms of 288 (12 × 24) were selected from 1,520 experimental palms of 9.5 ha through systematic random sampling selection within the family group (1520 /288 = 5.23 palms), i.e three palms/family by four replications (3 × 4 = 12) and the same selected plants were sampled at each round.

In this research, the procedure established by Basri and Norman (1997) was followed every month for 12 months (February 2019 – January 2020). The oil palm male inflorescences at the anthesis phase for each month were randomly selected based on families. For each anthesizing day, three spikelets from the male inflorescence were harvested, making a total of 18 spikelets. However, in determining the EK population abundance, the first three days of anthesis, i.e nine spikelets (three spikelets/day) were randomly harvested at different portions from the anthesizing male inflorescence between the hours of 8 a.m. and 10 a.m. The number of EK was counted on each harvested spikelet and based on Basri and Norman's (1997) formulation, the mean of EKpopulation abundance per ha was determined.

i. $$\mathrm{PA/EK} = \frac{(\mathrm{MEK/S} \times \mathrm{NMF/A} \times \mathrm{SM/MF})}{\mathrm{NFF/A}}$$

Where:

PA/EK = Population abundance of *E. kamerunicus* per palm

MEK/S = Mean of *E. kamerunicus* per spikelet

NMF/A = Number of male inflorescences at anthesis per palm

SM/MF = Spikelet mean of male inflorescence at anthesis

NFF/A = Number of female inflorescences at anthesis per palm

ii. $$\mathrm{PA/EK\ (ha)} = \frac{(\mathrm{MEK/S} \times \mathrm{NS/MF} \times \mathrm{TMF/A})}{\mathrm{Npalm\ per\ plot}} \times \mathrm{Npalm\ (ha)}$$

Where:

PA/EK $_{(ha)}$ = Population abundance of *E.kamerunicus* per hectarage

MEK/S = Mean of *E. kamerunicus* per spikelet

TMF/A = Total number of male inflorescences at anthesis per palm per replication

NS/MF = Number of spikelets per male inflorescence

Npalm/plot = 64 palms (16 palms/plot)]

Npalm/ha = 160 palms/ha

The effectiveness of the *E. kamerunicus* (EK) in the derivative oil palm families was measured based on oil palm average bunch weight (ABW), fruit to bunch (FTB) fertile fruit (FF), parthenocarpic/infertile fruit (PCF), inflorescence sex ratio (ISR), and fruit set ratio (FSR). One anthesizing female inflorescence per palm per round was selected and observed until the ripening stage, and the efficiency of EK was determined using the "S-shape" method as described by Rao et al. (1983). The 1st selection of the anthesizing female inflorescences was done in February 2019 and its efficacy in the 1st round was determined in June 2019, 2nd selection was in April 2019 and its efficiency was determined in September 2019, 3rd selection was in July 2019 and its productivity was determined in December 2019 and the final selection was done in October 2019 and its efficiency was determined in March 2020. The monthly population force of EKassessment was carried out among the 24 families from February 2019 to January 2020 as described by Basri and Norman (1997).

*Elaeidobius kamerunicus*population force data were collected on a monthly interval for 12 months. Whereas, data on oil palm traits were collected at 15 to 24 weeks intervals for four consecutive rounds. Environmental data on monthly rainfall (MRF mm), monthly wind velocity (MWV km/hr), monthly sunshine hour/duration (MSH Wm^2), monthly evaporation rate (MER mm), and monthly temperature (MT ^{o}C) were sourced from the local meteorological department in the experimental research station beginning from February 2019 to January 2020.

a. *Statistical analysis*

The number of *E. kamerunicus* captured during anthesis periods, average bunch (ABW), fruit to bunch (FTB) fertile fruit (FF), parthenocarpic/infertile fruit (PCF), inflorescence sex ratio (ISR), and fruit set ratio (FSR) was calculated based on individual palms and the means by progeny were precisely used for analysis using Statistical Analysis System (SAS) vision 9.4. The analysis of variance (ANOVA) was determined using the general linear model (PROC GLM) of SAS due to missing palms by families and Tukey's Studentized Range Test ($P < 0.05$) was used for mean separation. Variance component [genetic variance (σ^2_g), error variance (σ^2_e), and phenotypic variance (σ^2_{ph})], and simple statistics (mean and standard error) were calculated.

The relationship of the weevil density and its efficiency in respect of ABW, FTB, FF, PCF, ISR, and FSR were analysed using simple linear regression and Pearson's product correlation analysis using SAS vision 9.4. Thus, each of the traits was used as a response variable against the explanatory variable (*Elaeidobius. kamerunicus*).To acquire models for a functional relationship between dependent variables (FTB, ABW, FF, ISR, and FSR) and independent variables (PF/EK), Type two of the regression model was used since both of the variables (response and explanatory) were measurable and were subjected to error. The simple linear regression with a linear model form of $Y = \beta_0 + \beta_1 X_1 + \mathcal{E}$ was used as delineated by (Ngo et al., 2012), where Y = response variable, β_0 = intercept (value of Y, when X is 0), $\beta_1 x_1$ = slope (change in Y, for each unit change in X) known as the explanatory variable and Ɛ= random error.

The equations of interest are as follows;

1. $FTB = \beta_0 + \beta_1(\mathrm{PF/EK}) + \mathcal{E}$
2. $ABW = \beta_0 + \beta_1(\mathrm{PF/EK}) + \mathcal{E}$
3. $FF = \beta_0 + \beta_1(\mathrm{PF/EK}) + \mathcal{E}$
4. $ISR = \beta_0 + \beta_1(\mathrm{PF/EK}) + \mathcal{E}$
5. $FSR = \beta_0 + \beta_1(\mathrm{PF/EK}) + \mathcal{E}$

Note: The variables, fruit to bunch (FTB) in the 1st equation, average bunch weight (ABW) in the 2nd equation, fertile fruit to bunch (FF) in the 3rd equation, inflorescence sex ratio (ISR) in the 4th equation, and fruit set ratio (FSR) in the 5th equation are the response variables at a time, respectively, while β_0 is the intercept and β_1 (PF/EK) is the slope and Ɛ is the random error.

III. RESULTS AND DISCUSSION

3.1. Population mean of Elaeidobius kamerunicus that visited the male inflorescence each day of anthesis among D×P families

The population abundance of *E. kamerunicus* on male anthesizing inflorescence showed highly significant differences among the biparental progenies, while no significant effect was seen among the replications (Table 1). According to Swaray et al. (2021), the EK population density exhibited significant differences amid the hybrids of D×P genotypes. Results on the variance component exhibited that genetic variability (σ^2_g) had more influence on the number of spikelets per male inflorescence (NS/MF), spikelet length (SPL cm) and population abundance of *E. kamerunicus* (PA/EK ha.), whereas, error variance (σ^2_e) had a greater influence on the anthesizing male inflorescences due to anthesis phases (Table 1). Optimal pollination could be achieved based on the pollinating insect's activity when adjusted to flower physiology (Auffray et al., 2017). According to Tandon *et al.* (2001), as supported by Auffray et al. (2017), the inflorescences of both sexes in oil palm became functional during the morning hours of 8:00 to 10:00 a.m. The male inflorescences on anthesis will emit pollen and transmit to the anther of the stigma of the female inflorescence flowers by the actions of pollinating insects or wind.

Table 1. The mean square and variance components for population abundance of Elaeidobius kamerunicus that visited male inflorescenceon each day of anthesis

S/V	DF	EK-D1P	EK-D2P	EK-D3P	EK-D4P	EK-D5P	EK-D6P	NS/MF	SPL (cm)	PA/EK (ha)
Replications (R)	3	695.97^{ns}	11792.13^{ns}	75441.66^{ns}	27469.21^{ns}	511.10^{ns}	31.37^{ns}	54.60^{ns}	0.15^{ns}	14936072.00^{ns}
Progenies (G)	23	2528.43**	60.829.65**	278671.88**	60630.07**	13733.42**	142.67**	431.97**	2.02**	180054129.00**
Error (e)	60	553.59	11492.55	49782.38	18400.32	4068.64	48.30	34.98	0.33	20700947
Variance Component										
σ^2_g		517.32	12932.90	59754.70	11263.10	2682.3	26.33	107.4	0.47	40800545.00
		(48.58) $^{+}$	(53.16)	(54.77)	(38.03)	(40.86)	(35.74)	(75.52)	(58.86)	(66.76)
σ^2_e		547.51	11395.50	49353.60	18353.30	3882.20	47.33	34.82	0.33	20314477.00
		(51.42)	(46.84)	(45.23)	(61.97)	(59.14)	(64.26)	(24.48)	(41.14)	(33.24)
σ^2_{ph}		1064.83	24328.40	109108.30	29616.40	6564.50	73.66	142.22	0.79	61115022.00
Mean		149.80	917.87	1853.66	1058.24	476.59	11.21	137.51	10.96	36830.14
SE		3.53	16.84	35.85	18.50	8.67	0.92	1.29	0.09	851.68

Notes: S/V = source of variation, DF = degree of freedom, EK-D1P = *Elaeidobius kamerunicus*day-1 population force per inflorescence (palm^{-1}day^{-1}), EK-D2P = *Elaeidobius kamerunicus*day-2 population force per inflorescence (palm^{-1}day^{-1}), EK-D3P = *Elaeidobius kamerunicus*day-3 population force per inflorescence (palm^{-1}day^{-1}), EK-D4P = *Elaeidobius kamerunicus*day-4 population force per inflorescence (palm^{-1}day^{-1}), EK-D5P = *Elaeidobicus kamerunicus*day-5 population force per inflorescence (palm^{-1}day^{-1}), EK-D6P = *Elaeidobius kamerunicus*day-6 population force per inflorescence (palm^{-1}day^{-1}), NS/MF = number of spikelet per male inflorescence (palm^{-1} yr^{-1}), SPL = spikelet length (cmpalm^{-1}yr^{-1}), PA/EK =population abundance of *Elaeidobius kamerunicus* (ha),ns = non-significant $P > 0.05$, ** = highly Significant at $P< 0.01$, ()$^{+}$ = phenotypic variance in percentage, σ^2_g = genotypic variance, σ^2_e = error variance, σ^2_{ph} = phenotypic variance, SE = standard error

Table 2. The mean population abundance and standard error (±) of Elaeidobius kamerunicus per progeny that emerged on male inflorescence on each anthesis day, number of spikelets, and spikelet length

F/code	EK-D1P	EK-D2P	EK-D3P	EK-D4P	EK-D5P	EK-D6P
ECPHP415	134.88^{bc} ± 21.33	997.02^{a-d} ± 73.83	2182.00^{a-c} ± 209.21	1061.03^{a-c} ± 109.14	470.73^{a-c} ± 29.64	16.61^{ab} ± 5.62
ECPHP500	157.94^{bc} ± 4.29	1171.35^{a} ± 44.98	2367.94^{a} ± 140.74	1257.35^{ab} ± 116.87	544.69^{ab} ± 34.87	9.04^{b} ± 4.51
ECPHP550	230.96^{a} ± 18.07	1154.75^{ab} ± 68.02	2321.70^{ab} ± 142.45	1281.30^{a} ± 66.35	595.30^{a} ± 33.52	29.71^{a} ± 3.60
ECPHP618	141.81^{bc} ± 10.07	945.13^{a-d} ± 82.85	1792.80^{a-e} ± 131.12	1048.62^{a-c} ± 80.33	478.25a-c ± 25.38	10.13^{ab} ± 4.11
PK4118	160.81^{bc}± 16.28	1112.67^{a-c} ± 75.00	2175.70^{a-d} ± 103.54	1208.03^{ab} ± 32.55	529.58^{ab} ± 16.39	13.53^{ab} ± 3.38
PK4465	155.44^{bc} ± 3.21	930.32^{a-d} ± 39.67	1839.96^{a-d} ± 85.29	964.40^{a-c} ± 38.69	420.84^{a-c} ± 18.25	16.52^{ab} ± 3.77
PK4474	157.75^{bc} ± 19.47	990.56^{a-d} ± 18.08	2044.51^{a-d} ± 41.35	1144.59^{ab} ± 88.25	534.04^{ab} ± 63.01	7.49^{b} ± 3.06
PK4482	133.02^{bc} ± 6.02	848.73^{b-e} ± 63.87	1842.30^{a-d} ± 154.14	934.36^{a-c} ± 144.16	422.68^{a-c} ± 50.54	2.00^{b} ± 0.07
PK4504	154.56^{bc} ± 13.42	908.24^{a-e} ± 64.27	1879.30^{a-d} ± 111.62	1117.39^{ab} ± 73.48	556.37^{ab} ± 19.61	21.29^{ab} ± 2.07
PK4505	147.97^{bc} ± 3.83	919.46^{a-e} ± 34.64	1897.90^{a-d} ± 51.15	1122.22^{ab} ± 68.15	495.24^{a-b} ± 31.21	13.64^{ab} ± 6.97
PK4529	124.07^{bc} ± 8.41	771.22^{de} ± 26.22	1625.00^{c-e} ± 85.51	1014.43^{b-c} ± 37.24	485.46^{a-c} ± 19.11	9.15^{b} ± 2.47
PK4535	138.64^{bc} ± 7.57	845.61^{b-e} ± 51.74	1713.30^{b-e} ± 92.99	1017.90^{a-c} ± 79.16	457.55^{a-c} ± 31.44	11.37^{ab} ± 3.66
PK4539	129.38^{bc} ± 4.93	777.33^{de} ± 20.62	1533.70^{de} ± 65.21	933.03^{a-c} ± 31.96	420.03^{a-c} ± 19.94	8.03^{b} ± 5.23
PK4540	122.45^{bc} ± 8.32	824.01^{c-e} ± 23.41	1693.70^{b-e} ± 45.41	1014.54^{a-c} ± 50.04	493.78^{a-c} ± 53.23	5.50^{b} ± 2.90
PK4548	133.48^{bc} ± 8.12	777.94^{de} ± 15.83	1589.37^{c-e} ± 59.63	884.91^{bc} ± 38.33	402.20^{bc} ± 11.51	8.56^{b} ± 2.57
PK4550	166.81^{ab} ± 12.18	920.44^{a-e} ± 36.25	1872.72^{a-d} ± 143.49	1080.30^{a-c} ± 86.72	482.90^{a-c} ± 41.32	8.38^{b} ± 2.26
PK4570	141.68^{bc} ± 15.81	840.52^{c-e} ± 44.48	1674.10^{c-e} ± 33.81	944.89^{a-c} ± 36.69	435.60^{a-c} ± 30.35	3.95^{b} ± 0.48
PK4591	159.28^{bc} ± 9.55	873.07^{a-e} ± 53.03	1752.80^{a-e} ± 63.74	1068.33^{a-e} ± 24.21	438.16^{a-c} ± 37.75	2.24^{b} ± 1.33
PK4621	94.25^{c} ± 6.05	619.78^{e} ± 51.69	1175.70^{e} ± 82.75	719.98^{c} ± 44.86	309.59^{c} ± 9.61	6.84^{b} ± 1.32
PK4648	182.63^{ab} ± 14.18	1003.35^{a-d} ± 70.8	2138.20^{a-d} ± 202.93	1224.31^{ab} ± 93.82	539.97^{ab} ± 47.53	17.89^{ab} ± 4.57
PK4651	146.70^{bc} ± 4.41	954.28^{a-d} ± 42.70	1968.80^{a-d} ± 98.81	1101.96^{a-c} ± 71.70	488.58^{a-c} ± 24.13	6.53^{b} ± 1.69
PK4674	152.11^{bc} ± 5.81	942.02^{a-d} ± 167.14	1835.37^{a-d} ± 270.09	1050.51^{a-c}± 131.34	422.67^{a-c} ± 22.34	9.37^{b} ± 1.45
PK4679	151.56^{bc} ± 12.13	956.46^{a-d} ± 30.34	1824.87^{a-d} ± 51.62	1101.50^{a-c} ± 18.36	474.75^{a-c} ± 17.18	12.83^{ab} ± 2.91
PK4841	170.96^{ab} ± 16.70	897.57^{a-e} ± 72.22	1695.56^{b-e} ± 115.52	1008.67^{b-c} ± 72.93	462.12^{a-c} ± 39.84	10.93^{ab} ± 4.09
Mean ± SE	149.80 ± 3.53	917.87 ± 16.84	1853.66 ± 35.85	1058.24 ± 18.50	476.59 ± 8.67	11.21 ± 0.92

Notes: F/code = family code,*Elaeis guineensis* crossing program Hulu Paka, PK = Porim Kluang, EK-D1P = *Elaeidobius kamerunicus*day-1 population force per inflorescence ($palm^{-1}day^{-1}$), EK-D2P = *Elaeidobius kamerunicus*day-2 population force per inflorescence ($palm^{-1}day^{-1}$), EK-D3P = *Elaeidobius kamerunicus*day-3 population force per inflorescence ($palm^{-1}day^{-1}$), EK-D4P = *Elaeidobius kamerunicus*day-4 population force per inflorescence ($palm^{-1}day^{-1}$), EK-D5P = *Elaeidobicus kamerunicus*day-5 population force per inflorescence ($palm^{-1}day^{-1}$), EK-D6P = *Elaeidobius kamerunicus*day-6 population force per inflorescence ($palm^{-1}day^{-1}$), Stderr = standard error, Tukey's Studentized Range (HSD) = honestly significant difference Test at $P < 0.05$, Tukey's Studentized Range Test at (P < 0.05) determined that the population abundance of *E. kamerunicus* on anthesizing male inflorescence among the D×P progenies was significantly different on each phase of anthesis (Table 2). On the first day of anthesis, fewer weevils were found on the male inflorescence across the progenies with a trial mean of 149.80 ± 3.53 weevils per inflorescence. The weevil population on Day-1 ranged from 94.25 ± 6.05 to 230.96± 18.07 weevils per inflorescence, whereas, the highest was recorded in ECPHP550 and PK4621 had the least population. Based on a 50% opening of the florets with an increase in its odour, the population of the weevil on male inflorescence increased on the second day of anthesis with a trial mean of 917.87 ± 16.84 weevils.

Among the progenies in the present study. the second-day population ranged from 619.78± 51.69 to 1171.35± 44.98 weevils per inflorescence and the least was recorded in PK4621. The highest weevil population for Day-2 of anthesis was found in ECPHP500 and ECPHP550 at 1171.35 ± 44.98 and 1154.75 ± 68.02 weevils per inflorescence, respectively. On the alter stage (Day-3) of anthesis when all the florets opened, the weevil population increased and had a maximum trial mean value of 1853.66 ± 35.85 weevils. Syed (1982), Ponnamma (1999) and Yue et al. (2015) reported that on the male inflorescence flowers, the *E. kamerunicus* were higher in their population on Day-3 of anthesis. Therefore, more comprehensive observations were carried out in this current study and the results obtained were similar to those of former researchers' findings. It was observed that ECPHP500 recorded the highest weevils per inflorescence on Day-3 followed by ECPHP550 and PK4621 which continued to have the least population (Table 2).There was a progressive declined in the EK population on the fourth and fifth days in all the families. There were very few non-EK found on the sixth day of anthesis. This rise-and-fall trend in EK population abundance occurred across the families.

Experimental results on means for Day-1 to Day-3 per inflorescence showed that the EK population abundance was highly significant when correlated with EK Day-1 population force (EK-D1P), EK-D2P and EK-D3P with the correlation coefficient of r = 0.68, df = 3, 23, P < 0.0001; r = 0.97, df = 3, 23, P < 0.0001 and r = 0.99, df = 3, 23, P < 0.0001, respectively. Accordingly, any positive increase in NS/MF and SPL triggered an increase in EK population abundance per inflorescence. Understanding the interactions between the pollinator and its host provides an important benefit for management strategy and conservation of the weevils in palm plantations (Li et al., 2019). Thus, progenies with the characters such as producing huge and lengthy spikelets could be selected for future oil palm breeding programs.

The number of spikelets per male inflorescence (NS/MF) and spikelet length (SPL) and EK population abundance per ha. are presented in Figure 1.

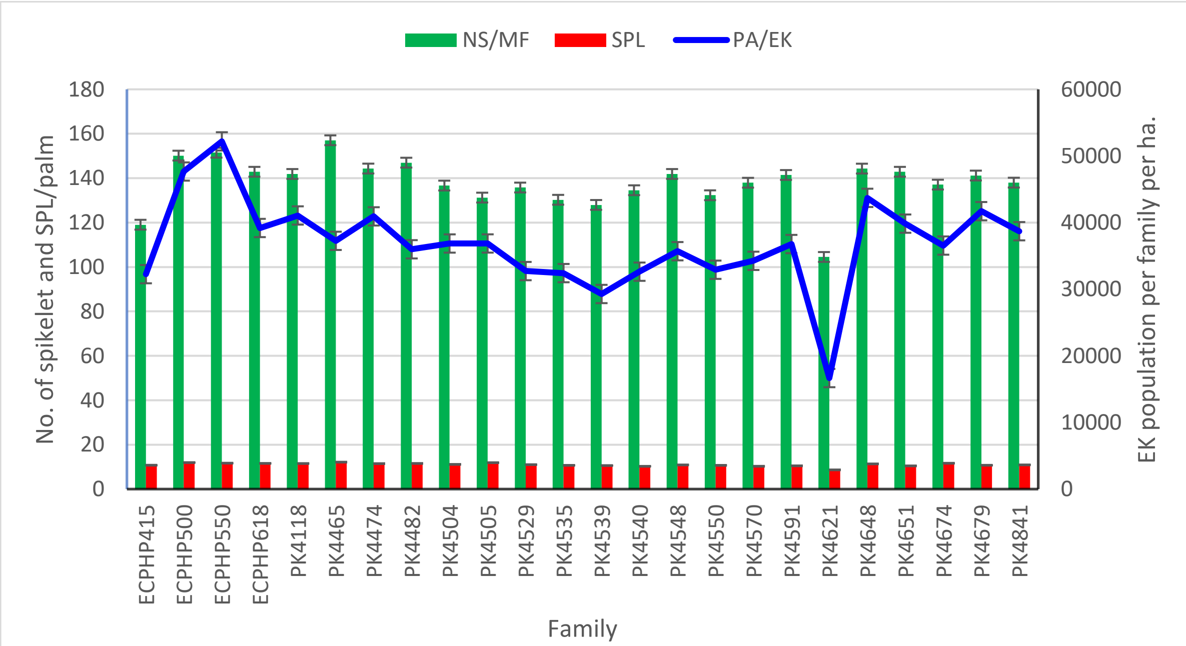

Fig. 1. Population abundance of Elaeidobius kamerunicus (PA/EK) per ha in biparental D×P families, number of spikelets per male inflorescence (NS/NF) and spikelet length (SPL)

Tukey's test (P= 0.05) showed that the number of spikelets per male inflorescence (NS/MF) 58.33% or 14 out of 24 progenies was above the trial mean value of 137.51 ± 1.29spikelets. Among the families, NS/MF ranged from 104.52 ± 1.06 to 157.07 ± 3.46 spikelets and family PK4465 had the highest quantity of spikelets per male inflorescence followed by families ECPHP550 (151.47 ± 2.81) and ECPHP500 (150.16 ± 2.46), with the least in family PK4621 (Fig. 1).The results obtained in the present study noted that all the families were within the range reported by Jacquemard and Baudouin (1998) that the male inflorescence was made up of 100-300 spikelets. The population abundance of the EK on individual progenies on anthesizing male inflorescence was based on the NS/MF coupled with the strong odour produced. Therefore, D×P families with these outstanding attributes could be used to develop future elite families.

A significant difference was found among the families for spikelet length (SPL cm) and 50% of the families were above the trial mean of 10.96 ± 0.09 cm. family PK4465 had the highest length at 12.14 ± 0.27 cm and the shortest SPL was found in family PK4621 at 8.65 ± 0.06 cm. However, findings in the present study were contrary to what was reported by Jacquemard and Baudouin (1998), that male inflorescences bore several cylinder-shaped spikelets of length 15 to 25 cm. The difference could be due to the genetic nature of the planting materials, location, and climate. Hence, SPL was found to be positively associated with EK-D1P (r = 0.39, df = 3, 23, $P < 0.0002$), EK-D2P (r = 0.49, df = 3, 23, $P < 0.0001$) and EK-D3P (r = 0.46, df = 3, 23, $P < 0.0001$). These experimental findings indicated that positive growth in SPL hastened the increase in the number of EK per anthesizing male inflorescence from Day-1 to Day-3.

In cultivated oil palm plantations, *E. kamerunicus* is the most dominant flower-visiting insect (Rizali, et al., 2019). The abundance of the population of EK per hectare in the present study had a trial mean of 36830.14 ± 851.68 and 50% of the families were above the trial mean. The mean population abundance of EK per hectare ranged from 16665.77 ± 786.86 to 52189.64± 2736.32 weevils per ha. Among the family, ECPHK550 recorded the highest population abundance of EK followed by ECPHP500 (47664.84 ± 3595.21), while the least was found in PK4621 (Fig.1). The study revealed that an increase in EK population abundance per ha occurred as a result of an increase in the production of male inflorescences at anthesis. The NMF/A showed positive and highly significant relationship with PA/EK (r = 0.81, df = 3, 23, $P < 0.0001$). A positive increase in the number of male inflorescences propelled anincrease in PA/EK.The observation was in agreement with Fatihah et al. (2019), who cited that the number of anthesizing male inflorescence increased the population of EK per ha. Similarly, Dhileepan (1994) supported that the abundance of EK strongly hinged on the male inflorescence availability.

The *E. kamerunicus* population abundance per ha recorded in Trial 0.502, for all the 11 years old D×P families indicated that there was a satisfactory number of *E. kamerunicus* to pollinate the entire female inflorescences produced, for the achievement of high fruit set (>60%). Dhileepan (1994) earlier reported that in India, to achieve a 60% fruit set, only 7,000 *E. kamerunicus* were needed. Donough et al. (1996) reported that 20,000 to 80,000 EK population per ha was needed to achieve 55% of the oil palm fruit set. Basri and Norman (1997) reported that a very low quantity of EK at 4,711 EK per ha could achieve an oil palm fruit set of more than 60%. There were conflicting statements made by earlier researchers regarding the population of EK needed per ha in achieving a good fruit set. Latip et al. (2018) reported that the lowest and highest number of EK per ha in D×P oil palm plantation was 6,435 and 83,676 weevils, respectively.

For oil palm clonal materials, the lowest and highest EK population abundance required was 9,318 and 141,431 weevil per ha respectively (Latip et al., 2018). When compared to those reported by Latip et al. (2018), it was evident that there was a decline in population abundance of EK per ha. These may perhaps be due to differences in the physiology of the hybridized D×P materials. Nevertheless, the population abundance of EK per hectare (PA/EK ha) was positively related and highly significant with NS/MF, SPL, EK-D1P, EK-D2P, EK-D3P, and population force were r = 0.80, df = 3, 23; $P < 0.0001$; r = 0.69, df = 3, 23, $P < 0.0001$; r = 0.63, df = 3, 23, $P < 0.0001$; r = 0.78, df = 3, 23, $P < 0.0001$; r = 0.73, df = 3, 23, $P < 0.0001$, and r = 0.91, df = 3, 23, $P < 0.0001$, respectively. The correlation outcomes indicated that any optimistic increase in NS/MF, SPL, EK-D1P, EK-D2P, EK-D3P, and population force would cause an increase in population abundance of *E. kamerunicus*per ha.

3.2. Relationship between Elaeidobius kamerunicus and oil palm traits on dura and pisifera biparental families

The outcome of the regression analysis for each response variable against the independent variable (PF/EK) is presented in Table 3. In assuming the fit of the regression model, the Adjusted (Adj) R-Square and R-Square are used and they are considered to be two statistics, and values near to one exhibited a better fit (Ngo et al., 2012). Nevertheless, the parameter estimates contained the intercept (β_0), slope (β_1), t-statistics including their corresponding p-values for each regression as to whether each of the parameters is significantly different from zero (Table 3). However, the *P*-values for each regression indicated that the intercept for each of the dependent variables (FTB, ABW, FF, ISR, and FSR) and the independent variable (PF/EK) was significant with the exception for ABW and FF where significant intercept was observed (Table 3).

In the overall model for Equation one, F-value was significant (F = 9.87, P < 0.05), indicating that a significant portion was explained by the model for the variation. The R-square for equation one was 0.31 indicating that PF/EK accounted for 31% of the variation in FTB. In the total model for Equation two, the F-value was significant (F=7.23, df = 1, df error = 22, P < 0.05) which implied that the realistic portion was elucidated by the model in terms of variation. Hence, the R-Square in twoequations of 0.25 showed that PF/EK was responsible for 25% of the variation in ABW.

Table 3. Analysis of variance and other parameters of regression analysis for the relationship between Elaeidobius kamerunicus and oil palm traits

1. **FTB**	Source	DF	SS	MS	F Value	Pr > F
	Model	1	11715	11715	9.87	0.0047
	Error	22	26099	1186.332		
	Total	23	37814			
		Root MSE	34.443	R-Square	0.3098	
		Dep. Mean	333.359	Adj R-Sq	0.2784	
		Coeff Var	10.332			
	Variable	DF	Para Estimate	Std Error	F Value	Pr > F
	Intercept	1	171.178	52.087	3.29	0.0034
	PF/EK	1	0.1668	0.053	3.14	0.0047
2. **ABW**	Source	DF	SS	MS	F Value	Pr > F
	Model	1	38.323	38.323	7.23	0.0134
	Error	22	116.556	5.298		
	Total	23	154.879			
		Root MSE	2.302	R-Square	0.2474	
		Dep. Mean	7.425	Adj R-Sq	0.2132	
		Coeff Var	31.000			
	Variable	DF	Para Estimate	Std Error	F Value	Pr > F
	Intercept	1	-1.851	3.481	-0.53	0.6002
	PF/EK	1	0.010	0.004	2.69	0.0134
3. **FF**	Source	DF	SS	MS	F Value	Pr > F
	Model	1	15153	15153	12.86	0.0016
	Error	22	25913	1177.844		
	Total	23	41066			
		Root MSE	34.320	R-Square	0.369	
		Dep. Mean	169.162	Adj R-Sq	0.340	
		Coeff Var	20.288			
	Source	DF	SS	MS	F Value	Pr > F
	Intercept	1	-15.290	51.900	-0.29	0.7711

	PF/EK	1	0.190	0.053	3.59	0.0016
4. **ISR**	Source	DF	SS	MS	F Value	Pr > F
	Model	1	190.757	190.757	7.71	0.0110
	Error	22	544.624	24.756		
	Total	23	735.381			
		Root MSE	4.976	R-Square	0.259	
		Dep, Mean	83.724	Adj R-Sq	0.226	
		Coeff Var	5.943			
	Source	DF	SS	MS	F Value	Pr > F
	Intercept	1	104.419	7.524	13.88	<.0001
	PF/EK	1	-0.021	0.008	-2.78	0.0110
5. **FSR**	Source	DF	SS	MS	F Value	Pr > F
	Model	1	389.538	389.538	10.62	0.0036
	Error	22	807.264	36.694		
	Total	23	1196.802			
		Root MSE	6.05754	R-Square	0.326	
		Dep Mean	49.96625	Adj R-Sq	0.295	
		Coeff Var	12.12327			
	Source	DF	SS	MS	F Value	Pr > F
	Intercept	1	20.392	9.161	2.23	0.0366
	PF/EK	1	0.030	0.009	3.26	0.0036

Note: DF = degree of freedom, ISR = inflorescence sex ratio, FSR = fruit set ratio, PF/EK = population force of *Elaeidobius kamerunicus*, Adj R-sq = adjusted R-square, Coeff var = coefficient of variation, Dep. Mean = dependent variable mean, SS = sum of squares, MS = mean square, MSE = mean square error

Also, in the inclusive model for Equation three, its F-value was significant (F= 12.86, df error = 22, P < 0.001) indicating that a significant portion was likewise explained by the model for the variation. Therefore, the R-Square for FF in Equation three was 0.37 indicating that model for Equation five had a significant F-value (F= 10.62, df =1, df error = 22, P < 0.001), exhibiting that there was a significant portion of variation that was explained by the model in Equation five. It was observed that the R-Square for the 5th equation of 0.33 revealed that the population force of EK accounted for 33% of the total variation in the oil palm fruit set ratio.

The fitted model from the parameter-estimates from Models one to five were as follows:

1. $FTB = 171.178 + 0.167$ (PF/EK)
2. $ABW = -1.851 + 0.010$ (PF/EK)
3. $FF = -15.290 + 0.190$ (PF/EK)
4. $ISR = 104.419 - 0.021$ (PF/EK)
5. $FSR = 20.392 + 0.030$ (PF/EK)

According to (Ngo *et al*., 2012), the Adj R-Square increases when the MSE decreases, hence, the smallest MSE or the largest Adj R-Square indicates the best fit for the model. Therefore, based on the Root MSE (Table 3), indicated the best fit for Models two, four, and five, whereas MSE of 34.44 and 34.32 was high in Models one and three, respectively, which did not best fit the models.

To determine the degree of the response variables as against the explanatory variables to which extent they are related, the Pearson's product correlation was used to determine their significance levels at $P \leq 0.05$ and $P \leq 0.01$, in which the correlation may well be positive or negative.Koo et al.'s (2016) estimation for determination of correlation coefficient was adopted, where r < 0.5 was estimated as weak correlation, 0.5 ≤ r ≤ 0.75 was estimated as moderate, 0.75 ≤ r ≤ 0.9 was estimated as strong and 0.9 < r =1 was estimated as a perfect relationship. The FTB, ABW, M, FF and FSR were positive and significantly correlated with PF/EK at (r = 0.56, F = 3.14, df = 1, df error = 22, P< 0.0047), (r = 0.50, F = 2.69, df = 1, df error = 22, P < 0.0134), (r = 0.54, F = 3.04, df = 1, df error = 22, P < 0.0061), (r = 0.61, F= 3.59, df = 1, df error = 22, P < 0.0016) and (r =0.57, F = 3.26, df = 1, df error = 22, P < 0.0036), respectively.

The effective fruit development of the oil palm hangs on EK population abundance (Yousefi et al., 2020).The relationships of FTB, ABW, FF, and FSR with PF/EK, were found to be moderate. However, as the population of EK increased, FTB, ABW, FF, and FSR increased. Similarly, as the male flower production increased, the population force of the EK increased, vice versa. PCF had a weak negative and non-significant relationship with PF/EK (r = -0.15, F = -0.71, df = 1, df error = 22, P > 0.4881), indicating a decline in PCF when there was an increase in EK population force. Conversely, ISR had a moderate significant negative correlation with PF/EK at (r = -0.51,F= -2.78, df = 1, df error = 22, P < 0.0110). The ISR relationship with PF/EK implied that the higher the ISR, the lower the population force of the EK, which could diminish the fruit set ratio. In conclusion, based on the results obtained, it signified a decline in the population and efficiency of the EK and hence, the fruit set ratio was influenced by EK.

The efficiency of EK is believed to have declined in Malaysia oil palm plantations (Swaray et al, 2021; Prasetyo et al, 2014), especially the male EK (Swaray et al, 2021). The inefficiency of the *E. kamerunicus* was due to the declinein the male *E. kamerunicus* population. This result was supported byYousefi et al. (2020), who reported that in India and Malaysia, in both peat and mineral soil conditions, the male *E. kamerunicus* could carry more pollen.Norman et al. (2018) reported that for both male and female inflorescences including soil types, the pollen viability remainedinsignificant.The alteration in the favourable pattern of environmental factors as against the weevil population and efficiency could have contributed to the low fruit set formation.

Major palm oil exporters (Indonesia, Malaysia, and Thailand) worldwide were no exception to the fruit set problem. Kushairi et al. (2019), reported that the utmost challenging year with lower crude palm oil production, counting its prices and exports for the Malaysian oil palm industry was 2018. They reported that a 2.0% decline of crude palm oil to 19.52% million tons in 2018 was recorded as against 2017 of 19.91 million tons of crude palm oil. The decrease in fresh fruit bunch (FFB) yield could have occurred as a consequence of the fruit set gap which could have finally led to a decline in crude palm oil production. The fresh fruit bunch of oil palm could commence yielding at year five, however, between 8 to 18 years, the FFB peak yields were obtained (United States Department of Agriculture (USDA) 2019) and this can only be realized when the efficiency of the pollinator was high to attain substantial fruit set. Hence, the sustainability of the palm oil sector had been a prime focus and concern for Malaysia as a country (USDA 2019).

2.3. Relationship between pollinator weevil (Elaeidobius kamerunicus) and environmental factors on dura and pisifera families

There has been a continuous decline in the oil palm fruit set which has been reported by several researchers. Therefore, improved yielding genetic materials of oil palm that are robust to endure the threats of key pests and diseases could be vital in improving oil palm yield and for better economic returns during its production lifespan (Swaray et al., 2020). Also, due to restrictions in the rooting area, nutrient deficiency or toxicity, anaerobic conditions, and following poor growth and development, extreme soil moisture may be a limitation on crop production especially at the phase of the rainy season (Lahai et al., 2013; Johnson et al., 2017). Most researchers believed that the decline in fruit set was due to the low population of *E. kamerunicus*. The monthly trend, (taken between February 2019 to January 2020) between the most efficient oil palm pollinator weevil (*E. kamerunius*) and environmental factors [monthly precipitation/rainfall (MRF mm), monthly wind velocity (MWV km/hr), monthly sunshine hour/duration (MSH Wm^2), monthly evaporation rate (MER mm) and monthly average temperature (MAT ^oC)are shown in Fig.2.

The figure (Fig. 2) shows that the lowest and highest *E. kamerunicus* were recorded in August and September, and January, respectively. The highest MWV was recorded in May at 1,152.16 km/hr/month followed by March (1,143.50 km/hr/month), while February recorded the least at 753.20 km/hr/month. The lowest MSH was recorded in November (161.65 Wm^2) and March (255.10 Wm^2) recorded the highest followed by August at 231.12 hrs/decimals.

The highest MER (mm) was recorded in December (188.02 mm) with the least in November (85.80 mm). The MRF varied from 40.30 to 286.96 mm/month and it was observed that the lowest MRF was recorded in February, while the highest was recorded in December followed by November at 274.40 mm). The MAT varied from 27.10^{o}C to 30.78^{o}C and it was observed that the highest was recorded in January 2020, and the lowest in December 2019.

The illustration further shows that the highest PF/EK recorded in January could have been due to the environmental factors, such as the incidence of moderate

MSH, MWE, MRF, MER, and with a MAT of 28.48°C. However, the low EK population recorded in August and September 2019 could be due to very low rainfall, high wind velocity, high sunshine duration. The months with a decline in EK population and efficiency could be due to a combination of the genetic makeup of the progenies and some environmental factors in which wind velocity, sunshine duration, rainfall, including the growing medium were no exception. Yousefi et al. (2020) reported that the circumstances of change in climate with varying quantity in environmental factors and readiness of male inflorescence, influenced*E. kamerunicus's* performance in the loading of pollen and pollen viability. Planting materials, soil types, including other management practices could similarly affect weevil population and efficiency (Norman et al., 2018) thereby resulting in adecline in the oil palm fruit set.

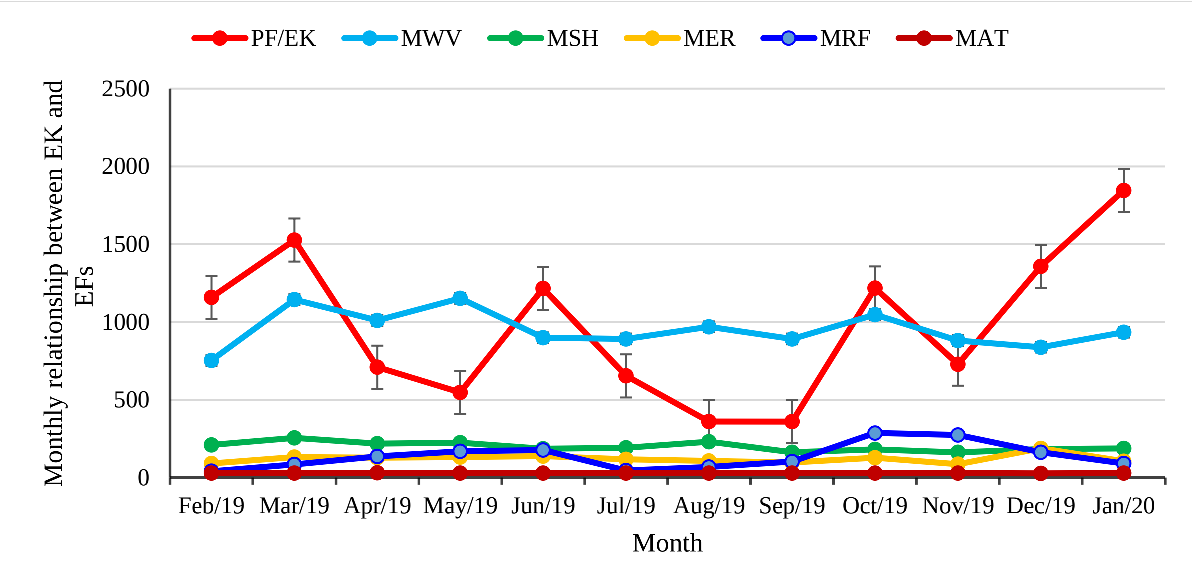

Fig. 2. Monthly relationship between Elaeidobius kamerunicus and environmental factors (precipitation, wind velocity, sunshine hour, evaporation, and temperature) on dura and pisifera genetic origins.

Note: (PF/EK) – monthly population force of *Elaeidobius kamerunicus*, (MRF) – monthly rainfall (mm), (MWV) – monthly wind velocity (km/hr), (MSH) – monthly sunshine hour/duration (Wm^2), (MER) – monthly evaporation rate (mm), (MT) – monthly temperature (°C).

IV. CONCLUSION

The analysis revealed that the genetic effect had a greater impact on the number of spikelets per male inflorescence, the length of the spikelet, and the population abundance of *Elaeidobius kamerunicus*. The highest population abundance of EK on anthesizing days was recorded on Day-3 and ECPHP500 was observed to record the highest weevils per inflorescence at 2367.94 ± 140.74 weevils on Day-3, followed by ECPHP550 at 2321.70 ± 142.45 weevils per inflorescence. However, on the fourth, fifth, and sixth days, a gradual decrease in population abundance of EK in all the progenies was noticed.A strong perfect relationship was established between Day-3 of anthesis with population abundance of EKper inflorescence of r = 0.99, $P < 0.0001$. The trial means and standard error of EK obtained from this study was 36830.14 ± 851.68 per ha with a range of 16,666.00 to 52,189.64 weevils per ha and ECPHP550 reported the highest population abundance of EKper ha. A decrease in the EK population was observed in Trial 0.502, but the productivity should have been able to hit above 60 percent of the fruit set despite the decline.

Also, the traits of the oil palm families and the population force of the *E. kamerunicus*were not significantly correlated, but fruit to bunch and fruit set was positively and significantly correlated. The relationship between the weevil and the oil palm traits indicated that Models two, four, and five had the best fit models among others. In general, the pollinator's effectiveness of this present study was low, based on the performance of the oil palm traits, as a result of population decline and its poor performance in pollination activities. It was further noticed that moderate rainfall and temperature will increase the weevil population and efficiency. However, to introduce additional pollinators into the existing oil palm plantations to overhaul the efficiency of EK is not required, but the factors that influence the population and the effectiveness of EK should be highly considered.

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Data Availability: Datasets used and analysed throughout the existing study are encompassed in this article.

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