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Pollinators of oil palm and relationship to fruitset and yield in two fruit forms in Ghana☆

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Abstract – Oil palm and its pollinators are native to Africa. Notwithstanding, it has been extensively cultivated outside its native range, so also has its pollinators been acquired and introduced. A concern, however is that most documentation on oil palm and its pollinators are non-indigenous, with little information of African origin commenting on their activities in Africa. Thus, a study on the insect pollinators of oil palm was carried out on two fruit forms: *Dura* and *Tenera*, (ages ten and seven, respectively), in Ghana. The aim was to understand how average monthly population density of the pollinators relates to one another, and to two bunch parameters (fruitset and fruit-to-bunch ratio). Nine species (all in the order Coleoptera) were consistently seen on the spikelets of anthesising male inflorescences, and eleven species on receptive female inflorescences. Six were of the *Elaeidobius* genus: *E. kamerunicus*, *E. plagiatus*, *E. singularis*, *E. subvittatus*, *E. bilineatus*, and *Elaeidobius* sp. 1 (unidentified species); two each were of the *Microporum* genus: *M. congolenses*, *M. dispar*, and the *Prosoestus* genus: *P. scuptilis*, *P. minor*; while one species was of either *Atheta* or *Forficula*. The pollinators were observed to be positively related, and to varying degree of significance. Fruitset level was acceptably high, indicating adequate pollinator population and efficient pollination. There was a positive relationship between population density of the pollinators and fruitset, and a negative relationship between the bunch parameters. A number of other insects were seldom observed around the male and female inflorescences; their role could not be defined.

Keywords: oil palm pollinators / *Dura*/*Tenera* fruit forms / *Elaeidobius* species / anthesising male inflorescence / receptive female inflorescence / population density

Résumé – Pollinisateurs du palmier à huile et relation avec la nouaison et le rendement de deux formes de fruits au Ghana. Le palmier à huile et ses pollinisateurs sont originaires d'Afrique. Malgré cela, il a été largement cultivé en dehors de son aire d'origine, de même que ses pollinisateurs ont été acquis et introduits. Il est toutefois préoccupant de constater que la plupart des documents sur le palmier à huile et ses pollinisateurs sont non indigènes, et que peu d'informations d'origine africaine commentent leurs activités en Afrique. Ainsi, une étude sur les insectes pollinisateurs du palmier à huile a été réalisée sur deux formes de fruits : Dura et Tenera (palmiers âgés respectivement de 10 et 7 ans), au Ghana. L'objectif était de comprendre comment la densité moyenne mensuelle de la population des pollinisateurs est liée à deux paramètres de la grappe (le nombre de fruits et le rapport entre les fruits et la grappe). Neuf espèces (toutes de l'ordre des coléoptères) ont été régulièrement observées sur les épillets des inflorescences mâles en anthèse, et onze espèces sur les inflorescences femelles réceptives. Six étaient du genre *Elaeidobius* :

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E. kamerunicus, *E. plagiatus*, *E. singularis*, *E. subvittatus*, *E. bilineatus* et *Elaeidobius* sp. 1 (espèce non identifiée) ; deux étaient chacune du genre Microporum : *M. congolenses*, *M. dispar*, et du genre Prosoestus : *P. scuptilis*, *P. minor* ; tandis qu'une espèce appartenait soit à Atheta, soit à Forficula. Les pollinisateurs ont été observés comme étant positivement liés, et à des degrés divers de signification. La quantité de fruits était élevée, ce qui indique une population adéquate de pollinisateurs et une pollinisation efficace. Il y avait une relation positive entre la densité de population des pollinisateurs et la quantité de fruits, et une relation négative entre les paramètres du bouquet. Un certain nombre d'autres insectes ont été rarement observés autour des inflorescences mâles et femelles ; leur rôle n'a pas pu être défini.

Mots clés : pollinisateurs / palmier à huile / *Dura* / *Tenera* / *Elaeidobius* / inflorescence / densité

1 Introduction

Oil palm is an important plantation crop, which is indigenous to Africa (Hartley, 1988), but extensively cultivated in many countries outside its native range. It is a high-yielding vegetable oil producing tree crop, which is able to produce oil from both the mesocarp of the fruit and the kernel; it produces more vegetable oil per unit area of land than any other crop (Qaim *et al.*, 2020). Oil palm is known to account for about 35–36% of the world's vegetable oil production and supply (Woittiez *et al.*, 2017; Meijaard and Sheil, 2019; Swaray *et al.*, 2021a), hence, stakes its claim as the world's most important, and largest source of edible vegetable oil commodity (Ngando-Ebongue *et al.*, 2013; Woittiez *et al.*, 2017). In Ghana, the oil palm is a major economic crop (Sapey *et al.*, 2017; Swaray *et al.*, 2021b) and the second most important cash crop after cocoa (Appiah and Agyei-Dwarko, 2013; Ofosu-Budu and Sarpong, 2013).

Pollination is an essential ecosystem service, which is fundamental to the reproduction and continuity of diverse species of flowering plant (Kevan, 1999; Stein *et al.*, 2017). It is a mutualistic, co-evolutionary interaction between plants and animals, which is crucial for sustainable crop production (FAO, 2011; Irshad and Stephen, 2014; Peace *et al.*, 2020). The importance of pollination and insect pollinators in bringing about adequate fruitset and desirable yield in oil palm and by extension ensuring an economically sustainable oil palm industry (Syed, 1979; Genty *et al.*, 1986; Auffray *et al.*, 2017; Siswanto and Soetopo, 2019) cannot be overemphasised. Malaysia and Indonesia – which dominate world production and trade of palm oil – as well as other non-African palm oil producing countries have been known to benefit – in terms of acceptable fruitset and improved yield – from the introduction of pollinating insect species from Africa (Syed, 1982; Basri, 1984; Mariau and Genty, 1988; Chinchilla and Richardson, 1991; Caudwell *et al.*, 2003; Swaray *et al.*, 2021).

Up until the late 1970s, there was very little evidence in literature to indicate that insects play an important role in oil palm pollination (Caudwell *et al.*, 2003, Appiah and Agyei-Dwarko, 2013; Swaray *et al.*, 2021). Hence, the oil palm was generally thought to be exclusively anemophilous – wind pollinated (Jagoe, 1934; Siew Kee, 1972; Syed, 1979; Appiah and Agyei-Dwarko, 2013; Robins, 2021). However, the constant occurrence of poor fruitset observed necessitated assisted pollination (Melendez and Ponce, 2016) so as to obtain satisfactory yield.

The work of Syed in Cameroon and Malaysia in the late 1970s and early 1980s, respectively, finally corrected this misconception. It was discovered that in addition to wind, insects were needed for pollination as well (Anggraeni *et al.*, 2013). More findings resulted in the conclusion that oil palm was in fact mainly pollinated by insects (Syed, 1982; Corley and Tinker, 2003; Aisagbonhi *et al.*, 2004; Melendez and Ponce, 2016; Haran *et al.*, 2020), and that the role of wind in pollination, especially during the wet season in Cameroon and Malaysia was limited. Eventually *Elaeidobius kamerunicus* – the major insect pollinator of oil palm in Cameroon – was introduced into Malaysia; assisted pollination ceased, saving cost and labour. This resulted in better fruitset, higher bunch weight and greater yield of fruits (Syed *et al.*, 1982; Apriyanto and Tambunan, 2020: Haran *et al.*, 2020). According to Basri (1984), the introduction resulted in a 36% improvement in fruitset, a 12% increase in fruit-to-bunch ratio and a 28% increase in mean bunch weight.

While the benefits of oil palm insect pollinators in these countries have been documented in literature, there is little information of African origin commenting on their activities in Africa, particularly West Africa. In order to address this observation and sustain industries that depend on oil palm produce, there is need for more research towards understanding the role played by insect pollinators, and how this can be explored, as well as factors that encourage or affect their activities on oil palm within the continent. It is in keeping with the call for more research and need to contribute to understanding of oil palm pollinators and their activities that this study on monthly population density of oil palm insect pollinators in relation to monthly fruitset and fruit-to-bunch ratio was undertaken in Ghana.

2 Materials and methods

2.1 Study area

The study was carried out at the Council for Scientific and Industrial Research – Oil Palm Research Institute (CSIR-OPRI), Kusi in the Denkyembour District of the Eastern Region of Ghana.

The area is located between latitudes 06.02° and 06.05° North and longitudes 00.52° and 00.54° West of Greenwich meridian; it has an elevation of 164 m above sea level (Danso, 2009), and lies within the semi-deciduous forest zone of Ghana; it possesses optimal conditions for the establishment of oil palm plantations (Yawson *et al.*, 2012).

2.2 Sampling location

Data was collected from two oil palm plots: K38 and K41a, planted to *Dura* and *Tenera* fruit forms, respectively. Plot K38 is a 10-acre plantation which was established in July, 2006, and is planted with *Elaeis guineensis Dura* accessions which were prospected from the wild for the purpose of conservation, evaluation and future utilisation, while plot K41a is 18.5 acres in size and was established in 2010 with *E. guineensis* D × P (*Tenera*) palms.

Due to the size of the plots, a "specific study area" measuring 2 acres (0.8 ha), and containing 120 trees was marked out from each plot for sampling of male inflorescences at full anthesis and female inflorescence at second day of receptivity. The marking out of plots was done to standardize the sampling procedure, and provide direction with sampling and consistency in data collection as samples were collected from within the specific study area.

2.3 Collection of insect pollinators from male and female inflorescences

Male inflorescences at full anthesis and female inflorescences at second day of receptivity were sampled within the first two weeks of each month, from August 2017 to May 2018, by adopting a "target sampling" approach. The target sampling approach was incorporated to achieve as much uniformity in data collection as possible. Preliminary survey of the field was done before the first week of each new month. During this survey, all palms (within the specific study area) whose inflorescence(s) (male and female alike) will probably be ready and useful for sampling within the first and second week of the new month, and most importantly will possess the right characteristic for sampling were identified and noted.

Insects were collected at hourly intervals from 8 am to 2 pm – which is the period of activity of the insects – by cutting three spikelets each, one apiece from basal, middle and top sections (Basri and Norman, 1997) of two male inflorescences, after which they were secured in a small, transparent polythene bag and labeled. Sampled inflorescence was re-visited after about a week when anthesis had stopped, and total number of all the spikelets in each inflorescences were counted and recorded. Sampling of the female inflorescences was at 10:30–11:00 am. Two inflorescences were cut and secured in a large, tough, transparent polythene bag. The sampled spikelets (of the male inflorescence) and the female inflorescences were taken to the CSIR-OPRI entomology laboratory and kept dry in the refrigerator. Separation of insects from the male spikelets and the female inflorescence, identification and sorting into constituent species, counting and recording was done afterwards. According to Swaray *et al.* (2021a), to estimate pollinator population and their activities in oil palm pollination, emphasis is placed on the male inflorescence and the pollinator weevil. As such, while data on insect pollinator population was collected on both male and female inflorescences, data from the male inflorescences is the basis on which discussion is based, relationship established and conclusions are made.

2.4 Bunch parameter data

During each month, data on two bunch parameters – fruitset and yield (fruit-to-bunch ratio) – was collected from female inflorescences pollinated at the time of sampling. Four female inflorescences (two per bunch parameter) for each fruit form were tagged with coloured ribbons. Harvesting of tagged inflorescences for fruitset data was scheduled for 2 months, while harvesting for fruit-to-bunch ratio data was scheduled for 4.5 months. Harvested bunches were taken to the CSIR-OPRI Fruit and Bunch analysis laboratory for normal bunch analysis.

3 Data analysis

Data was entered into Excel spreadsheet and imported into GenStat 12th edition and SigmaPlot version 10 for the analysis of average monthly population density of the insect pollinators, the plotting of bar graphs and regression analysis line graph. "R" (R Core Team, 2021) was used for correlation analysis to determine the relationship between average monthly population density of the insect pollinators and the bunch parameters. An accompanying correlation plot was generated using R package "corrplot" (Wei and Simko, 2021).

3.1 Estimated population density of insects on male spikelet and inflorescence

Estimated number of insects per spikelet (NIS) was calculated as: sum of total catches in "n" number of representative spikelets, divided by "n", while estimated number of insects per inflorescence (NII) was calculated as the product of average insect number per spikelet and total number of spikelets per inflorescence. These are mathematically expressed as follows:

$$\mathrm{NIS} = \frac{\mathrm{Ns}}{\mathrm{n}}, \tag{1}$$

where Ns = total number of insects in "n" number of spikelets and "n" = total number of representative spikelets (where n = 3 male spikelets).

$$\mathrm{NII} = (\mathrm{NIS} \times \mathrm{Ts}), \tag{2}$$

where Ts = total number of spikelets per inflorescence.

3.2 Estimated pollinator force (PF) of study area

Pollinator force (PF) of the study area was obtained by an adaptation of the methods described by Dhileepan (1994), and Basri and Norman (1997). It is the product of pollinator insect population in male inflorescence (*NII*) and number of anthesising male inflorescence per hectare per time. According to Dhileepan (1994), result from this formulation could represent (theoretically) the total number of weevils present in a unit area at a given time. The PF was estimated as follows:

$$\mathrm{PF} = (\mathrm{NII} \times \mathrm{Nm}), \tag{3}$$

where NII = (NIS × Ts and Nm = number of anthesising male inflorescences/ha/time of day.

3.3 Fruitset data per month

Fruitset data of bunches was obtained two months after pollination. Bunches were harvested and weighed; spikelet sample was obtained by dividing bunches into bottom, middle and top sections – a procedure known as chopping. Twenty representative spikelets (containing fruits) were randomly selected from each section, (giving a total of 60 spikelets). Fruits within each spikelet were counted, and the total number of fertile fruits (set fruits with nuts) and parthenocarpic (seedless) fruits were then determined and recorded. The total number of spikelets per bunch (*Ts*) was also counted and recorded.

Mathematical procedure to arrive at the percentage fruitset of harvested bunches are outlined as follows:

Average number of fruits per spikelet (*AFs*) in all 60 spikelet samples was obtained using the formula;

$$\mathrm{AFs} = \frac{\mathrm{Tf}n}{n}, \tag{4}$$

where AFs = average number of fruits per spikelet, and T*fn* = total fruits in "*n*" number of representative spikelets.

Similarly, average fertile fruits and average parthenocarpic fruits per spikelet in the 60 spikelet samples were determined by adapting the formula above to each case.

Next, the total number of fruits per bunch was calculated as the product of the average number of fruits per spikelets and the total number of spikelets per bunch. It was estimated as follows:

$$\mathrm{TNF} = \mathrm{AFs} \times \mathrm{Ts}, \tag{5}$$

where *TNF* = total number of fruits per bunch, *AFs* = average number of fruits per spikelet and *Ts* = total number of spikelets per bunch.

Similarly, total fertile fruits and total parthenocarpic fruits per bunch were determined by adapting the formula above.

Finally, the percentage fruitset level was calculated as the ratio of total fertile fruits to the total number of fruits per bunch, expressed in percentage (Chinchilla and Richardson, 1991).

$$\%\,\mathrm{FS} = \frac{\mathrm{TFF}}{\mathrm{TNF}} \times 100, \tag{6}$$

where *%FS* = percentage fruitset, *TFF* = total fertile fruits per bunch and *TNF* = total number of fruits (fertile and parthenocarpic) per bunch.

The fruitset data was matched with the average population density of each insect pollinator for the month pollination took place.

3.4 Yield component (fruit-to-bunch ratio) data per month

The yield data of tagged inflorescences for each month was obtained four and half months after pollination. Harvested bunches were first weighed to get the bunch weight (B.Wt) and then chopped. Stalk weight was taken after chopping, and subtracted from the initial bunch weight; the result became the standard by which the total chopped fruit per bunches was divided.

Each chopped bunch was then divided into two weights: weight of A (Wt.A) and weight of B (Wt.B). This division is based on a standard procedure where Wt.A must either be greater than, or equal to 5 kg (≥ 5 kg), and larger than Wt.B. Wt.A, underwent picking, a process whereby the fruits are separated from the spikelets, and the fruit sheath. The picked fruit were then weighed, to give the weight of fruit (Wt.Frt); empty spikelets weight was taken and recorded.

Thirty fruits, comprising ten outer fruits – well formed, big and well ripened (red) – and twenty inner fruits – angular, usually small and not well ripened (pale) – were randomly selected from the picked fruits and weighed; this gave the sample weight (S.Wt.). After weighing, the mesocarp was removed – a process called scraping – and weighed, giving the nut weight (N.Wt.). The nuts were dried in the sun for about four to five days, after which they were cracked and the kernel weighed, giving the kernel and shell weight.

Finally, the ratio of fruit weight to overall bunch weight (F/B) was arrived at, using the formula:

$$\mathrm{F/B} = \frac{\mathrm{Wt.C}}{\mathrm{B.Wt}} \times 100, \tag{7}$$

where Wt.C = fraction of fruit and B.Wt = bunch weight.

$$\mathrm{Wt.C} = \frac{\mathrm{Wt.Frt}(\mathrm{Wt.A} + \mathrm{Wt.B})}{\mathrm{Wt.A}}, \tag{8}$$

Fruit-to-bunch ratio data collected four and half months after pollination was matched with each pollinator insect population of the month pollination took place.

3.5 Correlation analysis

An all-inclusive correlation analysis was done on the cumulative average value of the studied variables to ascertain inter-relationship between average monthly pollinator insect population (on male spikelet) and their relationship to fruitset and fruit-to-bunch ratio. The analysis was done on a 5% threshold level of statistical significance (95% confidence intervals) and a correlation plot was generated to clearly show relationship among tested variables. In order to run the correlation analysis on the insect inventory dataset and physical characteristics of the bunches, each dataset was aggregated per month and put in relation to make a single dataset. The cumulative values of each variable were then accessed and their inter-correlation was done using the "corrplot" package on R software. Pearson correlation was used since it is the most appropriate for continuous variables.

3.6 Regression analysis

For confirmatory purposes, a simple regression analysis on average monthly values of the tested variables was done to ascertain relationship between the average population density of the insect pollinators as a single unit and percentage fruitset in the two fruit forms, as well as relationship between fruitset and fruit-to-bunch ratio; relationship was depicted using graphs.

Table 1. Other insect species found on oil palm inflorescence.

S/N	Species	Order	Family	Insect visit on inflorescence *Dura* Male	 Female	 *Tenera* Male	 Female
1	*Gnorimus variabilis*	*Coleoptera*	*Scarabaeidae*	√	x	√	x
2	*Oryctes rhinoceros*	*Coleoptera*	*Scarabaeidae*	x	x	x	√
3	Unidentified sp. 1	*Coleoptera*	*Scarabaeidae*	√	√	√	√
4	Unidentified sp. 2	*Coleoptera*	*Scarabaeidae*	√	√	√	√
5	Unidentified sp. 3	*Coleoptera*	*Scarabaeidae*	x	x	√	x
6	*Litargus connexus*	*Coleoptera*	*Mycetophagidae*	√	x	√	x
7	*Mycetophagus punctatus*	*Coleoptera*	*Mycetophagidae*	√	x	√	x
8	*Temnoschoita quadripustulata*	*Coleoptera*	*Curculionidae*	√	√	√	√
9	*Heterothops dissimilis*	*Coleoptera*	*Staphylinidae*	√	x	√	x
10	*Blattella orientalis*	*Dictyoptera*	*Blattidae*	x	x	x	√
11	*Chlorops* sp.	*Diptera*	*Chloropidae*	x	√	x	√
12	*Chlorichaeta tuberculosa*	*Diptera*	*Ephydridae*	x	√	x	√
13	*Megaselia rufipes*	*Diptera*	*Phoridae*	x	x	√	x
14	Unidentified sp. 4	*Diptera*	*Unknown*	√	x	√	x
15	*Oris insidiosis*	*Hemiptera*	*Anthocoridae*	√	x	√	x
16	*Pachycondyla* sp.	*Hymenoptera*	*Formicidae*	√	x	√	x
17	*Camponotus pensylvanicus*	*Hymenoptera*	*Formicidae*	x	√	x	√
18	*Monomorium pharaonis*	*Hymenoptera*	*Formicidae*	x	√	x	√
19	*Odontomachus* sp.	*Hymenoptera*	*Formicidae*	x	√	x	√
20	*Apis mellifera*	*Hymenoptera*	*Apidae*	√	x	√	x
21	Unidentified sp. 5	*Hymenoptera*	*Formicidae*	x	√	x	√

4 Result

4.1 Check list of insect species captured during sampling

Insects encountered throughout the study period included species of the order: *Coleoptera, Hymenoptera, Diptera, Hemiptera and Dictyoptera. Insect species of the order Coleoptera* constituted by far the majority of catches and were the only group that was consistently available on inflorescences throughout the period of study; the major pollinator insect group (*Elaeidobius*) belong to this insect Order.

Insect catches were predominantly from the male inflorescences of the two oil palm fruit forms: *Dura* and *Tenera* studied. The results of pollinator insects presented are average values, from the male spikelet and/or inflorescence except otherwise stated.

A checklist of a number of "other" insect species encountered either on or visiting the male and female inflorescence during the study is presented in Table 1.

4.2 Estimated population density of all insects

4.3 Male spikelet and inflorescence

Estimated mean population density of all insect species on a single male spikelet in *Dura* fruit form (Fig. 1a) was 169.3 insects per spikelet, with a range of 45.4 to 407.8, while in the *Tenera* fruit form (Fig. 1b) it was 181.5 insects/spikelets, with a range of 104.7 to 398.7. Minimum population density of 45.4 and 77.5, in the *Dura* fruit form was recorded in August and November, while minimum population density of 110.4, 104.7 and 105.3 in the *Tenera* fruit form was recorded in August and September 2017 and March 2018, respectively.

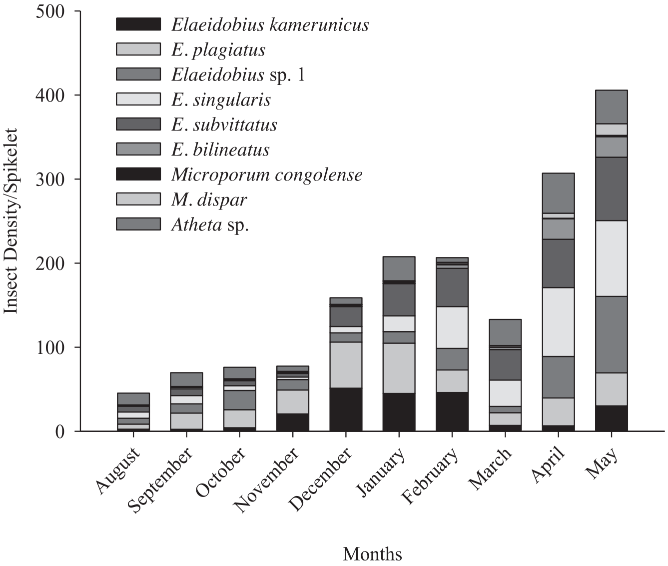

Fig. 1a. Cumulative insect population per male spikelet in *Dura* fruit form. Species legend (in Figs. 1a and 1b) should be matched with representative grayscale colours of each bar in reverse order from bottom to top.

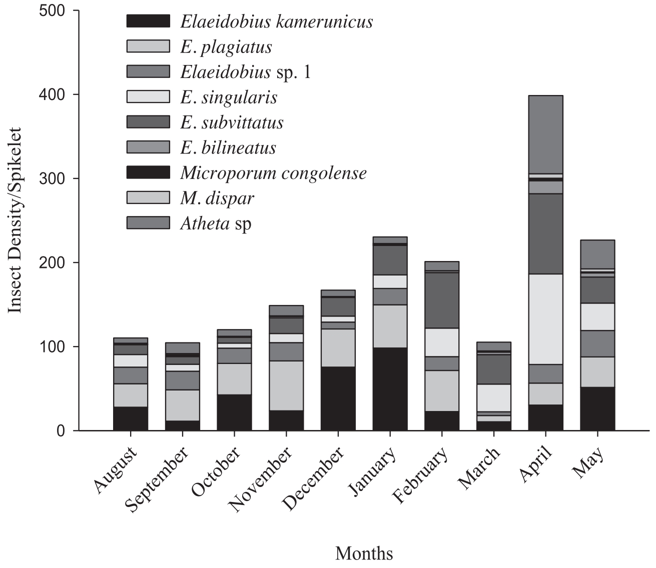

Fig. 1b. Cumulative insect population per male spikelet in *Tenera* fruit form.

Estimated mean population density of insects per inflorescence on the 10-year-old *Dura* palm (with an average of 130 spikelets/inflorescence) was 22 004.8, with a range of 5906.4 to 53 023.0, while mean population density per inflorescence in the 7-year-old *Tenera* palm (with 96 spikelets/inflorescence) was 17 422.4, with a range of 10 052.7 to 38 272.1.

4.4 Female inflorescence

Population density (plus or minus standard error of mean) of insects within the spikelets of the female inflorescence across the entire period of study is presented in Table 2.

In the *Dura* palms (Tab. 2a), the mean population density was 662.8 insects/inflorescence, with a range of 157.0 to 1858.5, while it was 358.8 insects/inflorescence, with a range of 53.0 to 1719.0, in the *Tenera* palms (Tab. 2b). Population density below 500 insects in the *Dura* fruit form (Tab. 2a) was recorded in five months: August, October, January, February and May, of the ten-month study period, with minimum population of 157.0 in October, while population density below 500 insects in the *Tenera* fruit form (Tab. 2b) was recorded in all months except May (which had a population of 1719.0); lowest population density of 53 insects was recorded in August.

4.5 Population dynamics of pollinator insect catches on male spikelets across period of study

The variation in average monthly population density (plus or minus standard error mean) of each pollinator insect species on a male spikelet (at full anthesis), in the two oil palm fruit forms, obtained during the period of study is presented in Figure 2.

In the *Dura* fruit form (Fig. 2a), the mean population density of *E. kamerunicus* per spikelet was 21.6, with a maximum population of 51.2 observed in December 2017. Population density in January and February 2018 (44.9 and 46.1, respectively) were equally high. A minimum population density was observed in August (2.5) and September (2.4) 2017; March and April 2018 also recorded low population density of 7.0 and 6.5, respectively, for the same species. Mean population density of *E. plagiatus* was 30.4, with a maximum population of 54.9 observed in December, while a minimum population of 6.0 was observed in August. May recorded a maximum population density of 90.9 for *Elaeidobius* sp. 1, August recorded a minimum population of 7.0 for the same species, while the mean population density was 25.1. The mean population density of *E. singularis* and *E. subvittatus* were 30.6 and 30.2, respectively; a maximum population of 90.4 and 75.3, respectively, was observed in May in both species; both had a minimum population density of 3.1 and 4.3, respectively, in November.

Although a maximum population density of 24.4 was observed in April and May 2018 for *E. bilineatus*, the population density in other months was generally very low; hence a mean population density of 6.0 was obtained for the entire period of study. The population density of *M. congolenses* and *M. dispar* was also generally very low throughout the period of study. Nevertheless, maximum population for both species of 2.1 and 13.9, respectively, was recorded in May. Minimum population of the former was in September (0.1), while the latter was in August (0.2); their respective means were 0.9 and 2.8.

In the *Tenera* fruit form (Fig. 2b), the mean population density of *E. kamerunicus* per spikelet was 39.4 with a maximum population density of 98.2 observed in January, and a minimum population density of 11.2 and 10.5 in September 2017 and March 2018, respectively. The mean population density of *E. plagiatus* was 37.8, with a maximum population density of 59.3 observed in November 2017 and a minimum population density of 7.5 in March 2018. A maximum population density of 31.4 for *Elaeidobius* sp. 1 was recorded in May, while a minimum population density of 4.5 was in recorded in March; the mean population density was 18.4. Maximum population density for *E. singularis* (107.7), *E. subvittatus* (95.5), *E. bilineatus* (15.5), *M. congolenses* (3.0), and *M. dispar* (5.3) were all observed in April, while minimum population density was in different months for each species. Their respective means were 27.1, 33.1, 3.0, 0.9, and 1.3. A minimum population density of 6.1 and 7.0 for *E. singularis* and *E. subvittatus*, respectively, was recorded in October. The population density of *E. bilineatus*, *M. congolenses* and *M. dispar* was generally low during the study period, hence population as low as 1.0 was observed in several months.

The population of *Atheta* (which is not a pollinator but was included due to their generally high numbers, and consistent availability on only the male spikelet during the period of study) in the *Dura* fruit form was highest in April (47.6) and lowest in November (6.3), with overall mean of 21.1. In the *Tenera* fruit form, a maximum population density of 92.9 was observed in April, while a minimum population density of 6.3 was observed in August; overall mean was 20.3.

Table 2a. Population density of insects within the spikelets of the female inflorescence in *Dura* fruit form.

Month	E.K	± SEM	E.P	± SEM	E.sp. 1	± SEM	E.Si	± SEM	E.Sb	± SEM	E.B	± SEM	M.C	± SEM	M.D	± SEM	P.S	± SEM	P.M	± SEM	F.A	± SEM	Total
August	0.5	0.5	0	0	0	0	1.5	0.5	1	1	0	0	0	0	0	0	29	7	354	71	3	1	389
September	0	0	1	1	2	1	2.5	1.5	0.5	0.5	0	0	0	0	0	0	90.5	30.5	443.5	319.5	24	24	564
October	0.5	0.5	1	0	1.5	1.5	0	0	0.5	0.5	0.5	0.5	0	0	0	0	14	11	137	114	2	0	157
November	1	1	0	0	0.5	0.5	0.5	0.5	0	0	0	0	0.5	0.5	0	0	18	7	1215	478	5.5	2.5	1241
December	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44.5	9.5	503.5	89.5	7.5	1.5	556.5
January	3.5	3.5	0	0	0	0	6	6	4.5	4.5	0	0	0	0	0	0	37	26	396.5	246.5	0.5	0.5	448
February	8.5	1.5	0	0	0	0	1	1	3.5	3.5	0.5	0.5	0	0	0	0	19.5	19.5	196	192	0	0	229
March	0	0	0	0	0	0	11	8	5	4	0.5	0.5	0	0	0	0	55	3	664	257	10	5	745.5
April	7.5	5.5	0	0	1.5	1.5	86.5	80.5	25	21	2	1	0	0	0	0	101.5	21.5	1599	16	35.5	35.5	1858.5
May	2	1	0.5	0.5	4	4	26	25	11	9	4	4	0	0	2	2	15	4	374.5	296.5	0	0	439

E.K: *Elaeidobius kamerunicus*; E.P.: *E. plagiatus*; E.sp. 1: *Elaedobius* sp. 1 (Unidentified sp); E.Si: *E. singularis*; E.Sb: *E. subvittatus*; E.B: *E. Bilineatus*; M.C: *Microporum congolenses*; M.D: *M. dispar*; P.S: *Prosoestus scuptilis*; P.M: *P. minor*; F.A: *Forficular auricularia* (Earwig); ± SEM: ± Standard Error Mean.

Table 2b. Population density of insects within the spikelets of the female inflorescence in *Tenera* fruit form.

Months	E.K	± SEM	E.P	± SEM	E.sp. 1	± SEM	E.Si	± SEM	E.Sb	± SEM	E.B	± SEM	M.C	± SEM	M.D	± SEM	P.S	± SEM	P.M	± SEM	F.A	± SEM	Total
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	30	18	22.5	7.5	53
September	3.5	3.5	1.5	0.5	1	0	0	0	0	0	0	0	0	0	0	0	14	0	37.5	3.5	13.5	3.5	71
October	0.5	0.5	2.5	2.5	0	0	0	0	1	1	0.5	0.5	0	0	0	0	15.5	8.5	322.5	246.5	17.5	8.5	360
November	3.5	3.5	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	12	3	308.5	161.5	63	59	387.5
December	3.5	3.5	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	12	12	147	124	30.5	0.5	193.5
January	1.5	0.5	1	1	0	0	1	1	0.5	0.5	0	0	0.5	0.5	0	0	19.5	5.5	341	159	5.5	1.5	370.5
February	2	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	0	0	0	0	0	10.5	0.5	202.5	105.5	0.5	0.5	217.5
March	2	1	0	0	0	0	12	12	6	6	3	3	0	0	0.5	0.5	62.5	59.5	3.5	2.5	8	5	97.5
April	11.5	5.5	1	1	1	1	16.5	15.5	8.5	7.5	0	0	0	0	0	0	1	1	56.5	26.5	22	3	118
May	2.5	0.5	0	0	0.5	0.5	13.5	2.5	1	1	0	0	0	0	0	0	13.5	0.5	1660.5	450.5	27.5	7.5	1719

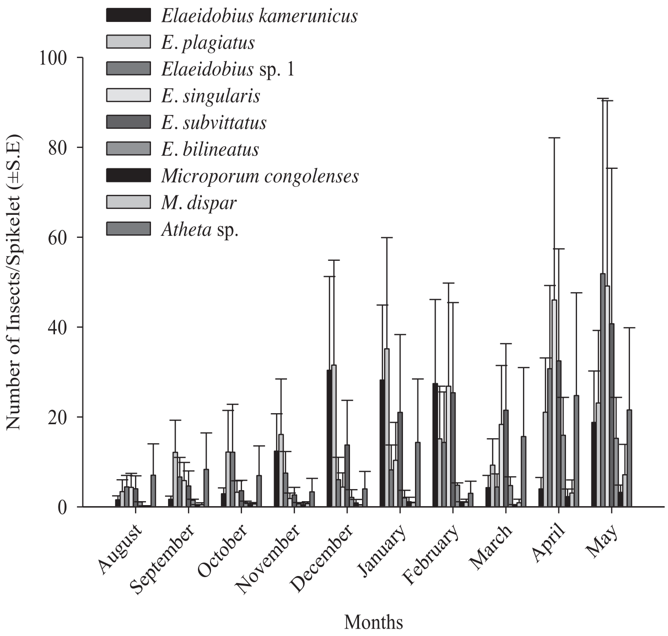

Fig. 2a. Pollinator insect population (± SEM) across period of study in *Dura* fruit form.

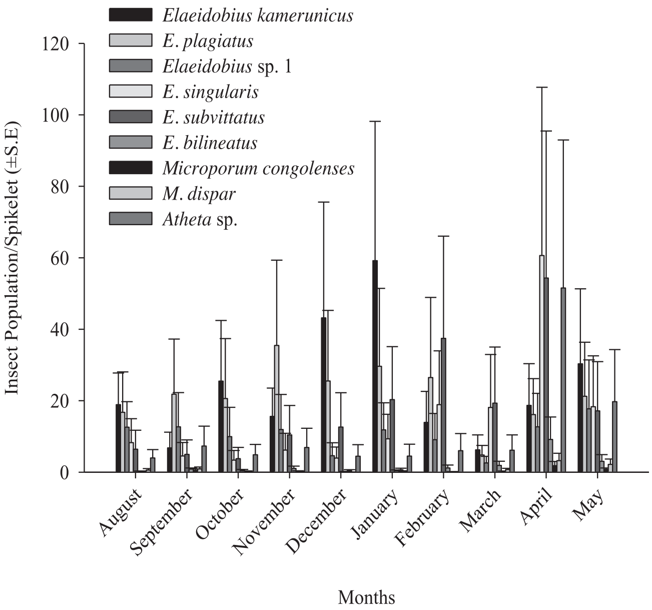

Fig. 2b. Pollinator insect population (± SEM) across period of study in *Tenera* fruit form.

4.6 Estimated pollinator force (PF) in study area

Tables 3a and 3b show estimated pollinator force within the study area. Data used to compute this result was from the male inflorescence.

Within the *Dura* plot, estimated mean monthly pollinator force for the entire period of study was 134 378.8, with a range between 28 583.8 and 332 901.1.

In the *Tenera* plot, estimated mean monthly pollinator force for the entire period of study was 108 137.1, and ranged between 61 570.8 and 205 332.0.

4.7 Correlation analysis

The correlation analysis to show relationship amongst the insect pollinators in the two fruit forms, as well as their relationship to fruitset and fruit-to-bunch-ratio, shows interesting correlation as depicted in the accompanying correlation plots (Fig. 3).

The correlation plot is graduated in ascending order of coefficient from −1 to +1, along a heatmap of differing colour intensity. The symbol of the number graduation indicates the kind of relationship (negative or positive) that exists between variables, while the heatmap shows how strong the correlation between variables is Furthermore, the p-value (level of significance) is indicated by the number of stars present, with one star indicating low significance ($\leq$ 0.05), two stars indicating moderate significance ($\leq$ 0.01) and three stars indicating high significance ($\leq$ 0.001). No significance is indicated by the absence of star ($>$ 0.05).

4.7.1 Relationship amongst insect pollinators

The result showed that all insect pollinators were positively correlated to one another in both the *Dura* and the *Tenera* fruit forms (see Figs. 3a and 3b). The relationship was however highly significant (three stars) in all pollinator insect interactions in the two fruit forms, except in interaction between *E. bilineatus* and *E. plagiatus*, *E. bilineatus* and *M. congolenses* for the *Dura* fruit form (Fig. 3a), and *E. singularis* and *E. subvittatus* for the *Tenera* fruit form (Fig. 3b), where the relationship was moderately significant (two stars). Relationship between *E. bilineatus* and *E. kamerunicus*, *E. bilineatus* and *E. subvittatus* for the *Dura* fruit form, and *M. congolenses* and *Elaeidobius* sp. 1, *M. dispar* and *E. subvittatus*, and between *M. congolenses* and *E. kamerunicus* for the *Tenera* fruit form were of low significance (one star). Relationship was not significant between *M. congolenses* and *E. bilineatus*, and between *M. congolenses* and *E. subvittatus* in the *Tenera* fruit form.

4.7.2 Relationship between pollinator insect population and fruitset

Average fruitset level per month during the period of study was 67.1% and 68.0% in the *Dura* and *Tenera* fruit forms, respectively. Figures 3a and 3b equally show the relationship between average monthly percentage fruitset values and average monthly pollinator insect population density per spikelet of the male inflorescence in the two fruit forms. The result generally showed a positive relationship between each pollinator insect population and fruitset in the two fruit forms. A look at the level of significance revealed a highly significant correlation between *E. bilineatus* and fruitset, a moderately significant correlation between *Elaeidobius* sp. 1, *M. dispar*

Table 3a. Pollinator force in *Dura* fruit form.

Months	*E. kamerunicus*	*E. plagiatus*	*Elaeidobius sp. 1*	*E. singularis*	*E. subvittatus*	*E. bilineatus*	*M. congolenses*	*M. dispar*	Cum. Total	Avg. No. Anth. Infl.	Estimated PF
August	319	783	910	969	898	145.5	27.9	31	4083.4	7	28 583.8
September	313	2504	1427	1285	1040	219.8	15.5	117.6	6921.9	7	48 453.3
October	548	2789	2965	752	768	86.7	99	123.8	8131.5	7	56 920.5
November	2690	3699	1597	399	563	52.6	108.3	148.6	9257.5	7	64 802.5
December	6661	7135	1433	984	3083	49.5	213.6	61.9	19 621	7	137 347
January	5838	7788	1789	2442	4983	37.1	278.6	133.1	23 288.8	7	163 021.6
February	5995	3488	3321	6472	5906	557.1	148.6	222.9	26 110.6	7	182 774.2
March	907	1965	953	4089	4720	362.1	37.1	219.8	13 253	7	92 771
April	848	4309	6401	10 672	7463	3166.4	74.3	776.9	33 710.6	7	235 974.2
May	3928	5101	11 811	11 746	9793	3166.4	204.3	1807.6	47 557.3	7	332 901.1

Avg. No. Anth. Infl.: Average Number of Anthesising Inflorescences; PF: Pollinator Force.

Table 3b. Pollinator force in *Tenera* fruit form.

Months	*E. kamerunicus*	*E. plagiatus*	*Elaeidobius sp. 1*	*E. singularis*	*E. subvittatus*	*E. bilineatus*	*M. congolenses*	*M. dispar*	Cum. Total	Avg. No. Anth. Infl.	Est. PF
August	2663	2693	1895	1435	1129	29.7	32	98.3	9975	7	69 825
September	1074	3575	2137	798	869	112	91.43	139.4	8795.83	7	61 570.8
October	4078	3589	1744	583	665	73.1	34.29	9.1	10 775.49	7	75 428.4
November	2261	5696	2089	1045	1792	162.3	36.57	20.6	13 102.47	7	91 717.3
December	7255	4347	793	677	2135	22.9	68.57	6.9	15 305.37	7	107 138
January	9426	4937	1865	1554	3371	61.7	107.43	36.6	21 358.73	7	149 511
February	2171	4695	1579	3259	6341	192	13.71	16	18 266.71	7	127 867
March	1003	718	427	3161	3362	294.9	29.71	102.9	9098.51	7	63 689.6
April	2914	2514	2117	10 341	9166	1483.4	288	509.7	29 333.1	7	205 332
May	4926	3490	3017	3127	2971	473.1	114.29	352	18 470.39	7	129 293

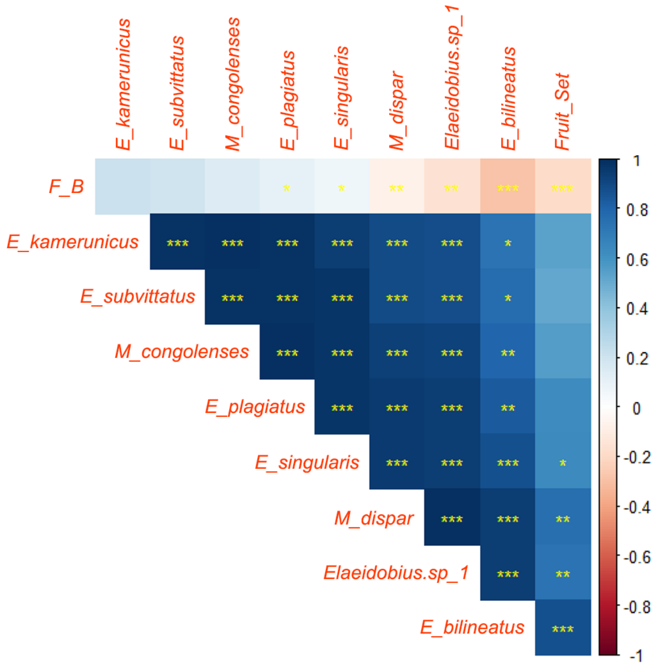

Fig. 3a. Inter-relationship between pollinator insect population density per male spikelet and relationship to % fruitset and fruit-to-bunch ratio in *Dura* fruit form.

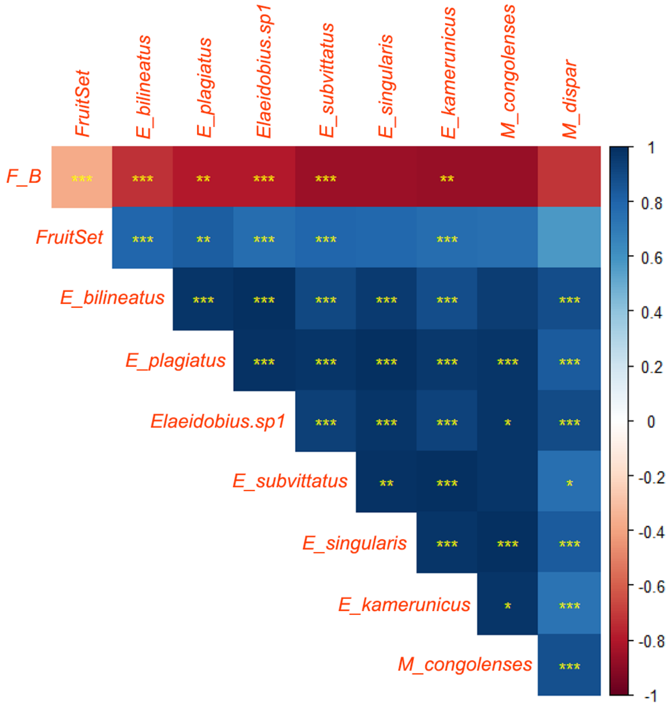

Fig. 3b. Inter-relationship between pollinator insect population density per male spikelet and relationship to % fruitset and fruit-to-bunch ratio in *Tenera* fruit form.

and fruitset, and a low significant correlation between *E. singularis* and fruitset in the *Dura* fruit form. In the *Tenera* fruit form (Fig. 3b), there was a highly significant correlation between *E. kamerunicus*, *E. subvittatus*, *E. bilineatus*, *Elaeidobius* sp. 1 and fruitset; correlation was moderately significant between *E. plagiatus* and fruitset.

4.7.3 Pollinator insect population and yield (fruit-to-bunch)

The result as observed *via* the correlation plot (Figs. 3a and 3b) presents an interesting correlation between the average monthly population density of insect pollinators and fruit-to-bunch ratio in the two fruit forms. The relationship between the insect pollinators and fruit-to-bunch ratio was basically evenly divided in the *Dura* fruit form, with some of the pollinators (*E. kamerunicus*, *E. subvittatus*, *M. congolenses*, *E. plagiatus*, and *E. singularis*) showing positive correlation with fruit-to-bunch ratio, while others (*M. dispar*, *Elaeidobius* sp. 1 and *E. bilineatus*) showing negative correlation with fruit-to-bunch ratio. In the *Tenera* fruit form however, all insect pollinators showed negative correlation with fruit-to-bunch ratio. Further exploration of the correlation plot showed that in the *Dura* fruit form, there was a high significant correlation between *E. bilineatus* and fruit-to-bunch ratio, moderate significant correlation between *Elaeidobius* sp. 1, *M. dispar* and fruit-to-bunch ratio, and low significant correlation between *E. singularis*, *E. plagiatus* and fruit-to-bunch ratio; there was no significant correlation between *E. kamerunicus*, *E. subvittatus*, *M. congolenses* and fruit-to-bunch ratio. In the *Tenera* fruit form, *E. bilineatus*, *Elaeidobius* sp. 1, *E. subvittatus* showed a highly significant correlation with fruit-to-bunch ratio, while *E. plagiatus*, *E. kamerunicus* showed a moderately significant correlation with fruit-to-bunch ratio; *E. singularis*, *M. congolenses*, *M. dispar* showed no significant correlation with fruit-to-bunch ratio.

From the result obtained, a more holistic interpretation of the above relationship between the insect pollinators and fruit-to-bunch ratio, warranted the need to ascertain the correlation between fruitset and fruit-to-bunch ratio. The result obtained in the two fruit forms showed that fruit-to-bunch ratio is negatively related to fruitset (Figs. 3a and 3b); the relationship was highly significant in both fruit forms.

4.11 Regression analysis

The simple regression analysis done to ascertain the relationship between the cumulative average pollinator insect population on a spikelet of the male inflorescence and fruitset, as well as relationship between fruitset and fruit-to-bunch ratio for confirmatory purposes, showed that there was a non-significant positive relationship between fruitset and cumulative average pollinator insect population (Figs. 4a and 4b), and a non-significant negative relationship between fruitset and fruit-to-bunch ratio (Figs. 5a and 5b) in the two fruit forms.

5 Discussion

As seen in this study, the spikelet of the oil palm male and female inflorescences are known to support a variety of insect species belonging to different insect orders as outlined in the result section. While the activities and functions of the major insect pollinator group (*Elaeidobius*) of the order *Coleoptera* is being focused on, leading to a number of targeted studies, the

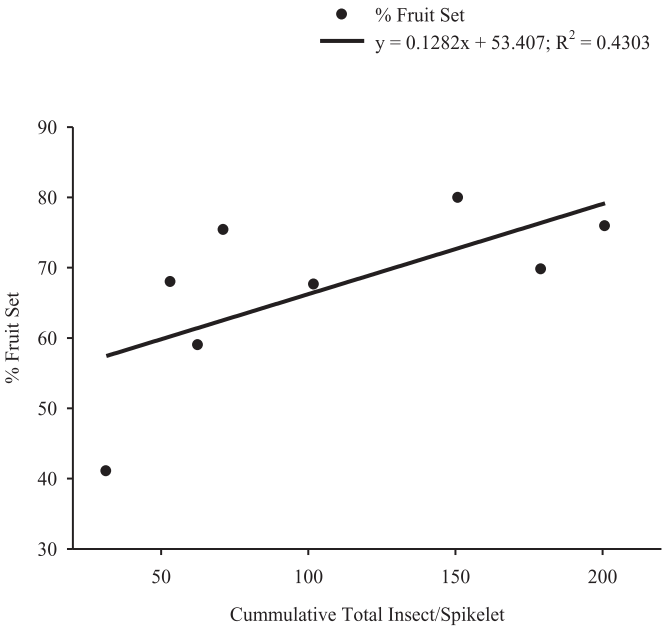

Fig. 4a. Relationship between cumulative total pollinator insect population density per male spikelet and % fruitset in *Dura* fruit from.

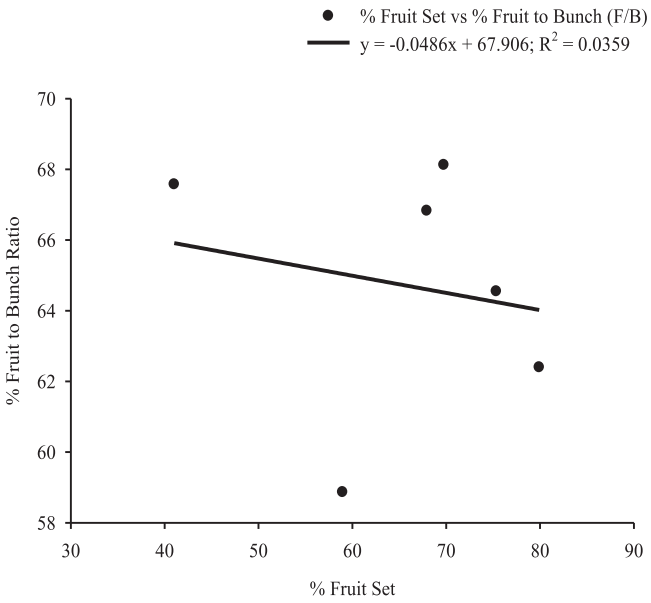

Fig. 5a. Relationship between % fruitset and % fruit-to-bunch ratio in *Dura* fruit form.

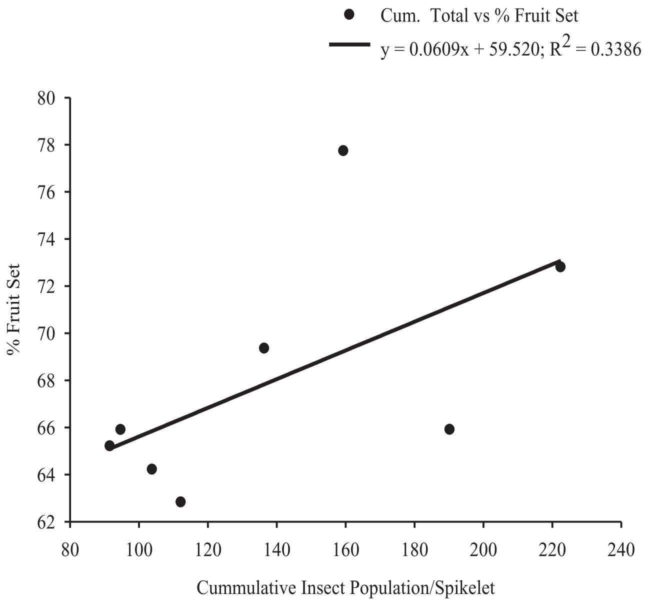

Fig. 4b. Relationship between cumulative pollinator insect population density per male spikelet and % fruitset in *Tenera* fruit from.

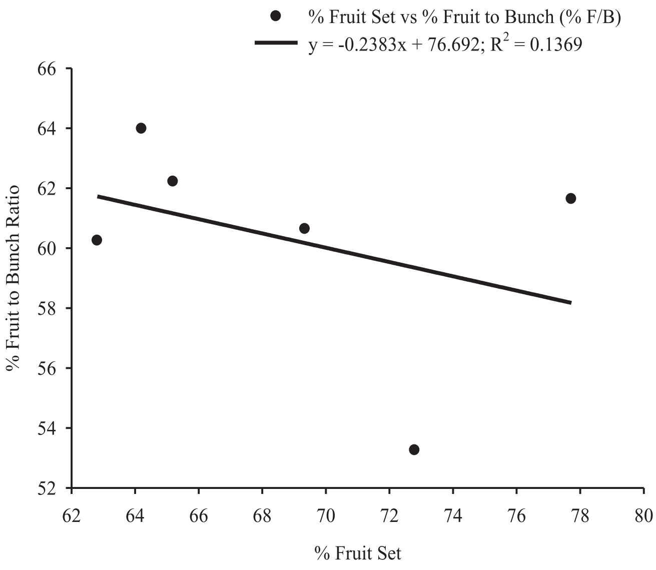

Fig. 5b. Relationship between % fruitset and % fruit-to-bunch ratio in *Tenera* fruit form.

activity and function of a number of other visiting insects found on the spikelet and inflorescence, have yet to attract much studies hence, their role have not been accurately defined. Notwithstanding the presence of these insect species is simply a pointer to the fact that the pollen produced by the oil palm inflorescence is attractive and desirable enough to accommodate a rich diversity of insect species.

The average monthly population density of the insect pollinators observed per male spikelet for the entire period of study on both oil palm fruit forms was within the range of result reported by Syed (1982) in Cameroon, and Aisagbonhi *et al.* (2004) in Benin City, Nigeria. Conversely, the average population density per spikelet in Ghana was generally higher than results obtained by Dhileepan (1994) in Kerala, India, Basri and Norman (1997) in Malaysia, Cik Mohd Rizuan *et al.* (2013) in Pahang, Malaysia, Yue *et al.* (2015) in Hainan Island in China, Daud and Ghani (2016) in Selangor, Malaysia, Siswanto and Soetopo (2020) in the PTP Nusantara VIII oil palm plantation in Cisalak, Baru, Indonesia, and Swaray *et al.* (2021a) in MPOB Teluk-Intan research station, Malaysia. Likely explanation to this occurrence is the fact that there are at least eight pollinator insect species: 6 *Elaeidobius* spp., 2 *Microporum* spp., not to mention the other sparsely occurring insects whose activities on the inflorescence haven't been clearly defined. Hence if resources (pollen) are readily available and conditions favourable, the average population density is expected to be comparatively higher due to the additive effect of species.

The average monthly population density of all insect pollinators (in terms of catches per spikelet) was higher in the *Tenera* fruit form than the *Dura* fruit form. On a species-by-species account, the average monthly population density of *E. kamerunicus*, *E. plagiatus* and *E. subvittatus* was higher in the *Tenera* fruit form, while average monthly population density of *E. singularis*, *E. bilineatus*, *Elaeidobius* sp. 1 and *M. dispar* was higher in the *Dura* fruit form. Estimated mean population density of these species per male inflorescence was however higher on the *Dura* fruit form. This was so because average number of spikelets per inflorescence in the *Dura* fruit form was more than that observed in the *Tenera* fruit form, thereby giving it a higher multiplicative advantage.

Although two different fruit forms were considered, a more credible explanation to the differences in the average number of spikelets per inflorescence is the fact that the *Dura* fruit form was 10 years of age while the *Tenera* fruit form was 7 years at the time of study. Several studies such as Corley and Gray (1979), Prasetyo *et al.* (2014), Siswanto and Soetope (2020), show that mean number of spikelets increases as the palm grow older. The average number of spikelets per inflorescence observed in the 10-year-old *Dura* palms sampled for this study was 130 while average number of spikelets in the 7-year-old *Tenera* palm sampled was 98. It would therefore seem that age difference between palms in the two fruit forms studied was the major reason for this occurrence. Notwithstanding, the suggestion that differences in average number of spikelets per inflorescence could also be as a result of the fact that *Dura* and *Tenera* are two different fruit forms should not be ruled out; this will however require targeted study on *Dura* and *Tenera* palms of the same age so as to make definitive conclusion.

It is noteworthy that irrespective of age differences, result obtained in this study, shows that the spikelet of the *Tenera* palms accommodated a higher population density of cumulative pollinator insects than the spikelets of the *Dura* palms. And while the intention is not to make absolute conclusions, this observation may be pointing to the fact the *Tenera* palms could possess qualities that encourages high pollinator insect population per unit spikelet; could it be that the pollen produced in the spikelets are more desirable? Could the average spikelet length of the *Tenera* palms be generally longer than that in *Dura*? Do the *Tenera* palms produce more pollen per unit spikelet? Could sex ratio be a factor? These are qualities that may give comparative advantage to the spikelet of the *Tenera* palm to support higher population density of cumulative pollinator insects, compared to the *Dura* palms. Furthermore, it may not be by chance that the population density of the generally acclaimed major insect pollinator, *E. kamerunicus* was higher in *Tenera*.

All except one insect species (*Atheta* sp.) found within the spikelets of the male inflorescences were frequently observed on the female inflorescences throughout the period of study. However, catches were smaller in the female than in the male inflorescence. Furthermore, there was a curious difference in species occurrence and diversity on the male and female inflorescences, as well as in their population density across the period of study. Only two species: *Prosoestus scuptilis* and *P. minor* occurred consistently, and in large numbers on the female inflorescences throughout the period of study and these also constituted species with the higher population density in each month. In general, *P. minor* was seen to have the highest population density in all the months throughout the period of study in both fruit forms, followed by *P. scuptilis* and then *Forficula auricularia* (Earwigs). Amongst the species of the *Elaeidobius* genus, *E. singularis* had the highest total population, followed by *E. subvittatus* and *E. kamerunicus* in the female inflorescence. Despite this, their numbers per month were still very low compared to the *Prosoestus* spp.

The result obtained is similar to that reported by Syed (1979). He showed that *Prosoestus* spp. as well as some earwigs (*F. auricularia*) dominated the insect catches found on receptive female inflorescence in Cameroon, with *P. minor* constituting the majority of catches. The result, however differ from the account of Yawson *et al.* (2012) who reported that *E. kamerunicus* was the predominant pollinator insect species on the female inflorescence in Ghana. According to Syed, most individuals of the *Prosoestus* species prefer to move from one female inflorescence to another with only few visiting the male inflorescence (Syed, 1979). Appiah and Agyei-Dwarko (2013) noted that *Prosoestus minor* are found on the female inflorescence, and that they function majorly as pollen distributors (Melendez and Ponce, 2016). Although, the population of the *Prosoestus* spp. constituted by far the majority of catches obtained in the female inflorescence, not even one of these species was found on the spikelets of the male inflorescence during the period of study; same was observed with *Atheta* sp., on the male inflorescence. This observation presents a curious case, especially if the implication of the very low number of *Elaeidobius* species (which are supposedly the major insect pollinators) on the female inflorescence on percentage fruitset is considered. The fact that the most consistent and readily abundant insect on the female inflorescence was never found in the male inflorescence during the period of study makes this observation all the more interesting. This is because the question of how pollination takes place in the female inflorescence begins to arise.

In a bid to explain this occurrence, it was realised that the sampling technique used in this study – which involved cutting of the full female inflorescence – may have influenced the nature of catches obtained. The sampling technique adopted was clearly seen to favour the catch of insects, which were resident within the spikelets of the female inflorescence rather than insects that will be termed as "landers" or "visitors", hence the high numbers of *Prosoestus* spp., and *F. auricularia*. Despite this, the result obtained has provided valuable confirmatory information on the entomofauna diversity of the oil palm female inflorescence in Ghana.

Various accounts on the activities of species of the *Elaeidobius* genus exist that supports this conclusion. According to Dhileepan (1994), each weevil (referring to *E. kamerunicus*) with its pollen load visited and remained on the female inflorescence for a few second to several minutes. Desmier (1981) and Mariau *et al.* (1991), reported that *E. kamerunicus* and *E. subvittatus* are both morning visitors on oil palm inflorescences in Africa. Yue *et al.* (2015) also made mention of visit by *E. kamerunicus* to oil palm inflorescence at specific times of the day, while Philipee (1993) reported that *Prosoestus* species carryout their entire life cycle on the female inflorescence. According to him, they however cause many damages to the stigma and the gynoecium of flowers in the process. From these accounts, it shows that the process of cutting the female inflorescence would either dislodge and/or scare away the visitor/landers, of which species of the *Elaeidobius* genus make up the majority. To further validate the claims made, an enquiry into the sampling technique adopted by some of the authors already mentioned, showed that sticky traps were used to sample in all these reports; leading to a high number of *Elaeidobius* species caught. This is expected because in the process of trying to land on the female inflorescences the visiting insects get stuck to the sticky gel smeared on the surface of the trap. Although Yawson *et al.* (2012) used similar sampling technique for the female inflorescence as adopted in this study, results obtained were inexplicably different as they had more catches of the supposed "visitor/landers" (*Elaeidobius* spp.), and they even made up majority of their catches.

Kevan *et al.* (1986) suggested the idea of quantifying weevil population as pollinator force (PF). PF is basically the measure of the number of weevils per unit area (Basri and Norman, 1997). Two major pollinator force estimates exist: Potential Pollinator Force (PPF) and Realistic Pollinator Force (RPF) (Dhileepan, 1994). While PPF estimates population density of weevil progeny emerging from male inflorescence per hectare, RPF estimates population density of mature adult weevil per hectare; an "adapted" Realistic Pollinator Force was obtained in this study. Most accounts on pollinator force are based on pollinator force per hectare (PF/ha). However, the pollinator force estimates obtained in this study was adapted to estimate the population density for 0.8 ha. In general, pollinator force range obtained in this study in both fruit forms was a lot higher than that reported in several accounts such as Dhileepan (1994), Basri and Norman (1997), Cik Mohd Rizuan *et al.* (2013), and Daud and Ghani (2016), despite being 0.2 ha less. The reason is that while estimated pollinator force in these accounts was on only *E. kamerunicus*, pollinator force obtained in this study was for eight species, as these were all found on spikelets of both the male and the female inflorescences in Ghana. Also, it should be taken into cognizance that the age of palm will also have its multiplicative effect on the final result of pollinator force of an area as older palms will have higher number of spikelets per inflorescence, hence higher pollinator force than younger palms.

The variability and subjectivity of directly relating fruitset to pollinator insect population density, and making conclusions out of results obtained, becomes more obvious if this relationship is probed further. According to Basri and Norman (1997), to effect adequate fruitset, a sufficient weevil population needs to be present; this is however difficult to determine. Several "population thresholds" have been put forward in literature as sufficient to achieve specific and desirable fruitset levels. For example, while Syed and Salleh (1987) suggested a "critical threshold" population of 700 weevils per female inflorescence, Basri and Norman (1997) realised that weevil number as low as 347 weevils per female inflorescence brought about satisfactory fruitset of 82%. In trying to ascertain sufficient weevil population on a per hectare basis that will be necessary to achieve acceptable fruitset, Donough *et al.* (1996) suggested that about 20 000 to 80 000 weevils per hectare would be required to effect a fruitset level of 55%, Dhileepan reported that a minimum number of 7000 (range 7000–80 000) weevils per hectare resulted in 60% fruitset, while the same fruitset level was achieved by even lower population density of 4711 (range 4711–30 000) weevils per hectare, as reported by Basri and Norman (1997).

Although the population density of pollinator insects obtained in this study was on a 0.8 ha plot area, the result nevertheless showed that very high population density of insect pollinators is capable of ensuring an acceptable fruitset level of 67.1% and 68.0% as observed in the *Dura* and *Tenera* fruit forms, respectively. A distinction of this study compared to most of those cited is the fact that six species of the *Elaeidobius* and other visiting insects contribute to pollination in the oil palm native range. Other studies cited were all conducted outside of the oil palm's indigenous range. It therefore explains why there is huge disparity in population density figures compared to that obtained in this study. While several threshold populations exist, as pointed out, it is important to note also that activities of pollen carrying insects on the female inflorescence cannot be adequately traced especially in answering questions such as the number of times an individual insect species visit the female inflorescence with pollen. It is therefore safe to conclude that sufficient weevil population required to achieve acceptable fruitset levels may be unique to each location. Furthermore, although adequate pollinator weevil population is a major requirement to achieving acceptable fruitset levels, this alone may not suffice; several factors such as possible competition between coevolved pollinator species, pollen availability and viability and/or other antagonistic interactions are as important as pollinator numbers, and may reduce pollination efficiency.

As observed in this study, all insect pollinators were positively correlated to one another in the two fruit forms, and majority of this relationship was highly significant amongst species, thus suggesting that an increase in the population density of one insect will be associated with an increase in population density of the other. This observation seems to throw more light on the curious question of how the multiple number of pollinator insect species are able to exist and sustain their existence. The results obtained simply indicates that there is a unique cooperation and co-existence amongst species on the spikelet and inflorescence, hence a pointer to a relationship that can be termed as "competitive-mutualism". The coined term is inferred because resources (*e.g.*, pollen, space) are shared, hence, it is expected that there will be some sort of competition amongst the pollinator species. However, each species is able to continue its existence in the presence of the other. From the result obtained, while some species consistently had higher population density than others throughout the period of study, this is no indication to assume that the interaction amongst the pollinator species is any of commensalism, parasitism or amenalism. Though a case can be made that the interaction is mutualistic, the fact that resources have to be vied for, negates this argument. Furthermore, the interaction cannot be said to be a pure competition/predation either as there is no proof to clearly conclude that the existence of one species is detrimental, or displaces, or excludes the other. In fact, it has been mentioned that pollinator population was positively correlated to one another. Another possible interaction that can be considered is competitive exclusion; this is however not tenable as much study has to be done to validate this assumption. At best, the pollinators could simply be showing that different species may be better adapted to certain conditions (internal *e.g.*, physiological response to inflorescence odour and/or external *e.g.*, effect of climatic factors), which gives them a comparative advantage over the others per time.

The work of Auffray *et al.* (2017), comments on coexistence amongst insect pollinators. According to them, coexistence is important among insect species as resources such as shelter, food and breeding site are in short supply as such need to be managed well for all to benefit. Result obtained in this study is supported by that of Basri and Norman (1997), who observed a mutualistic relationship amongst three different insect species (*Thrips hawaiiensis*, *E. kamerunicus* and *Pyroderces* sp.) on oil palm. Other works such as Syed (1982), Mariau *et al.* (1991) all support coexistence amongst insect pollinators on spikelet and inflorescence of oil palm. In addition, Anggraeni *et al.* (2013) attributed coexistence between *E. kamerunicus* and *T. hawaiiensis* to resource partitioning and different foraging time. They opined that both species respond differently to the smell of the volatile compound emitted by the oil palm inflorescences, which in turn creates a form of resource partitioning, expressed by their different foraging time. Riley *et al.* (2021) explained the observation of coexistence amongst pollen-loving insects on oil palm male inflorescence on a diurnal scale. According to them, the coexistence of oil palm pollinators is made possible due to a combination of internal and external factors that makes them active at slightly different time of the day. In essence, they stated that some species will be more active (with potential for maximum population density) at certain times of the day (*e.g.*, 8 am to 10 am), while others will be more active at other times of the day (*e.g.*, 12 pm to 2 pm).

The positive correlation observed between population density of each insect pollinator and fruitset, in both fruit forms, basically suggests that high population density of insect pollinators will bring about corresponding high fruitset levels, while low population density of insect pollinator will bring about the reverse condition. This result is similar to that obtained by Dhileepan (1994), Basri and Norman (1997) and Kouakou *et al.* (2014). According to Dhileepan, fruitset is positively correlated with pollinator force of *E. kamerunicus*; this was further confirmed by a backward stepwise regression. Basri and Norman (1997) also observed a positive correlation between actual pollinator forces per hectare of *E. kamerunicus* and fruitset, however, the relationship was non-significant. Kouakou *et al.* (2014) obtained significant positive correlation between monthly population density of three species of the *Elaeidobius* genus: *E. kamerunicus*, *E. plagiatus* and *E. subvittatus* and fruitset, in a controlled laboratory experiment to test efficacy of these pollinators. The result obtained in this study varies largely with that of Cik Mohd Rizuan *et al.* (2013) who reported that mean weevil population per spikelet as well as pollinator force per hectare did not significantly influence fruitset performance; this conclusion was made based on a non-significant negative relationship observed between mean weevil population in both cases and fruitset.

The observation where only *E. bilineatus* was seen to show a very strong positive and highly significant correlation with fruitset in the *Dura* fruit form, and more species (*E. kamerunicus*, *E. subvittatus*, *E. bilineatus* and *Elaeidobius* sp. 1) showed a strong positive and highly significant correlation with fruitset in the *Tenera* fruit form, suggests that the *Tenera* palms may be more dependent on activities of insect pollinators, and may require more insect pollinators to achieve required percentage fruitset level than the *Dura* fruit form. This may also be indicative of the fact that the *Tenera* palm is able to produces more pollen per unit area of the inflorescence spikelet than the *Dura* palm. In addition, while pollination in oil palm is predominantly carried out by insects, wind assisted pollination cannot be ruled out completely. It could be that a unit pollen in the *Dura* fruit form is less weighty than in the *Tenera* fruit form, hence has higher potential to be easily dispersed by wind. While it is known that all the insect pollinators will collectively exert their effect in order to achieve fruitset, the result obtained in this study (Figs. 3a and 3b) is quite unique as it presents relationship between fruitset and individual pollinator insects. Thus, the relationship and level of significance of each insect pollinator to fruitset can be better understood and appreciated. Furthermore, the result as presented by the correlation plot, gives the added advantage of being able make very basic distinction amongst the species.

A closer look at the correlation plot generated showed that though the relationship between the insect pollinators and fruitset is positive, it can be observed from the heat map that majority of the pollinator insect species in the *Dura* fruit form lies roughly within the lower to mid positive range of +0.2 to +0.5, while those in the *Tenera* fruit form lie within both the lower and high positive range of +0.3 to +0.7. The range observed in the two fruit forms may not be a coincidence, as a very strong positive relationship of correlation coefficient (near +1) could have invariably insinuated that an absolute relationship exists. Furthermore, such result could mean that as population density of the pollinators continues to increase so will fruitset levels continue to increase and that high pollinator population will always cause high fruitset level. This is however not obtainable because several other factors such as availability of pollen resources, pollen quality, response to inflorescence odour, climatic factors etc., will define to what extent the observed relationship will hold over time.

The work of Dhileepan (1994), and Basri and Norman (1997) seem to support this submission. Dhileepan stated that although fruitset levels increased and was generally acceptable after the introduction of *E. kamerunicus* to India, there were cases where higher fruitset (72–85%) was observed when the population of *E. kamerunicus* was minimum, while lower fruitset levels (47–78%) was observed when weevil population was maximum. This led to the suggestion that fruitset appears to depend to a greater extent on male inflorescence availability (pollen source) than on the pollinator population; a similar observation was made by Basri and Norman (1997) in Malaysia supports this submission. According to them efficiency of *E. kamerunicus* seemed to be greater when the weevil population per spikelet was very low (18.7 weevil/spikelet), resulting in fruitset level of about 84.9%, while high weevil population of 99.2, resulted in reduced pollination efficiency expressed by a 72.9% fruitset level. They therefore concluded that this reduction in pollination efficiency was presumably associated with intra specific competition for pollen resource, thus reducing their ability to influence higher percentage fruitset.

The correlation plot heat map showed that the negative correlation between the insect pollinators and fruit-to-bunch ratio is generally stronger in the *Tenera* fruit form than in the *Dura* fruit form, so also is the number of insects that showed a highly significant correlation with fruit-to-bunch ratio. While the reasons for the observed occurrence is out of the scope of this study, it is however a known fact that the *Tenera* fruit form is derived from the cross between *Dura* and *Pisifera* parents, extensively produced in breeding programmes and cultivated on an industrial scale. A probable inference for the observed homogeneity in relationship between the insect pollinators and fruit-to-bunch ratio in the *Tenera* fruit form, compared to the relationship observed in the *Dura* fruit form may be that the *Tenera* palm is likely to be more genetically homogenous in a plot than the *Dura* palm. Thus, it is expected that the effect of insect pollinator activities will be likely homogenous in its expression. This submission is by no means a conclusion but at best a speculation and open for validation.

As mention earlier, the correlation plot comes with the advantage of being able to observe the direct relationship between the insect pollinators and fruit-to-bunch ratio, however, a more holistic interpretation of result can be achieved and a better understanding of relationship gained by establishing the correlation between fruitset and fruit-to-bunch ratio. Ascertaining the relationship between fruitset and fruit-to-bunch ratio, is plausible in the first place, as there was a positive relationship between the average monthly population density of the insect pollinators and fruitset in both fruit forms. Thus, from the correlation plot, it can be seen that a negative relationship exists between both bunch components in the two fruit forms studied, implying that as fruitset levels increases, fruit-to-bunch ratio decreases. Furthermore, it can be seen that the relationship between fruitset and fruit-to-bunch ratio is highly significant in the two fruit forms, suggesting that both bunch parameters are strongly related to one another. However, the relationship lies within the lower to mid negative range (−0.2 to −0.5) in the two fruit forms, as indicated by the heat map, thus suggesting that there may be an expected threshold level where the established relationship stops to exist.

Results obtained when taken strictly, differs from that of Basri and Norman (1997) and Harun and Noor (2002), as both accounts generally reported significant positive correlation between fruitset and fruit-to-bunch ratio. Nevertheless, a further look at Harun and Noor’s results showed that results obtained in this study may actually be similar and may in fact confirm both results. According to Harun and Noor (2002), fruit-to-bunch ratio from seventy bunches analysed, increased with fruitset to a maximum, then began to decrease with higher fruitset levels. Their explanation for this occurrence was the fact that very high fruitset levels can lead to a decrease in average fruit weight and hence result in lower bunch weight. Since fruit-to-bunch ratio is dependent on the number and weight of individual fruit, as well as weight of the entire bunch, a decrease in the last two bunch parameters as a result of high fruitset level could greatly affect fruit-to-bunch ratio. This is further supported by the fact that bunch weight in the same study, was observed to increase with fruitset to a maximum level and then started to decrease beyond that level of fruitset (Harun and Noor, 2002).

The negative relationship reported in this study, therefore agrees with the condition put forward by Harun and Noor (2002). This is because, fruitset levels of bunches analysed during this study was generally high hence there was no allowance to observe fruit-to-bunch ratio from very low fruitset levels. Furthermore, there was still a progressive increase in high fruitset levels of bunches across months of the study, as such resulting in lowering of fruit-to-bunch ratio and hence, a high tendency for a negative relationship. A look at the regression analysis graph (Fig. 5) confirms this submission. The graph showed that fruit-to-bunch ratio was higher at comparatively lower fruitset level than at high fruitset levels. For example, Figure 5b, shows that fruit-to-bunch ratio at about 64% fruitset level was higher (64% fruit-to-bunch ratio) than at 70% and 73% fruitset levels (61% and 53% fruit-to-bunch ratio, respectively). Also, analysis for the bunch parameters was run on a smaller sample size in the two fruit forms compared to that of Harun and Noor (2002), and this may have influenced the result obtained.

Though the generated correlation plot gives a clear indication of the relationship between individual pollinator insects and fruitset, it is interesting to note that the regression analysis run, which considered the effect of the pollinator insects as a cumulative unit on fruitset returned with a relationship that is positive but non-significant in the two fruit forms. This somewhat confirms the result already obtained from the correlation analysis and the accompanying correlation plot generated. The confirmation by the regression analysis is helpful, reason being that if all the pollinator insects on an individual species basis, were positively related to fruitset in the two fruit forms, it is therefore expected that if taken as a collective unit they will most likely exert their effect on fruitset and by extension fruit-to-bunch ratio, hence the same positive relationship will be maintained at the very least.

6 Conclusion

The potential of oil palm to provide important raw material for many industries, as well as its likelihood to bring about huge foreign exchange, have encouraged several countries in Africa, particularly in West Africa and the world over, to venture into its cultivation. In a bid to better our understanding of the activities of insect pollinators of oil palm, the relationship between pollinator insect population and two bunch parameters (fruitset and fruit-to-bunch ratio) was studied.

It was observed that fruitset levels in Ghana are high and generally acceptable hence indicating that the pollinator insect population is adequate for efficient pollination. Several accounts have however submitted that though high fruitset will be obtained by high pollinator insect number, excessively high pollinator insect number could begin to cause decline in fruitset level due to competition for pollen resources and inefficient pollination. Though result from this study showed that the population density of pollinator insects was high, fruitset levels were acceptable. Hence, we could only conclude that the threshold pollinator insect population appears to be location and time specific.

A negative relationship was seen to exist between fruitset and fruit-to-bunch ratio. Although the cited reference showed that both bunch parameters were positively related, there was provision for a threshold level when a negative relationship between both is obtainable. However, due to the small sample size, coupled with generally high fruitset level in Ghana, the threshold fruitset level at which fruit-to-bunch ratio is impacted in Ghana could not be ascertained, hence an area that needs further study to fully understand and appreciate the important role insects play in oil palm pollination and its ripple effect on several bunch parameters.

The study revealed the presence of a number of entomofauna within the female inflorescence. While their identity and occurrence within the inflorescence were confirmed, their role (whether positive or negative) could not be defined. Furthermore, observation where some pollinator insect species had higher population in the *Dura* palms than in the *Tenera* palm and vice versa, and the observation where the spikelet of the *Tenera* palms was seen to hold more cumulative pollinator insect population per spikelets than the *Dura* palms are areas that will be interesting for further confirmatory studies. It may be worthwhile to know if the speculation on possible homogeneity in species occurrence in the *Tenera* fruit form compared to the *Dura* fruit form as inferred from the result is valid. In addition, the suggestion that a unit pollen may be less weighty in the *Dura* palm than in the *Tenera* palm may be another aspect to consider for studies.

Conflict of interest

The authors assure that they do not have any conflict of interest to the submission and potential publication of this manuscript.

Data availability statement

Data can be made available on the request of the Journal Editor-in-Chief.

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