Relationships Between Inflorescences and Pollinators and Their Effects on Bunch Components in *Elaeis guineensis,* in Colombia[1]

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Abstract The oil palm, *Elaeis guineensis* Jacquin, is an allogamous and monoecious plant that is mainly pollinated by insects such as *Mystrops costaricensis* Gillogly (Coleoptera: Nitidulidae) and *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae). To determine the relationship between inflorescences and pollinators as well as the relationship between pollinators and bunch components, 858 palms, divided equally between two plots planting with cultivars *tenera* and *dura* of *E. guineensis*, were monitored every 2 weeks over 1 yr. Male inflorescences (MIs) and female inflorescences (FIs) at anthesis, and pollinators collected from the inflorescences, were recorded at each sampling. Bunch components and the amount of rainfall during the study period also were recorded. Data were analyzed using Spearman correlations and linear regression. Significant positive correlations of the total number of MIs with the total number of pollinators were found in both cultivars ($\rho = 0.72$, $P < 0.0001$, $n = 24$ in cultivar *tenera*; $\rho = 0.65$, $P = 0.0003$, $n = 26$ in cultivar *dura*). The number of pollinators were linearly related with number of MIs in both cultivars ($F = 0.002$; $r^2 = 0.50$ in cultivar *tenera*; $F = 0.0005$; $r^2 = 0.40$ in cultivar *dura*). For both cultivars, we found significant negative correlations of the MIs and FIs with the rainfall recorded between 21 and 24 mo before anthesis. The number of MIs and the amount of rainfall were directly related to the number of pollinators. There was an inverse relationship of the inflorescences with the rainfall recorded between 21 and 24 mo before anthesis.

Key Words *Elaeidobius kamerunicus*, *Mystrops costaricensis*, oil palm, anthesis, fruit set

The oil palm, *Elaeis guineensis* Jacquin (Arecales: Arecaceae), is a monoecious plant with allogamous reproduction that requires cross-pollination. In this sense, the pollination of *E. guineensis* is characterized as anemophilous (Hormaza et al. 2010) or entomophilous (Syed 1979), with the latter being of more importance for palm cultivation.

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Pollinating insects are attracted to the inflorescences by aliphatic alcohols, esters, and ketones released during anthesis. Estragole is released in the greatest amount (Hussein et al. 1989). Pollinating insects come to the male inflorescences (MIs) searching for pollen upon which to feed, focusing on the flowering spikelets. At the onset of anthesis in the MI, pollinating insects begin to arrive in small numbers, reach maximum numbers at full anthesis, and begin to decline toward the end of anthesis (Syed et al. 1982). Subsequently, the pollen-laden insects are attracted by fragrances released by the female inflorescences (FIs), and fertilization occurs (Tandon et al. 2001). The arrival of pollinating insects to the FIs occurs in intermittent swarms during the day (Syed et al. 1982).

Until 1985, the main pollinating insects of oil palms that had been recorded in Colombia were *Mystrops costaricensis* Gillogly (Coleoptera: Nitidulidae), which is native to the Americas, and *Elaeidobius subvittatus* (Faust) (Coleoptera: Curculionidae), which is native to Africa (Mondragón and Roa 1985). However, because of the low pollination efficiency of these insects, it was necessary to introduce *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae) from Malaysia, which is considered to be the most efficient insect pollinator of oil palms to increase oil yield (Syed 1986). *Elaeidobius kamerunicus* is negatively impacted by different factors such as natural enemies and drought (Syed and Saleh 1987), while *M. costaricensis* responds favorably to drought conditions (Genty 1985).

Pollination in oil palm depends on the number of inflorescences at anthesis, the population of pollinator insects (abundance and richness), and the viability and ability of the pollen to germinate (i.e., $>70\%$) (Prada and Romero 2013). Efficient pollination results in greater proportions of normal or fertile fruits and increased oil production due to reduction in parthenocarpic fruits and aborted flowers (Corley and Tinker 2003).

In *E. guineensis,* floral differentiation is affected by three factors that occur 24 mo before anthesis: nutrition of the palm, defoliation, and rainfall excess or deficit (Corley and Tinker 2003, Hormaza et al. 2010). An inflorescence reaches anthesis when 70% of flowers are open (phenological stage 607 as described in the Biologische Bundesantalt Bundessortenamt und Chemische Industrie [BBCH] scale). In MIs, anthesis lasts for 2 d on average (Forero and Romero 2012, Hormaza et al. 2010), but during rainy weather, it can last up to 4 d. After the onset of anthesis, pollen is released (Corley and Tinker 2003). In FIs of 2- to 4-year-old palms, anthesis may last 36–48 h on average (Hormaza et al. 2010) but can last up to 1 week (Corley and Tinker 2003). This relationship between inflorescences and the timing of anthesis ultimately determines the proportions of normal fruits, parthenocarpic fruits, or aborted flowers, which affects both the production of fresh fruit bunches and oil.

The research reported herein was aimed at determining the influence of the main two pollinator insects on fruit set (with direct impacts in productivity) and to identify the factors that affect pollinators associated with *E. guineensis*. Our objective was to characterize the relationship between the availability of MIs in anthesis and the population fluctuations of the main two pollinating insects in oil palm, the relationships between these variables and rainfall, and the relationship between the population of pollinators and the bunch components in *E. guineensis*.

Materials and Methods

Study area. The study was conducted in two plots of oil palm plantations each covering 3 ha at Palmar La Vizcaína Experimental Field located in Barrancabermeja, Santander (N 6°58′30.5″, W 73°41′35.9″), in the central oil palm growing area of Colombia at an elevation of 99 m above sea level. This area has an average annual temperature of 28 ± 4°C, a relative humidity of 84 ± 16%, and annual rainfall of 3.487 mm.

Inflorescences and pollinators. Initially, 858 palms were selected and marked from the two plots of 8-year-old palms. Plot 1 was planted with *E. guineensis* cultivar *tenera*, and Plot 2 was planted with *E. guineensis* cultivar *dura*. MIs and FIs were recorded every 2 weeks for 1 yr, and the phenological stages of the inflorescences were recorded as described in the BBCH scale for oil palms (Forero and Romero 2012, Forero et al. 2012). Rainfall data between 20 and 26 mo before stage 607 (anthesis) were gathered to determine the effects of rainfall excesses or deficits on floral differentiation (Corley and Tinker 2003, Hormaza et al. 2010).

White cardboard intersection glue traps measuring 5 × 5 cm were used to estimate the abundance of pollinating insects at the MIs and FIs (stage 607) (Labarca et al. 2009). Traps were placed based on the numbers of inflorescences at anthesis at each sampling. FIs at stage 607 with traps were marked so that they could be identified at the time of harvest to determine their relationship with the pollinating insects collected in the traps and their impact on bunch formation. A total of 477 traps were placed in Plot 1, and 608 traps were placed in Plot 2 during the study. After 7 d, the traps were transported to the laboratory where pollinating insects were collected, counted, and sorted by species (*M. costaricensis* and *E. kamerunicus*).

Bunch components. Analyses of bunches were made using those coming from FIs that were at anthesis when insect monitoring traps were placed. A total of 171 bunches were analyzed in cultivar *tenera*, while 178 bunches were analyzed in cultivar *dura* during the study. The cut bunches and loose fruits found on the plant were packed in clean fiber bags and transported to the laboratory where the bunch components were determined based on the numbers of fruit sets, parthenocarpic fruits, and aborted flowers in accordance with the criteria of Prada and Romero (2013).

Data analyses. The data analyses were conducted separately for each cultivar based on the biweekly sample using Spearman correlations, because data did not follow normal distributions, and with linear regression when the correlation was statistically significant. All data were transformed before analysis, and all analyses were performed using SAS statistical package (SAS Institute 2010).

Biweekly records of the MIs and FIs at anthesis were correlated with the cumulative rainfall recorded between 20 and 26 mo before anthesis, which is the time of floral differentiation that influences the number of inflorescences in an oil palm plot. The pollinator insects *M. costaricensis* and *E. kamerunicus*, collected biweekly from the MIs and FIs, were correlated with the MIs at anthesis and the biweekly rainfall records. Moreover, the numbers of pollinating insects from MIs and pollinating insect from FIs were correlated. Then, the variables with significant correlations were linearly regressed. The observation unit was the plot.

Finally, the bunch components were correlated with total numbers of both pollinators collected in every FI because the bunch components resulted from presence and activity of both pollinator species. The observation unit was the FIs, and the spatial autocorrelation was determined using the Mantel test for each variable.

Results

Inflorescences and rainfall. In cultivar *tenera*, 477 inflorescences in phenological stage 607 were found with a sex ratio of 1.8:1 (♂:♀). The average MI density in phenological stage 607 was 4.3 ± 3.1/ha/biweekly sample, and FI density in stage 607 was 2.4 ± 0.9/ha/biweekly sample. In cultivar *dura*, 608 inflorescences in stage 607 were recorded with a sex ratio of 2.4:1 (♂:♀). The average MI density in stage 607 was 5.5 ± 3.0/ha/biweekly sample, and the FI density was 2.3 ± 1.1/ha/biweekly sample.

In cultivar *tenera*, the correlation of the number of inflorescences in stage 607 (MI and FI) with rainfall revealed a significant negative correlation of the MIs in stage 607 with rainfall recorded 22 and 23 mo before anthesis (Table 1); however, the greatest adjustment of the linear model was with the rainfall recorded 22 mo before anthesis ($F = 0.0005$, $r^2 = 0.43$ for 22 mo; $F = 0.0180$, $r^2 = 0.23$ for 23 mo). Similarly, a significant negative correlation and adjustment to the linear model were found in number of FIs in stage 607 with rainfall recorded 24 mo before anthesis ($F = 0.0012$, $r^2 = 0.38$).

In cultivar *dura*, significant negative correlations were found only of the MIs in stage 607 recorded biweekly with the cumulative rainfalls 20 and 21 mo before anthesis and of FIs in stage 607 with rainfalls recorded 22, 23, and 24 mo before anthesis (Table 1). However, the greatest adjustment to the linear model was observed with the relationship of MIs with the rainfall recorded 21 mo before anthesis ($F = 0.0847$, $r^2 = 0.12$ for 20 mo; $F = 0.0038$, $r^2 = 0.30$ for 21 mo). In addition, the greatest adjustment to the linear model of the relationship was of FIs with the rainfall recorded 24 mo before anthesis ($F = 0.0335$, $r^2 = 0.17$ for 22 mo; $F = 0.0082$, $r^2 = 0.26$ for 23 mo; $F = 0.0001$, $r^2 = 0.46$ for 24 mo).

Pollinators and inflorescences. *Mystrops costaricensis* and *E. kamerunicus* were the only pollinators collected from the deployed traps. The predominant species in the MIs of cultivar *tenera* was *M. costaricensis* (Table 2). The number of MIs in stage 607, and the numbers of pollinators for both species (*M. costaricensis* and *E. kamerunicus*) collected from the MIs, were significantly and positively correlated, and the relationship was adjusted to a linear model ($F = 0.0002$, $r^2 = 0.50$). An individual analysis with each species of pollinators and the MIs in stage 607 revealed that the correlation remained unchanged. With both species, the relationships were adjusted to a linear model ($F = 0.0086$, $r^2 = 0.30$ for *M. costaricensis*; $F < 0.0001$, $r^2 = 0.65$ for *E. kamerunicus*) (Table 3). No spatial autocorrelation was found in the numbers of *M. costaricensis* ($P = 0.676$) and both species combined ($P = 0.535$) in cultivar *tenera*.

In cultivar *dura*, the predominant pollinator species observed in MIs was *E. kamerunicus*. However, during certain periods, *M. costaricensis* outnumbered *E. kamerunicus* (Table 4). The number of MIs in stage 607, and the numbers of

Table 1. Spearman correlation coefficients (ρ), probabilities > |*r*| (*P*) of total male inflorescences (MI) and female inflorescences (FI) at anthesis with rainfall recorded during sexual differentiation in *Elaeis guineensis*.

Rainfall (No. Months Before Anthesis)	Plot 1*, n = 24		Plot 2*, n = 26	
	Total MI at Anthesis/ Biweekly	Total FI at Anthesis/ Biweekly	Total MI at Anthesis/ Biweekly	Total FI at Anthesis/ Biweekly
20				
ρ	−0.39	0.07	−0.51	−0.02
P	0.0622	0.7374	0.0079†	0.9171
21				
ρ	−0.32	−0.43	−0.55	−0.35
P	0.1252	0.0378†	0.0033†	0.0834
22				
ρ	−0.57	−0.35	−0.16	−0.51
P	0.0033†	0.0918	0.4272	0.0072†
23				
ρ	-0.41	-0.38	-0.27	-0.53
P	0.0452†	0.0690	0.1882	0.0054†
24				
ρ	-0.22	-0.64	-0.10	-0.73
P	0.2953	0.0007†	0.6304	<0.0001†
25				
ρ	0.028	-0.24	-0.08	-0.26
P	0.8962	0.2572	0.7096	0.1900
26				
ρ	0.09	-0.37	0.38	-0.19
P	0.6749	0.0737	0.0524	0.3516

* Plot 1 planted in *E. guineensis* cultivar *tenera*; Plot 2 planted in *E. guineensis* cultivar *dura*.

† Significance $P < 0.05$.

Table 2. Biweekly records of pollinating insects collected in intersection traps placed in male inflorescences in anthesis of cultivar *tenera* of *Elaeis guineensis* and cumulative rainfall recorded during time that traps remained in the field.

	Proportion		**Ratio**		
Biweekly Evaluation	***Mystrops costaricensis*** **Collected/ Biweekly**	***Elaeidobius kamerunicus*** **Collected/ Biweekly**	***Mystrops costaricensis*: *Elaeidobius kamerunicus***		**Rainfall (mm)**
1	—	—	—	—	—
2	—	—	—	—	—
3	0.5	0.5	1.0	1.0	70
4	0.5	0.5	1.2	1.0	192
5	0.6	0.4	1.6	1.0	140
6	0.4	0.6	1.0	1.5	150
7	0.6	0.4	1.4	1.0	16
8	0.8	0.2	4.1	1.0	0
9	0.9	0.1	6.1	1.0	5
10	0.9	0.1	17.1	1.0	29
11	1.0	0.0	33.0	1.0	6
12	1.0	0.0	27.8	1.0	20
13	0.8	0.2	4.5	1.0	15
14	0.9	0.1	14.5	1.0	176
15	0.8	0.2	3.4	1.0	102
16	0.9	0.1	10.1	1.0	61
17	0.7	0.3	2.6	1.0	118
18	0.7	0.3	2.2	1.0	36
19	1.0	0.0	1.0	0.0	84
20	0.8	0.2	5.4	1.0	7
21	0.7	0.3	2.6	1.0	114
22	0.6	0.4	1.6	1.0	24
23	0.7	0.3	2.0	1.0	22
24	0.9	0.1	14.4	1.0	67
25	0.7	0.3	2.0	1.0	30
26	0.8	0.2	3.4	1.0	94
Total	0.7	0.3	2.0	1.0	

Table 3. Spearman correlation coefficients (ρ), probabilities $> |r|$ (P) of pollinating insects collected in the male inflorescences (MI) at anthesis, with rainfall recorded in *Elaeis guineensis*.

	Plot 1*, n = 24			Plot 2*, n = 26		
	Total Pollinators in MI Collected/ Biweekly	***M. costaricensis* in MI Collected/ Biweekly**	***E. kamerunicus* in MI Collected/ Biweekly**	**Total Pollinators in MI Collected/ Biweekly**	***M. costaricensis* in MI Collected/ Biweekly**	***E. kamerunicus* in MI Collected/ Biweekly**
Total MI in 607/ biweekly evaluations						
ρ	0.72	0.56	0.85	0.65	0.40	0.65
P	<0.0001†	0.0044†	<0.0001†	0.0003†	0.0448†	0.0003†
Accumulated rainfall during pollinator sampling	0.27	0.16	0.32	0.30	0.05	0.56
ρ						
P	0.2073	0.4404	0.1210	0.1323	0.7894	0.0028†

* Plot 1 planted in *E. guineensis* cultivar *tenera*; Plot 2 planted in *E. guineensis* cultivar *dura*.

† Significance $P < 0.05$.

Table 4. Biweekly records of pollinating insects collected in intersection traps placed in male inflorescences in anthesis of cultivar *dura* of *Elaeis guineensis* and cumulative rainfall recorded during time that traps remained in the field.

	Proportion		Ratio		
Biweekly Evaluation	***Mystrops costaricensis*** **Collected/ Biweekly**	***Elaeidobius kamerunicus*** **Collected/ Biweekly**	***Mystrops costaricensis*****:** ***Elaeidobius kamerunicus***		**Rainfall (mm)**
1	0.4	0.6	1.0	1.4	211
2	0.4	0.6	1.0	1.5	108
3	0.3	0.7	1.0	2.4	115
4	0.2	0.8	1.0	5.2	96
5	0.4	0.6	1.0	1.2	123
6	0.5	0.5	1.0	1.0	9
7	0.6	0.4	1.6	1.0	11
8	0.6	0.4	1.5	1.0	3
9	0.7	0.3	2.4	1.0	4
10	0.9	0.1	13.8	1.0	0
11	1.0	0.0	26.8	1.0	9
12	0.8	0.2	5.2	1.0	27
13	0.7	0.3	2.8	1.0	61
14	0.6	0.4	1.5	1.0	83
15	0.7	0.3	2.5	1.0	133
16	0.3	0.7	1.0	2.1	92
17	0.5	0.5	1.0	1.0	122
18	0.4	0.6	1.0	1.5	13
19	0.5	0.5	1.0	1.2	29
20	0.3	0.7	1.0	2.0	70
21	0.5	0.5	1.0	1.2	11
22	0.3	0.7	1.0	2.5	18
23	0.4	0.6	1.0	1.6	23
24	0.2	0.8	1.0	3.1	28
25	0.6	0.4	1.4	1.0	24
26	0.3	0.7	1.0	2.4	63
Total	0.5	0.5	1.0	1.0	

pollinators for both species collected from the MIs, were significantly and positively correlated and were adjusted with the linear model ($F = 0.0005$, $r^2 = 0.40$). An individual analysis with each species of pollinator and the MIs in stage 607 revealed only significant positive correlation with the number of *E. kamerunicus* (Table 3), and the relationship was adjusted to a linear model ($F = 0.1502$, $r^2 = 0.008$ for *M. costaricensis*; $F = 0.0018$, $r^2 = 0.35$ for *E. kamerunicus*). No spatial autocorrelation was found in either the number of *E. kamerunicus* ($P = 0.262$), *M. costaricensis* ($P = 0.69$), or the two species combined ($P = 0.632$) in Plot 2.

Pollinators and rainfall. Analyses of insect pollinators and rainfall in cultivar *tenera* revealed no significant correlations of the numbers of pollinators collected from the MIs (Table 2) and FIs (Table 5) with the rainfall recorded during the sampling periods (Table 3). However, analyses that were conducted separately for each pollinator species revealed significant positive correlation of *M. costaricensis* collected from FIs with rainfall recorded during the biweekly sampling period ($\rho = 0.41$, $P = 0.0484$, $n = 24$), but the relationship of *M. costaricensis* with the rainfall during sampling period did not adjust to a linear model ($F = 0.0807$, $r^2 = 0.13$).

In cultivar *dura*, significant positive correlations of the populations of *E. kamerunicus* from the MIs (Table 4) with the total cumulative rainfall recorded during the biweekly sampling periods (Table 3), and of the populations of *E. kamerunicus* from the FIs (Table 6) with the rainfall during sampling periods were found ($\rho = 0.44$, $P = 0.0245$, $n = 26$). The relationship of *E. kamerunicus* collected from the MIs with FIs with the total cumulative rainfall recorded during the sampling periods were adjusted to a linear model ($F = 0.0015$, $r^2 = 0.36$ from MIs; $F = 0.0085$, $r^2 = 0.25$ from FIs).

There was no significant correlation of the total number of pollinators collected from the MIs with the total number of pollinators collected from the FIs in both cultivars of *E. guineensis*. However, in separate analyses for each pollinator species, cultivar *dura* data revealed a significant positive correlation of populations of *M. costaricensis* and *E. kamerunicus* from MIs with the pollinators populations from FIs ($\rho = 0.56$, $P = 0.0029$, $n = 26$ for *M. costaricensis*; $\rho = 0.42$, $P = 0.0335$, $n = 26$ for *E. kamerunicus*). The relationship of populations of *M. costaricensis* from MIs with from FIs was adjusted to a linear model ($F = 0.0032$, $r^2 = 0.31$), and the relationship of populations of *E. kamerunicus* from MIs with from FIs did not adjust to a linear model ($F = 0.0703$, $r^2 = 0.13$).

Bunch components and pollinators. A total of 171 bunches was analyzed in cultivar *tenera* and 178 bunches in cultivar *dura*, resulting from equal numbers of FIs in anthesis in each palm oil cultivar during the sampling period. In cultivar *tenera*, the mean percentage of fruit set in the ninth year of production without assisted pollination was 67.1% (± 2.5%) with a range of 20.6–94.8%. The mean percentage of aborted flowers was 25.2% (± 2.2%) with a range of 2.7–77.0%. The mean percentage of parthenocarpic fruits was 7.7% (± 1.4%) with a range of 0–55.2%.

In the cultivar *dura*, the mean percentage of fruit set in the ninth year of production without assisted pollination was 67.2% (± 2.1%) with a range of 11.6–98.6%. The mean percentage of aborted flowers was 23.3% (± 2.1%) with a range of 1.4–88.4%. The mean percentage of parthenocarpic fruits was 9.6% (± 1.5%) with a range of 0–41.2%.

Table 5. Biweekly records of pollinating insects caught in intersection traps placed in female inflorescences in anthesis of cultivar *tenera* of *Elaeis guineensis* and cumulative rainfall recorded during time that traps remained in the field.

	Proportion		Ratio		
Biweekly Evaluation	***Mystrops costaricensis*** **Collected/ Biweekly**	***Elaeidobius kamerunicus*** **Collected/ Biweekly**	***Mystrops costaricensis*: *Elaeidobius kamerunicus***		**Rainfall (mm)**
1	—	—	—	—	—
2	—	—	—	—	—
3	0.6	0.4	1.7	1.0	70
4	0.7	0.3	2.8	1.0	192
5	0.9	0.1	5.8	1.0	140
6	0.7	0.3	1.9	1.0	150
7	0.8	0.2	3.7	1.0	16
8	0.5	0.5	1.2	1.0	0
9	0.3	0.7	1.0	2.3	5
10	1.0	0.0	43.0	1.0	29
11	0.7	0.3	2.9	1.0	6
12	1.0	0.0	27.7	1.0	20
13	0.9	0.1	6.4	1.0	15
14	0.9	0.1	10.5	1.0	176
15	0.7	0.3	2.0	1.0	102
16	0.9	0.1	8.5	1.0	61
17	0.8	0.2	3.4	1.0	118
18	0.2	0.8	1.0	3.1	36
19	0.7	0.3	2.2	1.0	84
20	0.6	0.4	1.3	1.0	7
21	0.8	0.2	5.4	1.0	114
22	0.6	0.4	1.2	1.0	24
23	0.6	0.4	1.3	1.0	22
24	0.7	0.3	2.8	1.0	67
25	0.9	0.1	11.8	1.0	30
26	0.6	0.4	1.4	1.0	94
Total	0.8	0.2	4.1	1.0	

Table 6. Biweekly records of pollinating insects collected in intersection traps placed in female inflorescences in anthesis of cultivar *dura* of *Elaeis guineensis* and cumulative rainfall recorded during time that traps remained in the field.

	Proportion		Ratio		
Biweekly Evaluation	*Mystrops costaricensis* Collected/ Biweekly	*Elaeidobius kamerunicus* Collected/ Biweekly	*Mystrops costaricensis*: *Elaeidobius kamerunicus*		Rainfall (mm)
1	0.3	0.7	1.0	2.4	211
2	0.5	0.5	1.1	1.0	108
3	0.5	0.5	1.1	1.0	115
4	0.1	0.9	1.0	16.2	96
5	0.8	0.2	3.5	1.0	123
6	0.1	0.9	1.0	12.4	9
7	0.8	0.2	4.5	1.0	11
8	0.8	0.2	4.2	1.0	3
9	0.8	0.2	3.8	1.0	4
10	0.9	0.1	11.6	1.0	0
11	0.9	0.1	11.1	1.0	9
12	0.9	0.1	12.2	1.0	27
13	0.7	0.3	2.2	1.0	61
14	0.7	0.3	2.3	1.0	83
15	0.8	0.2	4.3	1.0	133
16	0.7	0.3	2.5	1.0	92
17	0.3	0.7	1.0	2.6	122
18	0.2	0.8	1.0	4.0	13
19	0.5	0.5	1.1	1.0	29
20	0.6	0.4	1.3	1.0	70
21	0.5	0.5	1.0	1.1	11
22	0.5	0.5	1.0	1.1	18
23	0.0	1.0	1.0	28.5	23
24	0.0	1.0	1.0	25.0	28
25	0.5	0.5	1.0	1.0	24
26	0.3	0.7	1.0	1.9	63
Total	0.6	0.4	1.6	1.0	

Negative significant correlations of the total number of pollinating insects collected in FIs in stage 607 with the total percentage of parthenocarpic fruits were found in cultivar *tenera* ($\rho = -0.16$, $P = 0.0346$, $n = 171$), but the relationship did not adjust to a linear model ($F = 0.2098$, $r^2 = 0.01$). No significant correlations were detected with other variables involving bunch components. No spatial autocorrelation was found in the total parthenocarpic fruits ($P = 0.240$), total aborted flowers ($P = 0.389$), and total normal fruits ($P = 0.381$) in Plot 1.

In cultivar *dura*, negative significant correlations of the total number of pollinator insects collected in FIs in stage 607 with the total number of aborted flowers was observed ($\rho = -0.21$, $P = 0.0056$, $n = 178$); however, this relationship did not adjust to a linear model ($F = 0.0014$, $r^2 = 0.06$). No spatial autocorrelation was found in the total parthenocarpic fruits ($P = 0.408$), total aborted flowers ($P = 0.988$), and total normal fruits ($P = 0.531$) in Plot 2.

Discussion

Sex ratio of inflorescences in both cultivars of *E. guineensis* in this study was similar to that recorded by Tandon et al. (2001). Overall, *E. guineensis* cultivar *dura* had more inflorescences at anthesis (phenological stage 607) than *E. guineensis* cultivar *tenera*. Furthermore, both varieties had more MIs than FIs in phenological stage 607.

According to Corley and Tinker (2003), the sexual differentiation of inflorescences in *E. guineensis* occurs approximately between 20 and 24 mo before anthesis and depends on three factors: nutrition, excesses or deficits in soil moisture (rainfall), and defoliations. One or more of these may alter sexual differentiation (Forero and Romero 2012, Forero et al. 2012). A review of the annual cumulative rainfalls recorded during floral differentiation at the study sites revealed higher than normal precipitation and, as a result, the soil had excess levels of moisture. In Plot 1, the total cumulative annual rainfall 22, 23, and 24 mo before anthesis was 3.961 mm, 3.616 mm, and 3.236 mm, respectively. These amounts were higher than the average rainfall recorded over the previous 9 yr at these sites which is normally a mean of 3.487 (± 0.414) mm annually. Moreover, for Plot 2, the cumulative annual rainfall recorded 20, 21, 22, and 23 mo before anthesis was 4.466 mm, 4.468 mm, 4.231 mm, and 3.921 mm, respectively. These amounts were higher than the average rainfall over the previous 9 yr in this site. Therefore, the high soil moisture due to the high rainfall likely affected sexual differentiation. Similar results have been reported by Chinchilla and Richardson (1991) and Burgarelli et al. (2002).

In the FIs of both palm cultivars, the proportions of *M. costaricensis* and *E. kamerunicus* observed were similar to those found in the MIs and were similar to those reported by Chinchilla and Richardson (1991) in Central American plantations.

In this study, as the MIs in stage 607 in both plant cultivars decreased in number, the populations of the two pollinator species also decreased. Research studies on *E. kamerunicus* in Southeast Asia, Africa, and Central America (Caudwell et al. 2003, Syed and Saleh 1987, Syed et al. 1982) suggest that this pollinator can reproduce only on the MIs of *E. guineensis*. Therefore, decreases in number of MIs affects the populations of this insect. It is important to note that the starch-rich pollen of the MIs is a major food source for pollinators (Tandon et al. 2001). Thus, variations in the amounts of pollen and the numbers of MIs probably affect pollinator populations in oil palm plantations.

In this study, when rainfall decreased, the populations of *E. kamerunicus* also decreased, thus corroborating the results of Syed and Saleh (1987), Dhileepan (1994), and Wahid and Kamarudin (1997), who indicated that dry periods reduce populations of *E. kamerunicus*, although high temperatures, natural enemies, and the availability of MIs may also be factors that affected the observed population decline.

Bunch components produced by each cultivar were similar and corresponded to earlier averages recorded for each planting cultivar at these sites (Prada and Romero 2013). In this study, the fruit set for the cultivar *tenera* planted in Plot 1 was similar to those recorded by Prada and Romero (2013) in the sixth year of production (minimum of 20; maximum of 96). The mean ratio of aborted flowers was higher than the mean ratio of parthenocarpic fruits. Flower abortions are caused by physiological imbalances in palms that result from excessive water or drought stress, nutrient imbalances, or severe defoliation during bunch development and fruit filling. The ratio of parthenocarpic fruits is directly affected by pollination. The recorded fruit-to-bunch ratio ranged from 22.6% to 74.5%, which was similar to the range recorded by Prada and Romero (2013) for the sixth year of production. Our observations correspond with reports that oil palms stabilize in terms of production and bunch cultivars after the sixth year of production. In cultivar *dura*, the minimum fruit set observed in our study was lower than that recorded by Prada and Romero (2013) for the sixth year of its production. The maximum value was similar to the previously recorded value for cultivar *tenera*; however, it should be noted that cultivar *dura* in Plot 2 has a higher genetic variability than that of the cultivar *tenera* in Plot 1. The average ratio of aborted flowers and parthenocarpic fruits was similar to that which was reported for the *tenera*.

Variations in populations of *E. kamerunicus* and *M. costaricensis* in relation to greater numbers of MIs and FIs did not affect the bunch components. However, the fruit sets recorded for both cultivars were 12.3% lower than fruit set data recorded in Brazilian varieties (79.4%) (Lacerda et al. 2008). Caudwell et al. (2003) stated that the presence of a second pollinator, such as *M. costaricensis*, offsets the decrease in populations of *E. kamerunicus*. Moreover, according to Tandon et al. (2001), approximately 2,500 insects visit FIs in stage 607 daily, and studies conducted in Tumaco, Colombia, estimated that between 9,606 and 156,753 insects per inflorescence can be found in MIs in stage 607 (Sánchez et al. 2004). Therefore, even with the varying populations, the number of insects is still sufficient for pollination. Syed et al. (1982) reported that even with varying populations, *E. kamerunicus* can respond relatively well under dry and high-humidity conditions and prevents negative impacts on the bunch components.

In conclusion, the population of pollinators did not adversely affect fruit set. However, the populations of pollinators were directly related to the number of MIs in anthesis and the rainfall recorded during the anthesis period. Due to the small number of FIs per hectare that were observed during the study period, no relationships were found between pollinator populations and formation of normal fruits or parthenocarpic fruits. This, in part, was due to the presence of two species of pollinators and other factors, such as the plentiful availability of pollen due to the high number of MIs in anthesis per hectare. Furthermore, the number of MIs and FIs in anthesis was inversely related to the rainfall recorded between 21 and 24 mo before anthesis, the period in which sexual differentiation occurs. Relationships of these factors evaluated require additional studies in conditions in which higher number of FIs per hectare are present.

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