

Impact of bee pollination on five sesame (*Sesamum indicum* L.) varieties yields in northern Côte d'Ivoire (West Africa)

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Abstract

The economic development of Côte d'Ivoire largely depends on agriculture with industrial crops in the first rank. However, with the global inflation, several countries including Côte d'Ivoire have found important to diversify their agricultural resources. Thus, sesame could present itself as an alternative to fight against malnutrition in low-income areas. Its seeds, rich in vitamins, contain nutrients able to compensate the nutritional deficiencies for humans. Unfortunately, there is no documentation about this crop in Côte d'Ivoire. Our study is one of the first in Côte d'Ivoire to assess the contribution of bees in sesame production improvement. It was carried out at the Botanical garden of Peleforo Gon Coulibaly University of Korhogo. Nine varieties of sesame were grown but only, five varieties germinated and were used for experimentation. The methodology consisted to apply three pollination treatments (control, cross-pollination, self-pollination) each, on different flowers of each variety. At the maturation, for each variety, it was noted whether the experimental flowers produced fruits or not. In case of fruit production, fruit weight, number of seeds and seed weight were measured. The results showed that cross-pollination significantly increases production parameters regardless of the variety. Alone, the honey bee presented the best performances on the production parameters of the five varieties of sesame. However, for the variety SI 099, the effect of cross-pollination was more accentuated. The findings highlight potential negative consequences of bees decline on crop yields in sub-Saharan Africa. They also make it possible to guide farmers' choice towards the varieties of sesame for which, the impact of pollinators could be considerable on the production.

Keywords: Sesame, control, cross-pollination, self-pollination, Korhogo

Introduction

Savannas in West Africa are characterized by a growing human population exposed to a certain food and economic insecurity, exacerbated by the climate change effects. Indeed, in the Sudanian savannas, the economy and livelihood of populations are essentially linked to agriculture that is highly dependent on climatic variations. Improving the livelihoods of smallholders, through higher and more stable crop yields, while minimizing negative environmental impacts, is essential to achieve overall poverty reduction in these regions (Godfray *et al.*, 2010) [8]. Sesame (*Sesamum indicum*, Pedaliaceae) is one of those crops, very tolerant to several agro-climatic conditions but, poorly known by African populations. It can be grown under several soil varieties, whether sandy or even heavy, although most of sesame cultivation is done on light soils. The species are found almost everywhere, throughout the world even if it's considered to come from Africa where it's easy to find it in the wild (Ashiri, 2007) [3]. It's probably the oldest oilseed known and used by human (Bedigian, 2003) [4]. It's currently cultivated extensively in Asia, Latin America and Africa, for its edible seeds from which oil is also extracted (Romain, 2001) [16]. In some countries, it's also used as a culinary, cosmetic and medicinal element. Its seeds are rich in protein, carbohydrates and mineral elements, such as calcium and phosphorus. It's also used on farms to feed livestock. In Cote d'Ivoire, sesame cultivation is still very little practiced. Its low production would be linked either to a lack of crop knowledge, or to the changing agronomic conditions and probably, to the lack of pollination services. The introduction of sesame cultivation into agricultural practices in Côte d'Ivoire is very recent.

Very few studies concerning the pollination of this plant have been carried out in Côte d'Ivoire. Indeed, sesame is known to be able to self-pollinate, though the levels of selfing and outcrossing differ in the literature (Pathirana, 1994; Abrol, 2013) [1, 12]. Most studies assessing the contribution of insect pollinators to the quantity and quality of sesame yields have been carried out in Europe and North America. Studies in Africa are generally focused on South African fruit and seed crops. Additionally, the majority of studies are based on large-scale farms, while small-farm cropping systems with fields smaller than 2 ha have received less attention in ecosystem services research (Stein *et al.*, 2017) [18]. Only a few studies on sesame have investigated the quality of offspring in terms of growth performance due to cross-pollination compared to individuals resulting to self-pollination. In addition, different sesame varieties may exhibit varying levels of pollinator dependence and possible yield deficits. It's therefore important to assess the potential impacts of pollination on each sesame variety (Hudewenz *et al.*, 2014; Benjamin & Winfree, 2014) [5, 10]. Furthermore, bees being known as the most important pollinators of sesame, their behavior in particular, their ability to pollinate, can also vary from one variety to another (Rhodes, 2002; Vaissière *et al.*, 1884) [15]. To assess the provision of pollination services provided by bees to sesame in northern Côte d'Ivoire, this study uses a new combination of pollinator effectiveness tests and qualitative and quantitative measurements of fruits from self-fertilization or cross-pollination on five varieties of sesame. The reaction of each sesame variety to the pollination effects could facilitate the choice of the suitable variety to be cultivated in northern Côte d'Ivoire.

Materials and methods

Study site

This study was carried out in Korhogo city (9° 26' 47.06" LN; 5° 38' 40.74" LW) in northern Cote d'Ivoire. The experiment was conducted during six months including the rainy season and the beginning of dry season in the north of Cote d'Ivoire. The experiments were carried out in the vegetable patch within the Botanical garden of Peleforo Gon Coulibaly University (Figure 1). We selected nine varieties of sesame for this study but only, five varieties germinated making the experiments possible. These varieties were named SI 097, SI 099, SI 100, SI 129 and SI 143. The experimental fields were each 100 m² in size, typically embedded in a matrix of other small fields of wind-pollinated cereal crops such as maize, millet and sorghum, or entomophilous crops such as beans and peanut, with a maximum distance of 50 m from a forest fragment. On the study site, usual agricultural practices continued during the study period: fertilizers were applied at the start of the planting season, insecticides and fungicides were applied irregularly depending on the infestation rate. Weeds were removed manually.

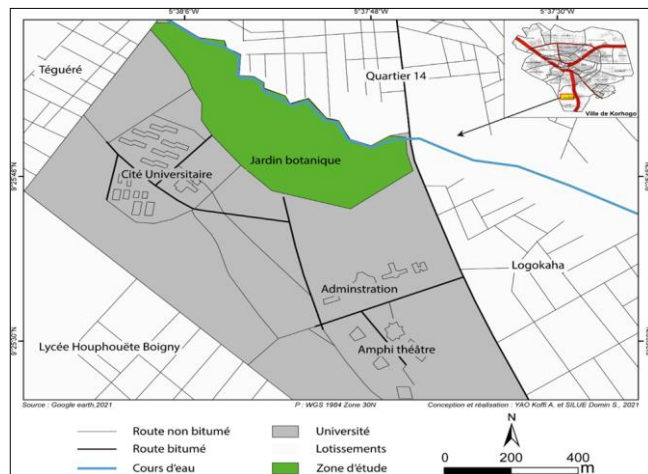


Fig 1: Location of the study site

Types of treatments performance

To assess the level of self-pollination and cross-pollination of the five sesame varieties, pollination experiments were conducted following Dafni (1992) [7] (Table 1). All manipulations were carried out during one day of floral anthesis, which ensured the receptivity of the stigma because sesame has one-day flowers (Stein *et al.*, 2017) [18]. The flowers usually open around 7 a.m. and the pollen is released 30 to 60 minutes later. For our experiments, 30 plants of each variety of sesame were randomly selected. Three different pollination treatments (Control, Self-pollination and Cross-pollination) were applied to each individual plant. For each treatment, we used one flower per plant. Each individual plant was subjected to all pollination treatments rather than just one treatment (Stein *et al.*, 2017) [18]. This approach was taken to avoid assessing the impact of the individual plant on reproductive performance rather than the impact of the treatment itself. For bagging buds and flowers, we used perforated pollination bags (hole diameter: 0.5 mm). Emasculation (removal of anthers), if necessary, was carried out in the morning between 7:00 and 7:30 a.m. before the anthers released pollen. When fruits were ripe,

we recorded whether the flowers set fruit and, if so, the number and weight of seeds per fruit. Mean fruit set, overall mean number of seeds per fruit, and mean seed weight were then calculated for each treatment. Fruit set is calculated as the number of fruits divided by the number of flowers.

Table 1: Pollination and flower manipulation experiments to determine sesame pollination systems (Dafni 1992, modified) [7]

Treatment	Treatment applied	Goal
1. Control	Flower not bagged, does not undergo any manipulation, free pollination	Assess pollination rates under natural conditions
2. Spontaneous self-pollination	Bagged flower, does not undergo any manipulation, pollen from the same flower	Prevent cross-pollination by natural pollinators and estimate the fertilization of the flower by its own pollen in a natural way
3. Cross pollination under natural conditions	Flower emasculated and not bagged, free pollination	Evaluate the rate of self-fertilization taking into account trials 1 and 2

Pollinator species and their effectiveness

To assess pollinating species and their ability to pollinate sesame flowers, we used the same method as Stein *et al.* in Burkina Faso (Stein *et al.*, 2017) [18]. We determined the flower-visiting species and their pollination effectiveness in terms of fruit set and fruit quality. In each field of each variety, 30 flowers of sesame in bud stage were bagged with pollination bags and marked. In total we assessed flower visitors and their effectiveness as pollinators on 150 flowers of sesame. Every day at 7:00 a.m., we checked if flowers had opened. If open, the bag was removed and we waited at a slight distance for the first pollinator to enter the focal flower. When leaving the flower, the pollinator was caught, etherized and stored in 70% ethanol. Thereon, the flower was bagged again after the insect visit. Care was taken that weather conditions were similar (sunny to bright, no rain) on all sampling days. Each pollinator specimen was numbered according to the visited flower and then pinned and identified to genus or species. At the end of the season, we recorded whether each visited flower set fruit, and if so, the quality parameters such as the number of intact and non-intact seeds, seed weight. For each visitor species, we calculated mean values and standard deviations for all parameters.

Data analysis

We used generalized linear mixed models to analyze the effect of pollination mode on fruit quality parameters (fruit weight, number of seeds, number of intact seeds and seed weight per fruit) of each variety of sesame and for all varieties with plant as random factor (glme package) (Weerahandi and Yu, 2020) [21]. The effect of pollination treatment on fruit set was analyzed through a binomial distribution (fruit = 1 and no fruit = 0). Pairwise comparisons were then calculated from these different models using Tukey procedure with p -value ≤ 0.05 as significance threshold (multcomp package, Hothorn *et al.* 2008) [9]. All statistical analyses were performed using R software version 4.2.2 (R Development Core Team, 2022) [14].

Results

Performance of treatments

Fruit set: For all treatments, the fruit set rate did not vary significantly between the different varieties of sesame. However, at the level of cross-pollination, the fruit set rate for the variety SI 099 was slightly higher compared to the other varieties ($p < 0.001$).

Fruit weight: The fruit weight resulting from self-pollination and cross-pollination was similar for all varieties excepted, between the varieties SI 100 and SI 129 (SELF: $p = 0.0335$, CROSS: $p = 0.0051$) and between the varieties SI 129 and SI 143 (SELF: $p = 0.0014$, CROSS: $p = 0.0234$). No significant difference was observed for the control (Figure 2).

Number of seeds: For each treatment, the number of seeds did not vary significantly between the varieties. However, a small difference was observed between the varieties SI 099 and SI 100 at the level of cross-pollination ($p = 0.0372$). No significant difference was observed between the number of seeds resulting of the self-pollination and the control (Figure 2).

Intact seeds: At the level of control, no significant difference was observed between the number of intact seeds for all varieties, excepted between the varieties SI 129 and SI 143 ($p = 0.0331$). Cross-pollination also revealed no significant difference in most varieties excepted, between the varieties SI 099 and SI 100 ($p = 0.0034$). Indeed, the variety SI 099 produced the highest number of intact seeds unlike the variety SI 100 which produced the lowest number of intact seeds. No differences were observed in self-pollination (Figure 2).

Seed weight: The seed weight per fruit significantly varied between the varieties SI 097 and SI 099 ($p < 0.001$), SI 099 and SI 100 ($p < 0.001$), SI 099 and SI 129 ($p = 0.0311$), SI 099 and SI 143 ($p = 0.001$) at the level of cross-pollination. No significant differences were observed between the seed weight at the level of self-pollination and control (Figure 2).

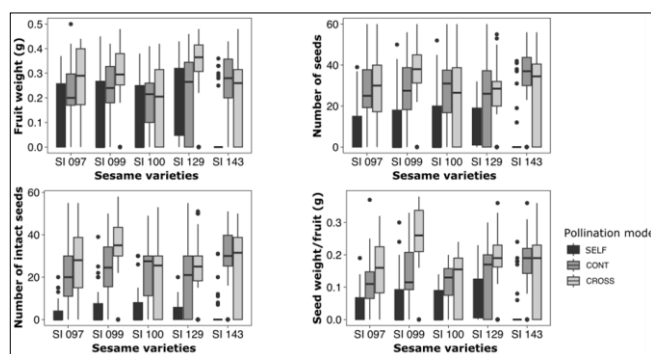


Fig 2: Fruit quality parameters of all sesame varieties resulting from pollinator dependency experiments in Korhogo. SELF: Self-pollination, CONT: Control pollination and CROSS: Outcross pollination

Effect of treatments

Variety SI 097

Pollinator exclusion (self-pollination) significantly decreased all quality and quantity parameters of the variety SI 097 compared to the control and cross-pollination (Figure 3). However, although these parameters were higher at the level of cross-pollination, there was no significant

difference between the control and cross-pollination excepted for fruit weight. Fruit weight resulting from the cross-pollination was significantly higher than that of fruits resulting from the self-pollination ($z = 3.563$, $p = 0.00114$). The seed number significantly decreased with pollinator exclusion and increased with the control ($z = 4.052$, $p < 0.001$) and cross-pollination ($z = 4.381$, $p < 0.001$). Fruits resulting from the self-pollination contained more non-intact seeds than the fruits resulting from the control ($z = 5.695$, $p < 0.001$) and cross-pollination ($z = 6.419$, $p < 0.001$). Regarding the seed weight per fruit, there was a significant difference between the self-pollination and control ($z = 3.568$, $p = 0.00105$) and between the self-pollination and cross-pollination ($z = 5.015$, $p < 0.001$). Fruit set was significantly lower with pollinator exclusion compared to the control ($z = 2.684$, $p = 0.0198$) and cross-pollination ($z = 2.684$, $p = 0.0198$).

Variety SI 099

All production parameters of the variety SI 099 significantly decreased with self-pollination compared to the control and cross-pollination (Figure 3). The best parameters resulted from the cross-pollination, which was significantly different that from the self-pollination and the control, excepted for the fruit weight where there was no difference with the control. Indeed, fruit weight was significantly lower when pollinators were excluded compared to the control ($z = 3.143$, $p < 0.01$) and cross-pollination ($z = 5.018$, $p < 0.001$). Regarding the number of seed, there was a significant difference between self-pollination and control ($z = 4.09$, $p < 0.001$), between self-pollination and cross-pollination ($z = 6.503$, $p < 0.001$) and between control and cross-pollination ($z = 2.412$, $p = 0.0419$). Fruits resulting from self-pollination contained fewer intact seeds compared to the control ($z = 5.248$, $p < 0.001$) and cross-pollination ($z = 8.331$, $p < 0.001$). On the other hand, fruits resulting from the control contained fewer intact seeds compared to that from cross-pollination ($z = 3.083$, $p < 0.01$). When excluding pollinators, seed weight per fruit was significantly lower compared to the control ($z = 3.64$, $p < 0.001$) and cross-pollination ($z = 8.355$, $p < 0.001$). On the other hand, seed weight per fruit was significantly lower for the control compared to cross-pollination ($z = 4.714$, $p < 0.001$). Fruit set was significantly lower in case of self-pollination compared to the control ($z = 4.116$, $p < 0.001$) and cross-pollination ($z = 5.065$, $p < 0.001$).

Variety SI 100

Self-pollination significantly decreased all production parameters of the variety SI 100 compared to the control and cross-pollination (Figure 3). There was no significant difference between the control and the cross-pollination. Pollinator exclusion significantly decreased fruit weight compared to the control ($z = 2.78$, $p = 0.015$) and cross-pollination ($z = 3.028$, $p = 0.0069$). Self-pollination also significantly decreased the number of seeds compared to the control ($z = 3.824$, $p < 0.001$) and cross-pollination ($z = 2.912$, $p = 0.01$). Fruits from self-pollination contained fewer intact seeds compared to that from the control ($z = 5.508$, $p < 0.001$) and cross-pollination ($z = 5.078$, $p < 0.001$). Seed weight per fruit was significantly lower with pollinator exclusion compared to the control ($z = 4.324$, $p < 0.001$) and cross-pollination ($z = 5.345$, $p < 0.001$). Self-pollination significantly produced fewer fruits than the control ($z = 2.992$, $p < 0.01$) and cross-pollination ($z = 2.393$, $p = 0.044$).

Variety SI 129

Self-pollination significantly decreased the production parameters of the variety SI 129 compared to the cross-pollination (Figure 3). Cross-pollination improved fruit weight and seed weight per fruit compared to the control (fruit weight: $z = 3.00$, $p < 0.01$; seed weight per fruit: $z = 2.618$, $p = 0.024$) and self-pollination (fruit weight: $z = 3.15$, $p < 0.01$; seed weight per fruit: $z = 4.959$, $p < 0.001$). The fruit weight and the seed weight per fruit obtained with cross-pollination were significantly different from those obtained by self-pollination and the control. Concerning the number of seeds and the number of intact seeds, there was no significant difference between the control and cross-pollination. However, the number of seeds and the number of intact seeds were significantly lower when pollinators were excluded compared to the control (number of seeds: $z = 2.629$, $p = 0.0231$; number of intact seeds: $z = 4.706$, $p < 0.001$) and cross-pollination ($z = 3.785$, $p < 0.001$; $z = 6.319$, $p < 0.001$). In terms of fruit set, there was no difference between the different treatments.

Variety SI 143

Self-pollination significantly decreased all production parameters of the variety SI 143 compared to the control and cross-pollination (Figure 3). But there was no significant difference between the parameters resulting from the control and cross-pollination. Indeed, fruit weight and seed weight per fruit were significantly reduced with the pollinator exclusion compared to the control (fruit weight: $z = 5.354$, $p < 0.001$; seed weight per fruit: $z = 5.714$, $p < 0.001$) and cross-pollination (fruit weight: $z = 4.118$, $p < 0.001$; seed weight per fruit: $z = 5.119$, $p < 0.001$). Similarly, the number of seeds and the number of intact seeds were significantly reduced with the pollinator exclusion compared to the control (number of seeds: $z = 6.201$, $p < 0.001$; number of intact seeds: $z = 6.927$, $p < 0.001$) and cross-pollination (number of seeds: $z = 4.635$, $p < 0.001$; number of intact seeds: $z = 5.795$, $p < 0.001$). Pollinator exclusion resulted in fewer fruits compared to the control ($z = 6.05$, $p < 0.001$) and cross-pollination ($z = 4.458$, $p < 0.001$).

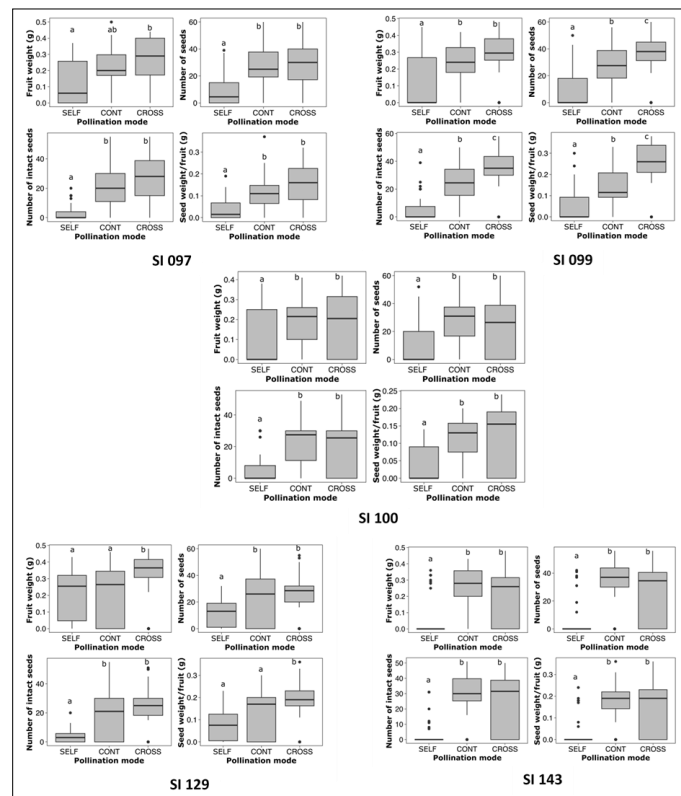


Fig 3: Fruit quality parameters of each variety of sesame resulting from pollinator dependency experiments in Korhogo. SELF: Self-pollination, CONT: Control pollination and CROSS: Outcross pollination. Letters indicate significance of differences in variables means at $P < 0.05$

Pollinator species and their effectiveness

Variety SI 097: The flowers of the variety SI 097 were visited by honey bee *Apis mellifera*, two species of wild bees (*Hypotrigona gribodoi*, *Lasioglossum atricum*) and other insect groups including wasp, fly and cricket. Only the visits of *Apis mellifera*, *Hypotrigona gribodoi* and the wasp resulted in the fruit set. The visits from other insects *Lasioglossum atricum*, wasp and fly produced no fruit. However, the level of pollination effectiveness was not the same for all insect groups. The highest number of visits (22 visits) was made by honey bee *Apis mellifera*. In addition, all flowers pollinated by *Apis mellifera* produced fruits. The other insect groups had pollinated only a small number of

flowers and each produced a single fruit. Only, pollination by *Apis mellifera* significantly increased fruit weight, seed number, and seed weight per fruit while, all other pollinators had no significant effect on these production parameters (Table 2).

Variety SI 099: Flowers of the variety SI 099 were visited by the honey bee *Apis mellifera*, the wild bee *Pseudapis* sp and a butterfly. The highest number of visits (28 visits) was made by *Apis mellifera* and only, these visits resulted in the fruit set. No visit from another insect has produced fruit. The honey bee is undoubtedly the main pollinator of the variety SI 099 (Table 2).

Variety SI 100: The flower visitors for the variety SI 100 were the honey bee *Apis mellifera*, two species of wild bees *Amegilla* sp and *Lasioglossum atricum*, a fly and a butterfly. Only, flowers visited by *Apis mellifera*, *Amegilla* sp and *Lasioglossum atricum* produced fruits. The visits made by the fly and the butterfly did not produced fruits. However, pollination effectiveness was not the same for all insect groups. Honey bee visited not only the highest number of flowers (21 flowers) but the majority of all its visits (19 visits) led to the fruit set. The other insect groups *Amegilla* sp and *Lasioglossum atricum* visited a low number of flowers and produced only one fruit. Only pollination by *Apis mellifera* significantly increased fruit weight, seed number, and seed weight per fruit while, all other pollinators had no significant effect on these production parameters (Table 2).

Variety SI 129: Sesame flowers of the variety SI 129 were visited by the honey bee *Apis mellifera*, the stingless wild bee *Hypotrigona gribodoi*, a cricket and a butterfly. Only,

visits made by *Apis mellifera* and *Hypotrigona gribodoi* produced fruits. The honey bee *Apis mellifera* visited the highest number of flowers (25 flowers) and all of its visits (24 visits) produced fruits. More than half of visits made by *Hypotrigona gribodoi* resulted in the fruit set. However, the number of flowers visited by *Hypotrigona gribodoi* was very low. The effectiveness tests indicated a slight improvement in production parameters in *Hypotrigona gribodoi* compared to the honey bee *Apis mellifera* (Table 2).

Variety SI 143: The flowers of the variety SI 143 were visited by *Apis mellifera*, a dragonfly, a fly and a butterfly. Only, the flowers visited by *Apis mellifera* produced fruits. Visits made by other insects did not produced fruits. However, if *Apis mellifera* was the main pollinator of this variety, its visits produced fewer fruits (21 fruits) compared to the number of fruits produced on the other varieties of sesame (Table 2).

Table 2: Most frequent pollinator species of each sesame variety in Korhogo and their effectiveness in terms of fruit set and quality parameters (n = 30 flowers; N = number of visits)

Variety SI 097											
Fixed effects	Fruit set		Fruit weight		Seed number		Intact seeds		Seed weight		N
	z	p	z	p	z	p	z	p	z	p	
<i>Apis mellifera</i>	8.34	0.001	7.33	0.001	8.55	0.001	7.95	0.003	6.71	0.013	22
<i>Hypotrigona gribodoi</i>	1.95	0.63	1.32	0.55	0.97	0.35	0.86	0.39	0.56	0.44	4
<i>Lasioglossum atricum</i>	0.42	0.88	0.37	0.97	0.51	0.81	0.83	0.76	0.33	0.84	1
Wasp	1.16	0.67	1.23	0.43	0.98	0.29	0.78	0.28	0.45	0.51	1
Fly	0.44	0.78	0.35	0.89	0.33	0.84	0.41	0.78	0.52	0.69	1
Cricket	0.27	0.92	0.31	0.73	0.38	0.80	0.37	0.75	0.41	0.76	1
Variety SI 099											
Fixed effects	Fruit set		Fruit weight		Seed number		Intact seeds		Seed weight		N
	z	p	z	p	z	p	z	p	z	p	
<i>Apis mellifera</i>	11.52	0.0001	9.33	0.002	11.03	0.0001	10.73	0.0001	8.77	0.003	28
<i>Pseudapis</i> sp	1.32	0.88	1.65	0.79	0.96	0.91	1.69	0.78	1.77	0.65	1
Butterfly	1.35	0.81	1.33	0.86	1.43	0.83	1.76	0.79	1.56	0.73	1
Variety SI 100											
Fixed effects	Fruit set		Fruit weight		Seed number		Intact seeds		Seed weight		N
	z	p	z	p	z	p	z	p	z	p	
<i>Apis mellifera</i>	10.21	0.001	8.32	0.012	9.41	0.001	9.23	0.001	8.87	0.002	21
<i>Amegilla</i> sp	5.17	0.034	5.88	0.027	6.90	0.014	6.91	0.013	6.99	0.019	4
<i>Lasioglossum atricum</i>	6.33	0.022	7.11	0.015	4.77	0.01	4.78	0.01	6.23	0.02	3
Fly	2.88	0.55	3.12	0.42	3.03	0.31	3.68	0.33	3.11	0.28	1
Butterfly	1.35	0.73	2.76	0.52	2.99	0.44	4.08	0.30	4.11	0.31	1
Variety SI 129											
Fixed effects	Fruit set		Fruit weight		Seed number		Intact seeds		Seed weight		N
	z	p	z	p	z	p	z	p	z	p	
<i>Apis mellifera</i>	8.54	0.001	4.56	0.011	8.12	0.001	4.37	0.013	3.88	0.02	25
<i>Hypotrigona gribodoi</i>	3.81	0.02	3.71	0.028	4.55	0.017	1.66	0.045	2.16	0.033	3
Cricket	0.98	0.87	1.22	0.71	1.56	0.67	1.03	0.83	1.81	0.75	1
Butterfly	1.52	0.66	1.15	0.76	2.11	0.59	1.10	0.78	0.99	0.72	1
Variety SI 143											
Fixed effects	Fruit set		Fruit weight		Seed number		Intact seeds		Seed weight		N
	z	p	z	p	z	p	z	p	z	p	
<i>Apis mellifera</i>	11.46	0.001	11.33	0.001	10.47	0.002	8.92	0.012	7.28	0.003	25
Dragonfly	0.60	0.76	2.27	0.62	1.10	0.69	0.67	0.72	0.56	0.81	1
Fly	2.29	0.63	1.12	0.68	0.81	0.71	0.59	0.77	0.54	0.83	3
Butterfly	3.11	0.57	2.35	0.61	2.22	0.65	1.16	0.66	1.09	0.69	1

Discussion

To our knowledge, this study is the first focused on sesame in Cote d'Ivoire, a country from sub-Saharan West Africa. It focused on five varieties of sesame, grown in Korhogo, a locality in the north of the country, to select the varieties

whose production parameters are more improved with cross-pollination. Pollination treatments revealed that the studied varieties of sesame have a mixed mating system and produce fruits through self-pollination and cross-pollination. The self-fertilization rate was relatively high for some

varieties and less pronounced for the others. That is consistent with other studies on sesame, according to which sesame is primarily self-pollinating, although cross-pollination occurs (Abrol, 2013, Rhodes, 2002) ^[1, 15]. Our results are not consistent with a study from Weiss, who found that sesame is mainly self-pollinated (Weiss, 1983) ^[22]. However, our results corroborate other studies conducted in Brazil (Andrade *et al.*, 2014) ^[2] and Burkina Faso (Stein *et al.*, 2017) ^[18] revealing the better performance of sesame after cross-pollination. Our study revealed a relatively high rate of cross-pollination, which could be due to the high abundance of pollinators in the study site. In addition, the sesame fields were embedded in a landscape mosaic of various other crop fields within the botanical garden and placed near a forest fragment favoring the proliferation of pollinators. The dependence level of sesame varieties on cross-pollination was variable. These variations also high in the levels dependence on pollinators for cross-pollination are typical of species grown with mixed breeding systems (Pathirana, 1994) ^[12]. Cross-pollination improved the production parameters (fruit set, fruit weight, seed weight) of the variety SI 099 compared to other varieties. This may be due to the fact that apart from the honey bee, only a wild bee and a butterfly visited the flowers of this variety while the other varieties were visited by several insect groups. The variety SI 099 would produce sufficient nutrients for bees or provide quality nectar able of attracting bees. The findings showed that cross-pollination by *Apis mellifera* significantly increased yield quality of all sesame varieties, consistent with findings from Stein *et al.*, (2017) ^[18] and Andrade *et al.*, (2014) ^[2]. Indeed, the effectiveness of honey bee is due to its abundance, its social life and its ability to pollinate a wide variety of flowers. A single colony of honey bee can include 20,000 to 80,000 specimens, which can normally visit flowers over a distance of 2 km when collecting pollen or nectar. If they find nothing nearby, they can travel up to 7 km. The honey bee could even make 4 million trips per year, and visit around 100 flowers per trip. In addition, the honey bee is an extremely effective pollinating insect because its body is covered in hairs where thousands of pollen grains are easily attached when it travels through the flower; then, it only visits one plant species on each of its outings; and finally, it forages constantly, not only to collect the food necessary for its own needs, but also to meet the daily nectar and pollen needs of the colony. This result is consistent with those of several other studies carried out elsewhere in the world. The honey bee *A. mellifera* was effective on Glycine max flowers in USA (Chiang & Kiang, 1987) ^[6], Brazil (Milfont *et al.*, 2013) ^[13] and Maroua in Cameroon (Settele *et al.*, 2016) ^[17]. Our results revealed even higher benefits of bee pollination in terms of fruit quantity and quality. For all sesame varieties, the quality increased significantly for the economically important parameters of fruit weight, seed number and seed weight. Higher numbers of intact seeds and increased seed weight per fruit are desirable traits, both from a commercial and ecological perspective, serving as an important indicator of plant reproductive success (Stein *et al.*, 2017) ^[18]. A loss of pollinating bees, concomitant with self-pollination of cultivated species would lead to yield decline of 50% and 87% for sesame (Stein *et al.*, 2017) ^[18]. Thus, our study clearly revealed the value of bee pollination for sesame production in smallholder systems in sub-Saharan Africa. In the context of human population growth and land conversion, with loss of natural habitat being one

of the main drivers of bee decline (Potts *et al.*, 2010; Winfree *et al.*, 2011) ^[13, 23], and increasing climate unpredictability (Tchuenguem & Dounia, 2014) ^[19]. In West Africa particularly, the targeted establishment and preservation of semi-natural habitats would consistently increase the diversity and abundance of wild pollinators (Tchuenguem & Dounia, 2014) ^[19].

Conclusion

This study for the first time, focuses on bee contribution in improving yield production of sesame in northern Cote d'Ivoire. In addition, taking into account the pollination contribution, it focused on five varieties of sesame in order to select the most suitable for large-scale production. Pollination treatments have shown that cross-pollination is beneficial in terms of improving production parameters. The honey bee *Apis mellifera* is the main pollinator of the five varieties of sesame. However, this species better improves the production parameters of the variety SI 099 compared to the other varieties. These results have implications for the management of insect pollination services in cash crop fields such as sesame, and highlight the potential consequences of any declines in specific taxa, thus making the case for the conservation of bee populations.

Author contributions

DC and YT designed the study. DC and DSS collected data in the field. DC determined insect specimens and their traits. DC analyzed and plotted output data. DC wrote the first draft of the manuscript. MK and BSB contributed to improve the draft. All authors contributed substantially to revisions.

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Data availability

Data of this study are available upon request from the corresponding author. The data are not publicly available due to privacy restrictions.

Conflict of interest

All authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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