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DO FRENCH BEANS (*PHASEOLUS VULGARIS*) GROWN IN PROXIMITY TO MT KENYA FOREST IN KENYA EXPERIENCE POLLINATION DEFICIT?

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Abstract—Yields of commercially important crops in Kenya are often far below their potential. Amongst the possible reasons for such low yields may be the ecosystem degradation that can be expected to have negative impacts on pollinator presence in cropland, and the consequent food security issue for smallholder farmers who depend on these crops for their livelihood. Our study was carried out to assess the potential pollination deficit of French beans (*Phaseolus vulgaris* L.), a major export vegetable crop in Kenya grown by small-scale farmers. Sufficient pollination of French beans likely results in high seed set and uniform heavier green pods. Such pods get the highest grade while malformed pods are unmarketable, reducing family income. We hypothesized that pollination success was linked to the abundance and diversity of large pollinators, itself associated with the proximity to natural habitats. Flower visitors to French beans were sampled in 2011 and 2012 in ten farmer-managed plots, five within 200 m from the edge of Mt. Kenya forest and five farther away, more than 1000 m. Each plot measured 760 m^2 and was planted at the same time, with the "Julia" variety. Flowers were observed for 2 h in each plot once weekly for three weeks at peak flowering from 0900-1100 h in the morning and 1200 – 1400 h in the afternoon on alternate days. Honey bees (*Apis mellifera*) were the most abundant visitors of French bean flowers followed by carpenter bees (*Xylocopa* spp.) and leafcutter bees (*Megachile* spp.). Significantly higher numbers of leafcutter bees were recorded on farms far to the forest. There was no significant difference in honey bee abundance among the study sites, probably because apiaries and wild colonies are located across the landscape. French bean yield was significantly correlated with the mean abundance of carpenter bees in 2011. This suggests the possible occurrence of pollination deficit in French beans where the density of carpenter bees is insufficient, which was reflected by the high variability of yields in the farmland. We advocate that area-wide management and conservation of carpenter bees should be initiated to support French bean farming in the area.

Keywords: carpenter bees, honey bees, leafcutter bees, wild bees

INTRODUCTION

About 80% of growers in Kenya are small-scale farmers. Their level of farm operation as well as investments in farming varies across different agro-ecosystems. Those in areas with high potential, such as the Mt Kenya region, invest substantial amounts of money in farming, including high use of inputs such as fertilizers and pesticides. Land subdivision is intense in these areas, which has created small land holdings. Farmers are therefore mainly interested in maximising their production to sustain their livelihood. Small-scale farmers in Kenya do not usually manage pollination (Kasina et al. 2009a) and pollinator conservation therefore, is incidental. For example, farmers bordering the Mt Kenya forest are known to carryout some farm practices that could positively impact pollinators such as keeping hedgerow plants, land having set-aside areas for natural vegetation, and growing diverse crop species within a small area. At the same time, various intensive agricultural practices such as pesticide applications are used in this area and could negatively impact pollinators. The Mt Kenya forest is an area protected by the Kenyan government even though it has shrunk over the years as a result of expanding human settlement (Mugo 2007). Given the high degree of land fragmentation into intensively managed small agricultural units, the Mt Kenya forest may be an important reservoir of pollinators in the area. Thus there may be a forest-farmland gradient of pollinator availability along which the potential for pollination deficit could be assessed in entomophilous crops.

French bean (*Phaseolus vulgaris* L.) is the most important vegetable crop in Kenya, both in terms of production and income generation (HCDA 2013). The crop is produced for export, particularly to European markets,

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and it is grown intensively by small-scale farmers who generally use high amounts of inputs (water, fertilizers and plant protection products (Monda et al. 2003; Nyakundi et al. 2010). French beans are grown throughout the year in periods of low rainfall as their growth and productivity are negatively affected by large amounts of rainfall. Both flooding and sprinkler irrigation systems are commonly used to supplement rains. We found no records on the pollination needs of the 'Julia' variety of French beans cultivated in Kenya, but carpenter bees visit and pollinate different cultivars of *P. vulgaris* grown for dry seeds in Cameroon (Kingha et al. 2012) and in Puerto Rico (Bliss 1980). In the USA, Ibarra-Perrez et al. (1999) found that bumble bees (*Bombus* spp.) were the most effective pollinators of *P. vulgaris* and their flower visits had a significant positive effect on seed production in two determinate varieties. Honey bees are abundant visitors of French bean flowers in Kenya (Kasina et al. 2009c), but exposure of bean plants to honey bee pollination did not result in higher pod yield of dry seeds in the UK nor in the USA (Free 1966; McGregor 1976; Delaplane & Mayer 2000). In Kenya, Kasina et al. (2009b) found that cross-pollinated common beans resulted to increased seed set and nutrition improvement of the dry harvested seeds. Yet since French bean marketing quality is based on individual pod weight as well as uniformity in pod shape, commercial yield might be affected by insect pollination. Indeed, there is no parthenocarpy nor apomixis in *Phaseolus vulgaris* (Bliss 1980) and pod uniformity is influenced by seed set constancy: when all ovules are fertilized, the pods grow uniformly, giving the producer a first grade product. On the other hand, poor pollination results in fewer developing ovules, leading to curved pods that are rejected during the sorting of marketable pods. Although French beans are reportedly fully self-fertile (White & Izquierdo 1991), visits by large robust bees such as carpenter bees and bumble bees that can trip flowers could enhance pollination with auto- as well as allo-pollen. Therefore we investigated the potential for pollination deficit for French beans grown for green pods in Kenya. Indeed, should such a deficit be documented, it could provide an incentive for pollinator management by farmers to maximise their yield (Deguines et al. 2014), as well as some much needed data on crop pollination in Africa (Archer et al. 2014).

The objective of our study was to examine if distance from forest (a possible reservoir for large pollinators) affected the abundance and diversity of bees visiting French bean flowers, which in turn might impact their pollination level and ultimately the green pod yield of this crop.

MATERIALS AND METHODS

Study sites

The study was conducted in farmlands bordering the northern slopes of Mt Kenya forest national park (between latitudes 0° 15' S and 0° 45' N, longitudes 36° 11" and 37° 24' E, and altitude 1600-2140 m). The study sites were located on the leeward side of the mountain straddling a climatic gradient that ranges from a mean annual rainfall of 637 mm far from forest to 1300 mm in areas close to the forest. Rainfall is bimodal in this area with peaks in October-November and April-June and distinct seasons with little precipitation in-between. Temperatures range from 20 to 28°C (Jaetzold and Schmidt 1983). Subsistence rain-fed mixed farming is the main source of livelihood in the area with staple crops such as maize (*Zea mays*), dry common beans (*Phaseolus vulgaris*), potatoes (*Solanum tuberosum*) and sweetpotatoes (*Ipomoea batatas*). Vegetable crops commonly grown include snow peas (*Pisum sativum*), cabbage and kales (*Brassica oleracea*), and French beans, grown in small plots for commercial purposes. The plot sizes are dependent on capital and availability of labour. Farmers have organised themselves in cooperatives through which they are able to access credit for inputs such as seeds, pesticides, and fertilizers which are deducted after selling the produce. In addition to crops, farmers usually keep cattle, sheep, goats and chicken.

Study design

The study took place in 2011 and 2012 over the May-July growing season. The study design was based on a protocol developed and agreed upon by global partners for testing pollination deficit in crops (Vaissière et al. 2011). Farmers growing French beans of the 'Julia' variety and under the contract farming system were contacted to provide plots for this study.

We selected five farms within 200 m from the edge of Mt. Kenya forest and another five farms located in a similar environment, but farther than 1000 m from the forest edge. Selected farms had a minimum 760 m^2 plot of land planted with French beans at the sampling location. The crop was grown for commercial purpose, hence farmers applied their usual farm practices, including use of inputs to secure high yields.

At each farm, flower visitors (here the 'visitor' was described as those individuals found collecting nectar or pollen on the flower) were sampled once a week on sunny days for three weeks between June 20th and July 20th each year. Flowers were observed for 2 h on each plot starting at the time when the crop reached 50% flowering (50% of the plants with at least one flower at anthesis). Observations took place at 0900-1100 h and 1200-1400 h (local time) on alternate days. Scan sampling for bees visiting French bean flowers was performed by counting bees on 600 flowers following FAO protocol (Vaissière et al. 2011) and identified to species level based on a reference collection established the previous years (e.g. Kasina et al. 2009b,c). Sweep netting was carried out for 10 minutes after each recording to capture visitors for identification. Data on crop inputs and yields were provided by the farmers.

We compared bees between farms within 200 m of the forest and those farther than 1000 m from the forest edge using ANOVAs. This was after square-root (i.e. $(x + 0.5)^{0.5}$) transformation to ensure that the data is normally distributed, which is a requirement for ANOVA tests. Analyses were conducted based on functional group (lowest taxonomic level possible) as well as individual species level based on the abundance of the individuals observed. In addition, the data was used to assess the dependence of

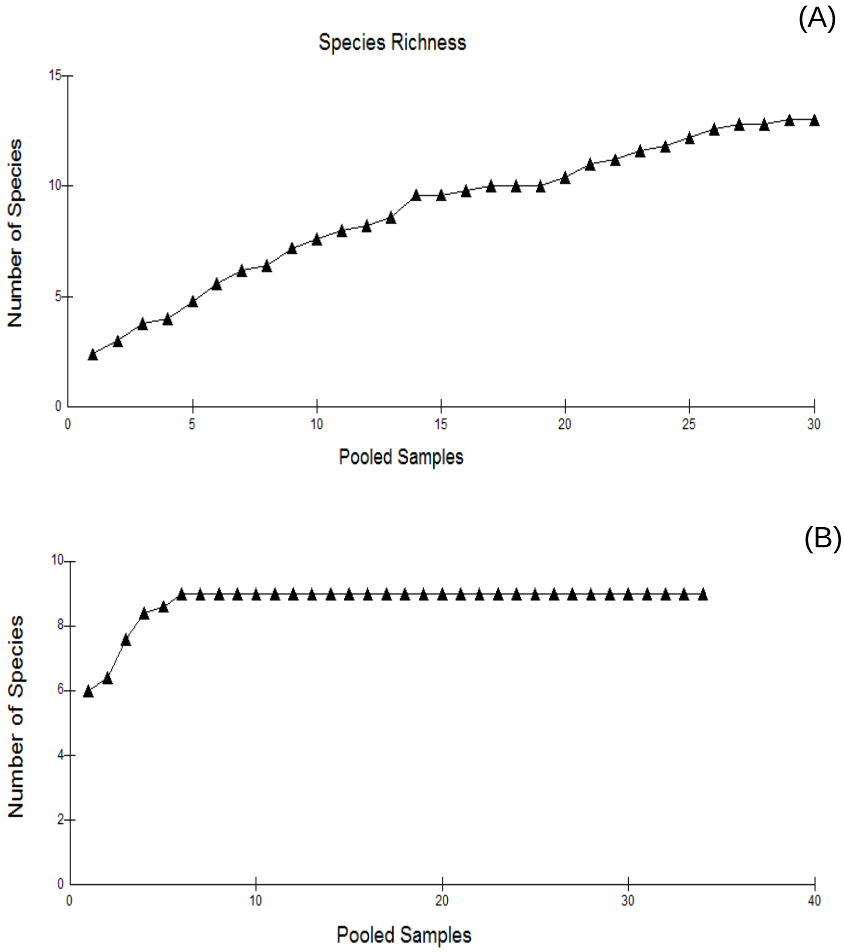

FIGURE 1. Species richness curve for bees visiting French bean flowers in ten farms neighbouring Mt Kenya forest in 2011 (A) and 2012 (B).

French beans on pollinators by looking also at crop yields. Correlation analysis was used to test the relationship between crop yield data and the density of bees observed visiting the crops in the different farms. Genstat Discovery ed. 4 was used for general statistical analysis while BiodiversityPro software was used to measure species richness expressed by the species accumulation curves.

RESULTS

Floral visitors of French bean flowers

A total of 2,669 flower visitors were recorded in French bean flowers in the Mt Kenya region over 30 sampling sessions in 2011 and 2,772 over 30 sampling sessions in 2012. These insects comprised only bees in four families: Apidae, Megachilidae, Colletidae and Halictidae, majority of which were from family Apidae. We cannot be confident that the bees sampled in the first season (year 2011) were fully representative of the bee species visiting French bean flowers in the farmland, as the species richness curve did not reach a plateau to indicate saturation (Fig. 1A). This implies that more bee species might have been recorded with extended observations. Compared to 2011, the number of bee species visiting French beans that were observed in the different sampling periods in 2012 appears to be a more accurate representation of the bees visiting French beans as shown by the species richness curve (Fig. 1B). The difference shown between the 2011 and 2012 species accumulation curves is based on the species recorded per observation period. The difference in years could probably be due to several reasons: plenty of resources in 2011 for bees to choose, presence of a better floral patch in 2011 compared with French beans or just biological dynamics across the years.

Bees observed included honey bees (*Apis mellifera*), carpenter bees (*Xylocopa calens* and *X. flavorufa*), leafcutter bees (*Megachile rufipes* and *M. bituberculata*), *Colletes* spp., *Ceratina* spp. and *Halictus* sp. The numbers of species in the *Colletes*, *Ceratina* and *Halictus* genera were too low for analyses hence analysis was carried out at genus level (Tab. 1). Likewise, data for carpenter bees and leafcutter bees were analyzed as two functional groups rather than for individual species due to the low numbers of individual species observed.

The total numbers of bees recorded visiting French bean flowers differed between the farms within 200 m of Mt Kenya forest and those more than 1000 m away (Tab. 1). The number of carpenter bees and leafcutter bees was higher in farms more than 1000 m from the forest edge while the numbers of honey bees were higher in farms within 200 m of the forest edge (Tab. 2). The number of leafcutter bees recorded was significantly higher in 2012 compared with 2011 (Tab. 2). There was also significant difference in the

TABLE 1. Mean number of bees recorded visiting French bean flowers over two seasons at farms bordering Mt Kenya forest, Kenya.

Family	Species	Distance from forest edge	
		200 m (SD†)	1000 m (SD†)
Apidae	*Xylocopa* spp.	4.6 (4.3)	6.3 (10.6)
	Apis mellifera	80.9 (47.8)	74.1 (47.2)
	Ceratina spp.	0.1 (0.37)	0.04 (0.19)
Colletidae	*Collete* spp.	0.0 (0.00)	0.04 (0.19)
Megachilidae	*Megachile* spp.	0.8 (1.4)	2.6 (5.0)
Halictidae	*Halictus* sp. 1	0.1 (0.34)	0.04 (0.19)

†Number in the brackets denote the standard deviation

TABLE 2. Probability value of factors influencing abundance of bees visiting French bean flowers in farms bordering Mt Kenya region.

Family	Species	*Parameter*		
		Distance from forest edge	Year of observation	Distance*Year interaction
Apidae	*Xylocopa* spp.	0.370	**0.004***	0.704
	Ceratina spp.	0.501	0.106	0.843
	Apis mellifera	0.565	0.236	0.15
Colletidae	*Collete* spp.	0.264	0.143	0.09
Halictidae	*Halictus* sp.1	0.748	0.169	0.915
Megachilidae	*Megachile* spp.	**0.039***	**0.008***	0.346

*significant at $P < 0.05$

TABLE 3. Effects of yield of French beans grown 200 m and 1000 m from Mt Kenya forest edge in 2011.

Factor	No. of harvestings	Yield (kg/ha)		Net monetary gain KES†/ha
		Per harvest	Per season	
200 m	6.80 (2.7)	738.49 (112,659.52)	5,400.00 (13,675,346.26)	48,843.16 (2,205,696,598.34)
1000 m	8.60 (1.8)	697.84 (45,046.84)	5,815.79 (1,248,182.13)	54,123.68 (201,319,296.23)
P-value	**0.04***	0.41	0.41	0.40
SE††	0.85	132.81	38,770.58	16,412.88

†Kenya Shillings (= 0.0112 USD); *significant at $P < 0.05$; ††Standard error of means
Numbers in brackets denote the variance of the observations from the means

number of honey bee visits to French beans between years, which may be due to the multiple apiaries present in the farmland. The interaction between year of observation and distance from the forest edge was not significant for all bees, with or without *Apis mellifera*, nor for any group of bees (Tab. 2)

French bean yields

Generally, green pods of French beans are harvested over a period of two to three weeks at an interval of 3-4 days to ensure the right pod quality is harvested. Higher yields are achieved with more harvestings, resulting in higher incomes. Farms located more than 1000 m from the forest edge had significantly higher frequency of pod collection (harvest) as well as a tendency for higher yields and net gain from French bean farming compared to farms close to the forest in 2011 (Tab. 3). Unfortunately, this information was not adequately collected from farmers in 2012. Correlation analysis did not show a significant relationship between any bee group and yield component, except for the number of carpenter bees and the yield per harvest ($r = 0.42$; $N = 10$; $P = 0.022$) and net yield ($r = 0.50$; $N = 10$; $P = 0.014$). Yield variability across the different farms was higher near the forest compared with farm from the forest, probably relating to the preferred pollinator presence.

DISCUSSION

French beans, just like many other varieties of *Phaseolus vulgaris*, are largely autogamous, but the impact of pollinator activity on their production is not clear. Beans grown for seeds reportedly benefit from insect pollination, especially by large bees that are capable of forcefully opening the flower keel, thus releasing pollen and exposing the stigma to allo-pollen (Free 1966; Crane & Walker 1984; Ibarra-Perez et al. 1999). In Kenya, studies of common bean reported increased seed production per pod with insect pollination (Kasina et al. 2009b). However, French beans are mostly harvested and sold as green pods prior to full seed maturation so that pollination needs are probably associated solely with pod formation and pod quality. Earlier studies from several locations reported little change in pod yield of *P. vulgaris* when exposed to bee pollination, but none of these was concerned with green pod production (Free 1966; McGregor 1976).

Honey bees have been observed visiting bean flowers in Kenya, but their pollination efficiency remained unclear (Kasina et al. 2009c). They are the most frequent visitors, but French bean flowers do not provide many resources and so they are not very attractive to honey bees and their foraging on bean flowers may be reduced whenever a patch of more attractive floral resources is available at the same time that French beans flower.

The sole bee species whose visitation was positively correlated to yields and quality of French bean production in the Mt Kenya region were carpenter bees (*Xylocopa* spp.). As long-flying species, we found that they readily visited French bean flowers far from the protected habitat of Mt Kenya. While it was not possible to determine where these carpenter bees visiting French beans far from Mt Kenya were nesting, it is interesting to consider why they were recorded more frequently at the sites far from the forest edge than the ones close to it. This was not expected, but, the French bean fields at lower elevations and farther from the forest edge must be irrigated, and so they may have been preferentially foraged during the dry season, because the flowers from these irrigated French bean plants may provide more resources, in terms of both pollen and nectar, than those on non-irrigated sites close to the forest edge at a higher elevation.

It would be essential to conduct further studies to confirm or inform whether the green pod yield of French beans is positively affected by visitation by carpenter bees. If confirmed, the vulnerability of this crop to pollination deficit near Mt Kenya would be high since these most important pollinators are not managed by farmers. To minimise the effects of insufficient pollination, the presence of carpenter bees in the landscape should then be enhanced. Methods that increase the population of these bees, such as habitat management and adoption of good agricultural practices should be promoted (Corbet & Willmer 1980). In fact, EuroGAP (European Good Agricultural Practices) is currently a prerequisite for farmers to access external markets for French beans, and farmers are working to meet such standards. Also, it might be beneficial to provide artificial nesting sites made of local materials such as those developed in Brazil to increase the population of carpenter bees to improve pollination in passion fruit orchards (Freitas et al. 2003).

In the recent past, several studies have shown that high diversity of pollinators is important in increasing crop yields through their complementary pollinating activity with honey bees (e.g. Kremen et al. 2002; Klein et al. 2003; Hoehn et al. 2008; Brittain et al. 2013; Garibaldi et al. 2013). Evidence from these studies show that for entomophilous crops, diversity may be as important as abundance in influencing the yield gained from good pollination. In Kenya, commercial farming systems should consider carefully the need to increase the diversity of pollinators: at present, farms only rely on honey bees, even on crops that honey bees do not efficiently pollinate. The commercial cropping systems of Kenya so far, reinforce monoculture, with little motivation for diversity. Nor do they consider an ecological approach to pollination management because honey bee colonies can be moved at any time to where they are needed, and there is as yet little perception that honey bees may not be effective pollinators for some crops. In general, a wide range of crops and shrub lands exist within the farms amongst small-scale farming systems and these can support a high diversity of pollinators when well managed. However, our results indicate that farmlands in Mt Kenya do not support a high diversity of bees compared with Kakamega farmlands where a higher diversity and abundance of bees were recorded on French beans (Kasina et al. 2009c). This is probably due to the high intensification of agriculture with no consideration of bees or the loss of natural habitat and to the high degree of water stress. Our results suggest that the adoption of bee-friendly agricultural practices in Mt Kenya region would be useful to increase the populations of different bee species within the farms to enhance pollination for improved crop yields. Such practices would include capacity building of farmers to empower them with the knowledge on why and how to conserve bees, and on pollinator friendly farm practices (e.g. proper timing and use of pest control products) and habitat management practices (e.g. pollinator friendly hedgerow system, nest provisioning) specifically targeted toward carpenter and megachilid bees (Kasina et al. 2009a). Providing user-friendly information to growers on the expected benefits of pollinator conservation as well as its associated costs would provide incentives to encourage farmers to become more receptive and act in favour of the conservation and protection of bees.

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