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POLLINATION ACTIVITY OF *Elaeidobius kamerunicus* FAUST IN OIL PALM AND COCOA (*Theobroma cacao* L.) INTERCROPPING SYSTEM IN INDIA

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ABSTRACT

Pollinating activity of Elaeidobius kamerunicus *Faust (Coleoptera: Curculionidae) was studied in oil palm-cocoa intercrop conditions in Andhra Pradesh, India. The study showed a high abundance of* E. kamerunicus *on anthesising as well as post-anthesised male inflorescences for a greater part of the year* i.e., *62.2 to 162.2 and 39.3 to 87.3 weevils/spikelet respectively. Although, pollinator density declined during summer months, it was sufficient for effecting satisfactory fruit sets. Peak activity was noticed in February. Pearson correlation analysis showed highly significant negative correlations between pollinator population and minimum, maximum and mean temperatures. Pollinator population peaked on 3rd day of anthesis on male inflorescences, and on 2nd day of anthesis on female inflorescences. Weevil activity recorded on the day of highest abundance during anthesis revealed a peak activity between 10:00-12:00 hr and 10:00-13:00 hr on male and female inflorescences respectively. Rat predation on the pollinator was noticed throughout the year with a higher level of predation during summer months. In spite of negative effects posed by abiotic and biotic factors,* E. kamerunicus *density and pollinating efficiency were high throughout the year for the purpose of achieving a higher fruit set (79.6%-93.6%). The practical implications of this knowledge are discussed.*

Keywords: *Elaeidobius kamerunicus*, fruit set, oil palm-cocoa intercrop, pollinating activity, rat predation.

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INTRODUCTION

Oil palm (*Elaeis guineensis* Jacquin) is known to be the highest edible oil yielding perennial crop, capable of yielding 4.0-5.0 million tonnes of palm oil and 0.4-0.5 million tonnes of palm kernel oil with good planting material, irrigation and proper management (Ministry of Agriculture and Farmers Welfare, 2018). In India, it is grown in an area of 0.32 million hectares under both rainfed and irrigated conditions (ICAR, 2019). Oil palm, being a monoecious crop and seldom both male and female inflorescences of the same plant simultaneously receptive, demands cross pollination. Several insect species are reported as natural pollinating agents, of which, *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae), is the most efficient insect pollinator of oil palm (Syed, 1979). It was introduced from Cameroon (West Africa) to Malaysia (Syed *et al.*, 1982) and subsequently to other oil palm growing regions of Southeast Asia, South Pacific Islands and India resulting in a significant increase in fruit set (Basri *et al.*, 1983; Dhileepan and Nampoothri, 1989). However, there have been reports of poor fruit set and decline in oil palm yield after few years of introduction, from many parts of the world due to population fluctuation of *E. kamerunicus.* It has been reported that poor fruit formation

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indicates insufficient pollination due to the low population of the oil palm pollinating weevil (Prasetyo *et al*., 2014). The population is affected by hot and dry weather conditions (Dhileepan, 1994; Prasetyo *et al.,* 2014; Syed, 1984), rainfall (Sugih *et al.,* 1996), lower male inflorescence density per hectare (Bulgarelli *et al.,* 2002; Rao and Law, 1998) and predation by rats, spiders (Ponnamma *et al.,* 2006; Siswanto and Soetopa, 2020) and parasitism by nematodes (Krantz and Poinar, 2004). Cropping systems normally play a vital role in the arthropod population dynamics. Conventional oil palm monoculture system is characterised with increased fluctuations in microclimate (Luskin and Potts, 2011), which can influence arthropod population density and diversity. Changes in air temperature within an area can influence the physiological conditions of arthropods, in particular, for specialist species like *E. kamerunicus,* preventing them from colonisation (Cornelissen, 2011) and affecting their activity either positively or negatively. Manipulating microclimatic conditions in oil palm plantations might bring a favourable environment for enhanced pollinator activity and thereby decrease bunch failure. Alley cropping in oil palm may have the potential to ameliorate unfavourable microclimate and increase the pollinator efficiency and oil palm yield. Several trials on oil palm intercropping systems with reference to profitability, compatibility and pest status are conducted globally (Bawa *et al.,* 2011; Dissanayake and Palihakkara, 2019; Gawankar *et al*., 2018; Reddy and Suresh, 2009; Van Leeuwen, 2019), yet, to date, no study is undertaken aiming to know the activity and pollinating efficiency of *E. kamerunicus* in oil palm intercropping systems in India. Globally too, such studies are scarce. Oil palm-cocoa (*Thebroma cacao* Linnaeus) intercropping is a popular cropping system owing to its multiple advantages in India (Bhagya and Suresh, 2018). However, there is a common biological threat caused by rats in this system. For instance, on oil palm, rats gnaw post-anthesised male inflorescences in search of immature stages of the pollinator and predate them, thereby reducing the pollinator density (Siswanto and Soetopa, 2020). On cocoa, rats damage ripe cocoa pods either directly by making holes and consuming cocoa beans or indirectly by biting and scratching the pods (Asunbo, 2021; Smith and Nott, 1988). So far, no attempts are made to know the rat activity and its predation on pollinating weevil in this system. Therefore, this study aimed to determine the seasonal and diurnal activity of *E. kamerunicus*; to know seasonal activity of rats and their predation on the pollinators; and to quantify the pollinator efficiency in terms of oil palm fruit set in spite of effect of abiotic and biotic factors in the oil palm-cocoa intercropping.

MATERIALS AND METHODS

Study Site

The study was conducted in a farmer's field at Suryaraopeta village, West Godavari District, Andhra Pradesh, India having oil palm (seven years old) intercropped with cocoa (six years old) in 10 ha of land. In this system, palm trees were planted in a triangular spacing of 9.0 m while, cocoa was planted in a spacing of 3.0 m in and between oil palm rows. The GPS coordinates for the study site is as follows: 16º49'35.0"N and 81º05'12.1"E.

Seasonal Variation of *E. kamerunicus* Population on Male Inflorescences

Number of weevils per male inflorescences were determined at monthly intervals from January 2014 to December 2015. Weevil population was recorded on 10 randomly selected male inflorescences from the first day of the anthesis and continued until it was complete. From each inflorescence, 15 spikelets (five each from the top, the middle and the bottom of the inflorescence) were selected, gently cut and placed individually in plastic bag and number of weevils congregating on each spikelet was then counted.

Seasonal Variation in Progeny Emergence

Ten post-anthesised male inflorescences (7-10 days after opening) were randomly selected each month from January 2014 to December 2015. From each inflorescence, 15 spikelets (five each from the top, the middle and the bottom of the inflorescence) were collected and placed in perforated transparent plastic containers (20 x 15 cm size) and maintained in the laboratory for progeny emergence. The number of weevil progeny emerging from the spikelets was recorded daily until no further emergence.

Activity of *E. kamerunicus* on Male and Female Inflorescences During Anthesis

Observations on the population of *E. kamerunicus* on both male and female inflorescences during the time of anthesis were taken on each five male and female inflorescences separately and the experiments were repeated twice at different periods to know the effect of stages of anthesis on weevil activity. Inflorescences that were about to enter anthesis were covered with cotton cloth bags of 60 x 40 cm size and firmly tied with twine around the collar portion of the inflorescence to prevent the entry of weevils into the inflorescences (*Figure 1*). To determine the number of weevils that visited inflorescences during the anthesis, the weevils that congregate on the surface of cotton bag were collected between 09:00 hr and 18:30 hr every day at every 2 hr interval using camel brush, secured in transparent polythene bag, labelled and counted in the laboratory later. Observations were continued from the first day of anthesis until the seventh day in case of male inflorescences and until the fifth day in case of female inflorescences.

Figure 1. Congregation of E. kamerunicus *on the surface of cotton bag covered on inflorescence.*

Diurnal Variation of *E. kamerunicus*

To understand the diurnal variation of *E. kamerunicus* visiting male and female inflorescences, weevils that congregate on the surface of cotton bag were collected gently on the third day and second day of anthesis for male and female inflorescences respectively (as initial observations revealed, the weevils visited in large numbers) at every hour from 08:00 hr to 18:30 hr. Collections were brought to the laboratory and the number of males and females were determined.

Effect of Rat Activity on *E. kamerunicus* Population

For estimating the rat damage, 20 palms were selected randomly every month starting from January 2014 to December 2015 and observations were recorded on rat incidence (number of palms with damaged male inflorescences/total number of palms x 100) and percent rat damage based on visual estimation in the scale of 5%, 10%, 25%, 50%, 75% and 100% damage on male inflorescences.

Effect of *E. kamerunicus* Population on Fruit Set

Ten post anthesis female inflorescences were randomly selected and marked on every month from January to December 2015 at the time of taking census of *E. kamerunicus* on male inflorescences. Marked ripe bunches were harvested at about five to six months later. All the harvested bunches were subjected to normal bunch analysis and the fruit set (the ratio of the total number of normal fruits, divided by the total number of fruits in the bunch, expressed as percentage) was estimated according to the method described by Rao *et al.* (1983).

Recording of Weather Parameter

Weather parameters like minimum and maximum temperature, morning and evening relative humidity and rainfall were recorded daily by the automatic weather station located at Indian Institute of Oil Palm Research, Andhra Pradesh, India. The data were combined on the basis of meteorological weeks and used for statistical analyses.

Analyses

Data collected during January 2014 to December 2015 (two years) on seasonal population of *E. kamerunicus* on male inflorescences during anthesis, progeny emergence and rat activity were cumulated for the analyses and presentation in the study. Cumulative data on seasonal population of *E. kamerunicus* on male inflorescences during anthesis, progeny emergence and rat activity on inflorescences was used for Pearson correlation co-efficient analysis to know their relationships with weather parameters. Bunch characters were correlated with weevil population to understand the effect of weevil activity on fruit set. Percentage values were subjected to arcsine transformations before statistical analyses. Regression analyses were carried out for factors which showed significance in order to understand the strength of relationships and contribution of various factors to the population variation of *E. kamerunicus* and its influence on bunch characters. Analyses were performed using SAS version 9.3 software.

RESULTS AND DISCUSSION

Seasonal Activity of *E. kamerunicus* on Anthesising and Post-anthesised Male Inflorescences in Relation to Weather Factors

Results of seasonal variation in *E. kamerunicus* population is depicted in *Figure 2*. *Elaeidobius kamerunicus* was active throughout the year in the study site with noticeable seasonal fluctuation within the range of 32.7 to 162.2 weevils/spikelet. During summer months, *i.e.*, April, May and June, weevil population was low on male inflorescences (35.7, 32.7 and 46.3 weevils/spikelet respectively). In spite of this decline, weevils recovered rapidly since end of June and maintained higher for a greater part of the year. *Elaeidobius kamerunicus* population was higher during dry seasons, *i.e.*, January, February, November and December with a peak population during February (162.2 weevils/spikelet). Rainy period (from July to early November) did not cause any adverse effect on the multiplication and activity of *E. kamerunicus*, rather, the population was being built up steadily.

Pearson co-efficient of correlation analysis between weevil population and weather parameters like minimum, maximum and mean temperature indicated a highly significant negative correlation, *i.e.*, r = -0.905, $p \leq 0.01$; r = -0.974, $p \leq 0.01$ and r = -0.973, $p \leq 0.01$ respectively. Relative humidity did not exert significant effect on the weevil activity. Although, rainfall had negative effect on the weevil activity, it did not influence significantly during the study period (*Table 1*). Results of regression analysis indicated that minimum, maximum and mean temperature exerted 81.80%, 94.80% and 94.60% role respectively on *E. kamerunicus* population variation on anthesising male inflorescences (*Table 2*).

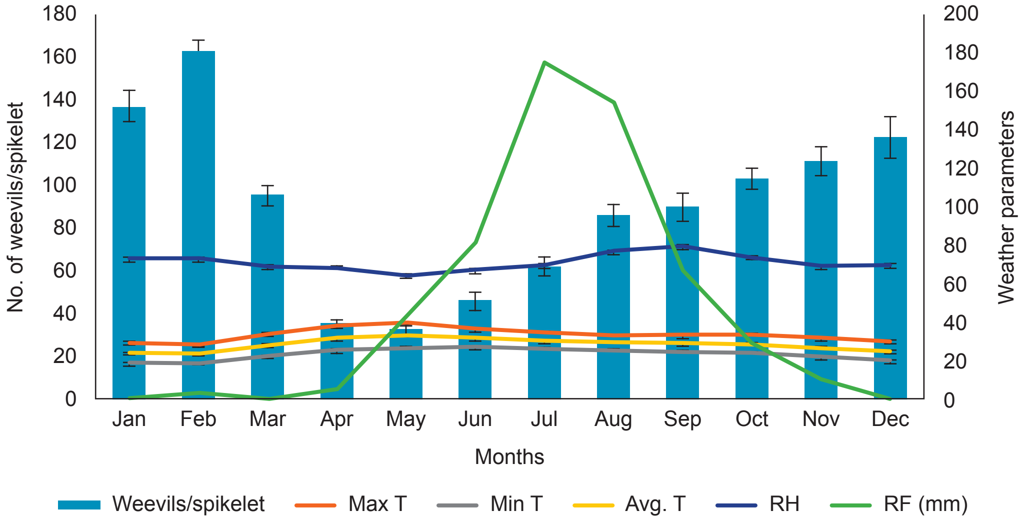
TABLE 1. CORRELATIONS OF ACTIVITY OF *Elaeidobius kamerunicus* POPULATION IN RELATION TO ABIOTIC AND BIOTIC FACTORS AND BUNCH CHARACTERS

Weather parameters	Weevil activity during anthesis	Progeny emergence
Max. temperature (°C)	-0.974**	-0.905**
Min. temperature (°C)	-0.905**	-0.966**
Average temperature (°C)	-0.973**	-0.965**
Average RH (%)	0.469^{NS}	0.246^{NS}
Rainfall (mm)	-0.410^{NS}	-0.549*
Rat incidence	-0.593*	-
Percent rat damage	-0.333^{NS}	-
Fruit set (%)	0.726**	-
Bunch weight (kg)	0.620*	-
Sterile fruits (%)	-0.726**	-

Note: ** - $P \leq 0.01$; * - $P \leq 0.05$; N - 12; NS - non significant.

TABLE 2. REGRESSION MODELS DEPICTING *Elaeidobius kamerunicus* ACTIVITY IN RELATION TO ABIOTIC AND BIOTIC FACTORS AND BUNCH CHARACTERS

Details	Regression equation	r	$100R^2$
Weevil population *vs.* minimum temperature	Y = -12.217x + 377.008	0.905	81.80
Weevil population *vs.* maximum temperature	Y = -11.804 + 485.448	0.974	94.80
Weevil population *vs.* mean temperature	Y = -12.858x + 456.536	0.973	94.60
Weevil progeny emergence *vs.* minimum temperature	Y = -6.499x + 205.874	0.966	93.20
Weevil progeny emergence *vs.* maximum temperature	Y = -5.466x + 236.387	0.905	81.90
Weevil progeny emergence *vs.* mean temperature	Y = -6.367x + 234.736	0.966	93.40
Weevil progeny emergence *vs.* rainfall	Y = -0.181x + 62.050	0.549	30.10
Rat incidence *vs.* weevil population	Y = -0.805x + 102.133	0.593	35.10
Weevil population *vs.* fruit set	Y = 0.086x + 62.919	0.726	52.70
Weevil population *vs.* bunch weight	Y = 0.030x + 76.560	0.620	38.50



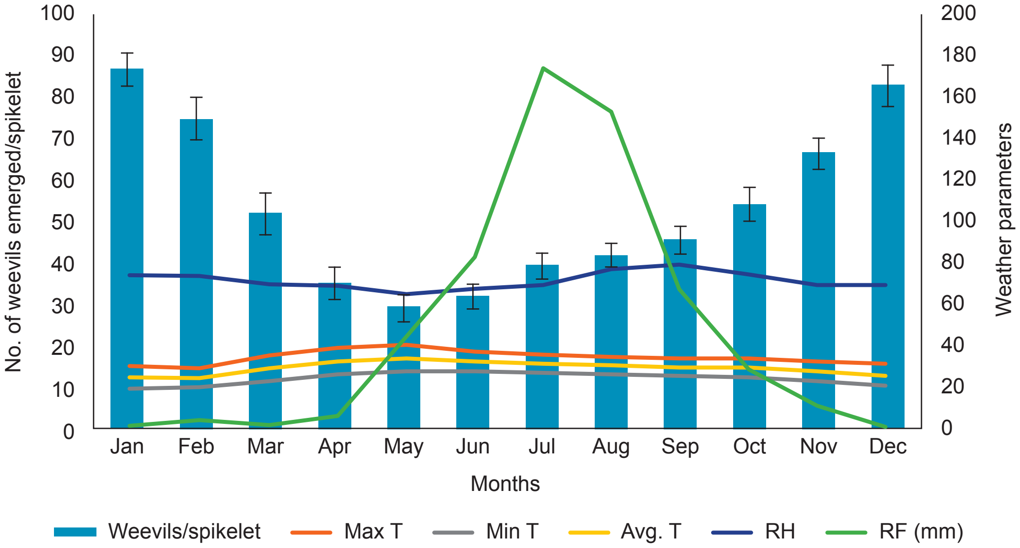
Note: Each data point in the figure is presented as mean ± SE.
RH - relative humidity (%); RF - rainfall.

Figure 2. Seasonal variation of E. kamerunicus *on anthesising male inflorescences (cumulative data of two years).*

Progeny emergence was noticed throughout the year from the post-anthesised male inflorescences with considerable variation in weevil population between the seasons (*Figure 3*). It ranged from 35.0 to 87.3 weevils/spikelet with peak emergence on January. There was a remarkable reduction in the progeny emergence during summer months, *i.e.*, April, May and June (35.0, 29.1 and 31.7 weevils/spikelet respectively). During dry seasons, *i.e.*, January, February, November and December, progeny emergence was consistently higher (ranging 66.8 to 87.3 weevils/spikelet) compared to wet seasons, *i.e.*, July, August, September and October (ranging 39.3 to 54.4 weevils/spikelet). The number of female weevils was always greater than that of the males.

Pearson co-efficient correlation analysis between weevil progeny versus minimum, maximum and mean temperature and rainfall indicated a highly significant negative correlation, *i.e.*, $r = -0.966$, $p \leq 0.01$; $r = -0.905$, $p \leq 0.01$; $r = -0.965$, $p \leq 0.01$ and $r = -0.549$, $p \leq 0.05$, respectively. Relative humidity did not exert significant effect on the progeny (*Table 1*). Results of regression analysis indicated that minimum, maximum and mean temperature and rainfall exerted 93.20%, 81.90%, 93.40% and 30.10% role respectively in causing variation in the progeny emergence of *E. kamerunicus* (*Table 2*).

Conventional oil palm plantations use a monoculture management system, experiencing higher temperatures and reduced humidity (Sabajo *et al.*, 2017). Greater canopy openness in oil palm plantations results in greater penetration of sunlight to the ground, thus, leading to a hotter and drier micro-climate (Comte *et al.*, 2012; Luskin and Potts, 2011), which affect the population dynamics of the insects severely and paves way for bunch failure in oil palm. On the other hand, Ashraf *et al.* (2019) reported that oil palm alley-cropping system can promote greater vegetation heterogeneity and improve micro-climate compared to the monoculture system by increasing vegetation cover, reducing sun exposure, reducing drying and buffering extreme temperature; and creating the habitat that is required to enhance biodiversity and ecosystem functions such as nutrient cycling, pest regulation and pollination, *etc*. In the present investigation, it was found that there was a high abundance of *E. kamerunicus* on anthesising as well as post-anthesised male inflorescences for a greater part of the year, *i.e.*, 62.2 to 162.2 weevils/spikelet and 39.3 to 87.3 weevils/spikelet, compared to the studies reported elsewhere in sole oil palm conditions (Chinchilla and Richardson, 1991; Dhileepan, 1994; Mohamad *et al.*, 2021; Siswanto and Soetopo, 2020; Syed, 1981). Moreover, it was found that, although hot dry summer [maximum temperature ranging from 36.1ºC-39.4ºC; minimum temperature 25.1ºC-27.1ºC; mean temperature 31.6ºC-33.2ºC and relative humidity (RH) 64.1%-68.6%] caused a decline in the pollinator population, interestingly, both the anthesising and post-anthesised male inflorescences were not devoid of the pollinators during this period, but were found with 32.7 to 46.3 and 29.1 to 35.0 weevils/spikelet, respectively. On the contrary, in sole oil palm cropping situation, Bulgarelli *et al.* (2002) reported that during April and May months, although anthesising male inflorescences were found, these were completely



Note: Each data point in the figure is presented as mean ± SE.
RH - relative humidity (%); RF - rainfall.

Figure 3. Seasonal variation of E. kamerunicus *progeny on post-anthesised male inflorescences (cumulative data of two years).*

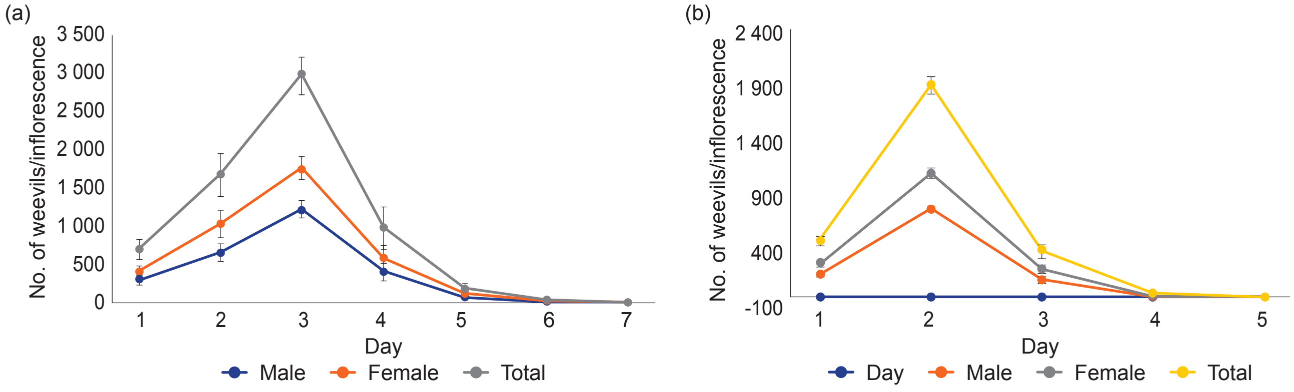
free of *E. kamerunicus* and caused bunch failure in Costa Rica. Dhileepan (1992) and Syed (1982) also reported that very hot and dry summer weather caused a severe decline in the weevil population in West Africa and India. Findings of Sugih *et al.* (1996) also showed that population of the pollinating weevil declined sharply to its lowest level in April in Riau, Sumatra due to very low rainfall coupled with hot temperature and caused bunch failure. Similarly, from India, Kalidas (2020) reported that high temperature coupled with low relative humidity could be the reason for poor pollinator population during the summer months leading to poor fruit set in oil palm. Hence, it is conveniently assumed that the favourable micro-climate created in oil palm-cocoa intercrop conditions, might be one of the reasons for the increased, unceasing and satisfactory weevil activity during most part of the year including during summer. Findings of Ashraf *et al.* (2019) revealed that oil palm intercropped with black pepper and cocoa had lower air and surface temperatures, *i.e.*, 1.3°C and 1.2°C of air temperature and 2.1°C and 2.0°C surface temperature respectively, which may alter the insect activity positively. Oil palm intercropped with cacao plants have diversified vegetation structure with a high ground vegetation cover; such as grass or ground litter, and a wider canopy cover for cacao (Somarriba and Beer, 2011). These vegetation structure characteristics influence not only the air temperature, but also the interception of solar radiation to the ground. In addition, physical characteristics of cacao such as wider canopy cover will act as a wind barrier and reduces the vertical mixing of warm air due to the longer distance for the wind to reach the ground surface (Hardwick *et al*., 2015). Therefore, increasing relative humidity and lowering air temperature (Ashraf *et al*., 2019), which create a favourable environment for enhanced activity and efficiency of the oil palm pollinator. The present findings are in conformity with the results of Bawa *et al.* (2011), who reported that *Elaeidobius* sp. was abundant in oil palm-cocoa intercrop than in sole oil palm due to crop diversity. Studies of Huber *et al.* (2022) also revealed that intercropping led to the increase in activity of pollinators like bumble bees and honey bees and improve the species richness. Further, these results are in conformity with one of our observations of field surveys conducted during summer. In which, in one of oil palm gardens, located in Nellore district of Andhra Pradesh, (where the mean daily maximum temperature is normally about 38°C and RH less than 50% in May) having banana (*Musa paradoxica*) as intercrop, the weevil activity was observed satisfactorily, while the sole oil palm plantations were devoid of weevils in same area (data unpublished).

Activity of *E. kamerunicus* on Male and Female Inflorescences During Anthesis

Adults of *E. kamerunicus* congregated on male inflorescences from the first to the sixth day of anthesis. Population increased with progress in anthesis and was highest during the third day of anthesis when all the florets had opened. There were about 698.7 weevils on male inflorescences on the first day of the anthesis when about 25% of the florets had opened. The number increased on the second day (1673.7 weevils) when 50% of the florets had opened and reached a maximum of 2970.1 adults on the third day, when all the flowers had opened. Thereafter, the number of adult weevils progressively declined until the sixth day due to emigration. No weevils were collected on the seventh day (*Figure 4a*). By this time, male inflorescences started withering. While, on female inflorescences, weevils visited from the first to the fourth day of anthesis. On the first day, 508.2 weevils visited the female inflorescence. On the second day, when maximum florets had opened, the total number of weevils reached a maximum of 1911.3. Thereafter, the number of weevils declined sharply on the third and the fourth day of anthesis to 414.4 and 22.4 respectively (*Figure 4b*). Later, no weevils were attracted to female inflorescences, as the florets turned to pink colour indicating the end of receptivity. The number of females visiting inflorescences was always greater than that of males on both male and female inflorescences. The present findings are more or less similar to the findings reported elsewhere in sole oil palm conditions (Dhileepan, 1994; Ponnamma, 1999; Sambathkumar and Ranjith, 2011; Syed, 1982; Yue *et al*., 2015).

Diurnal Activity of *E. kamerunicus*

On the third day of anthesis, the weevil population varied remarkably on male inflorescences. Weevils began to visit inflorescences between 08:00 and 09:00 hr and were very active between 10:00 and 12:00 hr. Maximum weevils (455.1) visited at around 11:00 hr, of which 298.1 were females and 163.0 were males. After 14:00 hr, weevil population declined sharply and began to be active again between 17:00 and 18:00 hr (*Figure 5*). While, on female inflorescences, on the second day of anthesis, weevils began to visit and increase in number at 09:00 hr. They were very active between 10:00 and 13:00 hr and reached a maximum number of 377.6 at 12:00 hr, of which 220.5 were females and 157.1 were males. Weevil population sharply declined after 14:00 hr and again began to congregate between 17:00 and 18:00 hr (*Figure 6*). The difference in peak activity of weevils between male and female



Note: Each data point in the figure is presented as mean ± SE.

Figure 4. Number of E. kamerunicus *weevils visiting inflorescences during the anthesis on (a) male inflorescence and (b) female inflorescence.*

inflorescences is because of the emigration of overcrowded weevils from male inflorescences to female inflorescences due to competition for food and oviposition. Reduced weevil activity in the afternoon and slightly increased activity in the evening could be explained as the weevils were reluctant to fly from the shelter or settlement to the field during hot hour of the day and resumed the activity as the temperature drop down in the evening (17:00-18:00 hr). Although some variations are reported in the timing of weevil activity by various researchers (Ponnamma, 1999; Sambathkumar and Ranjith, 2011; Syed *et al*., 1982) under sole oil palm crop conditions, in general, they conform to the basic pattern of activity in intercropping situation too.

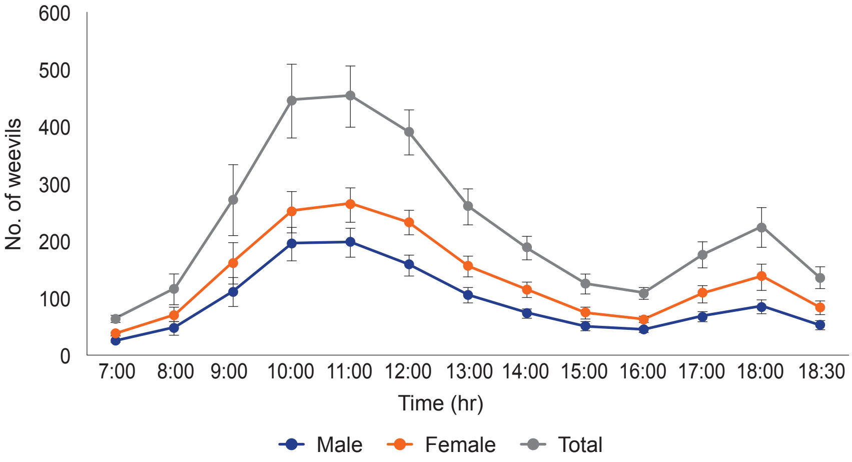
Rat Predation on *E. kamerunicus*

Rats gnawed post-anthesised male inflorescences and damaged them for search of eggs, larvae, pupae and imago of *E. kamerunicus* and preyed upon them. Rat incidence and damage on male inflorescences varied over the months and they ranged from 47.2% to 85.4% and 44.2% to 67.1% respectively. Although rat incidence and damage were noticed throughout the year, maximum incidence (March-June) and damage (April-June) were recorded during summer months (*Figure 7*). Pearson correlation analysis indicated that rat incidence had significant negative influence on the weevil population (r = -0.593; $p \leq 0.05$) (*Table 1*). Regression analysis showed that rat incidence exerted 35.1% variation on the population density of *E. kamerunicus* in the study site (*Table 2*).

There are reports of poor fruit set and yield decline in oil palm due to predation of rats on weevils apart from weather factors (Chiu *et al*., 1985; Yusdayati and Hamid, 2015). Although rat predation was noticed throughout the year, the level of predation was higher during summer months (April-June) due to less or non-availability of the right stage of cocoa pods. Rat predation might be one of the causes for decline in *E. kamerunicus* population during summer, in addition to hot weather conditions. A high degree of rat damage recorded in the present study site could be due to cocoa as intercrop. The study revealed that the two crops have common problem of rat damage and their association will compound rat problems of either crop, if rat management practices are ignored. Interestingly, even in the face of rat predation, weevil population was still maintained for effecting satisfactory pollination as reported in the study.

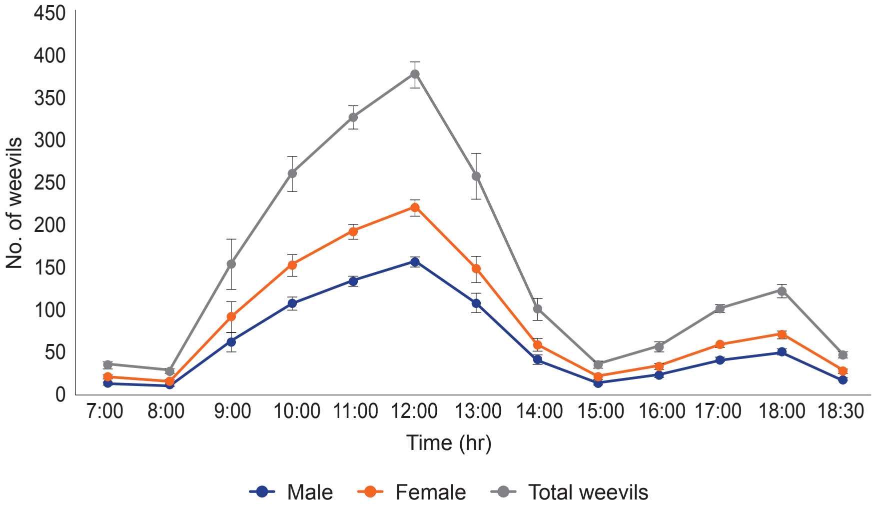
E. kamerunicus and its Relation to Fruit Set

In this study, it was observed that the average fruit set oscillated between 79.6% and 93.6% during the year 2015-2016. Fruit set (at harvest time) was lowest in October (79.6%). It was a response associated with a reduction in the pollinating weevil population that occurred about five months earlier, *i.e*., May 2015 (38.8 weevils/spikelet). Fruit set was comparatively less in November, January, February and March (ranging from 80.1% to 85.9%) when compared to April to September months (≥90.0% fruit set). It was a response associated with wet months about five months earlier (June, July, August and September) (*Figure 8*). Norman *et al.* (2018) also found that wet weather of between 200 to 400 mm seemed to cause low fruit set and low oil extraction rate (≤18.0%) in several oil palm estates in Sarawak, Malaysia. Pearson correlation analysis indicated that activity of *E. kamerunicus* on male inflorescences during anthesis was contributing positively and significantly towards fruit set (r = 0.726; $p \leq 0.01$) and bunch weight (r = 0.620; $p \leq 0.05$). There was an existence of significant positive correlation between fruit set and bunch weight (r = 0.668; $p \leq 0.01$) too (*Table 1*). Regression analysis indicated that weevil population contributed 52.7% and 38.5% of variation in the fruit set and bunch weight respectively (*Table 2*).



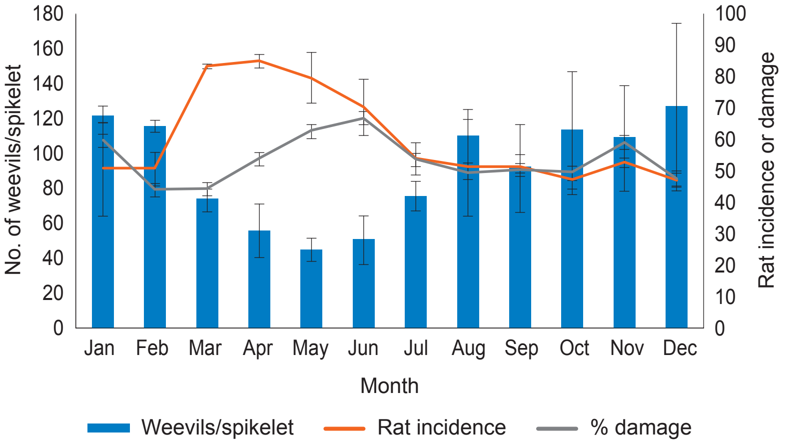
Note: Each data point in the figure is presented as mean ± SE.

Figure 5. Diurnal variation of E. kamerunicus *population on male inflorescences on the 3rd day of anthesis.*



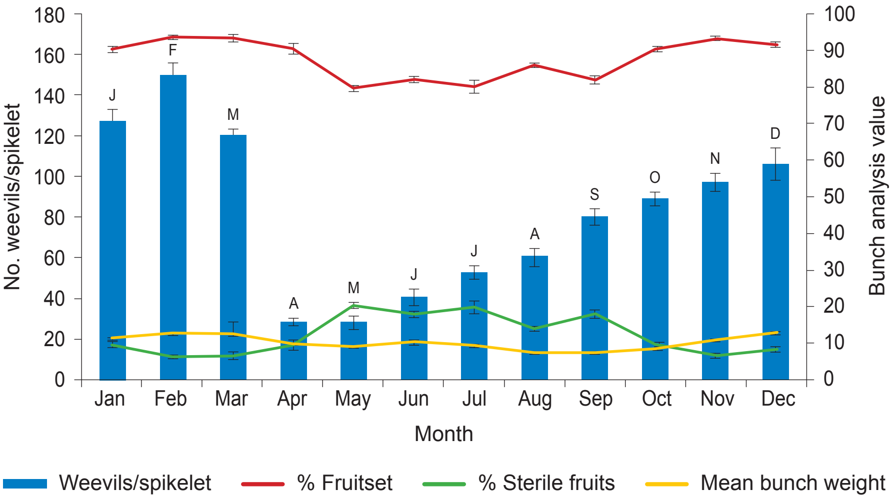
Note: Each data point in the figure is presented as mean ± SE.

Figure 6. Diurnal variation of E. kamerunicus *population on female inflorescences on the 2nd day of anthesis.*



Note: Each data point in the figure is presented as mean ± SE.

Figure 7. Rat incidence and damage on male inflorescences (cumulative data of two years).



Note: Each data point in the figure is presented as mean ± SE.

Figure 8. Relationship between E. kamerunicus *population and fruit set.*

The study showed that fruit set values were higher (around more than 80%) throughout the year. Higher fruit set values could be attributed to adequate weevil population and increased pollinating efficiency of the weevil in the altered micro-climatic conditions under oil palm-cocoa intercrop as discussed earlier. It was found that *E. kamerunicus* population was satisfactory throughout the year even during summer months for the purpose of achieving a higher fruit set, as evidenced by the level of fruit set which was always above 60%; the minimum considered adequate indicating that there was sufficient pollination activity (Syed, 1984). Furthermore, the present results are in conformity with the findings of Dissanayake and Palihakkara (2019), who reported that oil palm yield in intercropping system was significantly increased every year with yield increment of 36.40% than sole crop due to addition of biomass into the system.

CONCLUSION

This study showed a satisfactory pollinator activity and pollination efficiency throughout the year in spite of biotic (hot temperature) and abiotic stresses (rat predation). Since, it is understood that oil palm-cocoa intercrop conditions can provide not only additional income to oil palm growers, but also can improve vegetation cover, increase faunal and floral biodiversity, reduce sun exposure, and reduce drying and mitigate extreme micro-climate; thereby increasing pollinating activity of *E. kamerunicus* and oil palm yield, it should be considered as a key strategy in sustainable and climate smart oil palm production. Further, based on the information obtained from the present study, future line of research should be conducted in different oil palm intercropping systems *vis-a-vis* oil palm monoculture to know their effect on arthropod biodiversity, including pollinator activity and natural enemies of the pests.

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