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FORAGING DYNAMICS AND POLLINATION EFFICIENCY OF *APIS MELLIFERA* AND *XYLOCOPA OLIVACEA* ON *LUFFA AEGYPTIACA* MILL (CUCURBITACEAE) IN SOUTHERN GHANA

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Abstract—As a result of different levels of pollination efficiency of pollinators, knowledge on appropriate pollinators of a plant has become important, especially in the management and conservation of both the pollinators and the plants. In this study, the pollination efficiency of *Apis mellifera* and *Xylocopa olivacea*, important pollinators of *Luffa aegyptiaca*, were assessed in the southern coastal part of Ghana from June 2009 to September 2010. Pollination efficiency of *A. mellifera* and *X. olivacea* was estimated in terms of fruit set and fruit size. Further, data on daily and seasonal nectar dynamics of *Luffa aegyptiaca* were collected. In the early mornings (0600-0700), *X. olivacea* was the most frequent visitor (0.47 min^{-1}) on the female flowers compared to *A. mellifera* (0.13 min^{-1}). The mean nectar (sugar) concentration in the dry season was 36.58 ± 0.55 %, which was higher than the 34.03 ± 0.38 % obtained for the rainy season (F = 14.986; df = 2; P < 0.0001). Total amount of sugar in the early mornings was 1.88 ± 0.37 mg which was higher than 0.28 ± 0.04 mg in the mid mornings ($\chi 2$ = 14.33, df = 1, P < 0.0001). Fruits that developed from flowers that had received a single visit from *X. olivacea* had a mean weight of 428.7g and were 1.5 times heavier than fruits from flowers visited by *A. mellifera* (286.76 g). *X. olivacea* was more efficient than *A. mellifera* in terms of number of fruit set per single visit. This study has provided some knowledge on pollination ecology of *L. aegyptiaca*, which can be exploited to improve fruit production in commercially grown vine crops.

Keywords: nectar concentration, nectar energetics, foraging dynamics, cucurbit plants

INTRODUCTION

Luffa aegyptiaca Mill (Cucurbitaceae) is a vigorous, annual climbing herb found in tropical and subtropical regions and in the same family with most of the commercially grown vine crops. *L. aegyptiaca* is monoecious, having separate male and female flowers on the same plant, a characteristic of many species in the family, that makes them even more dependent on pollinators, especially on bee species. Cucurbit plants do not just rely on pollinators but also require repeated visits from pollinators (Collinson 1976; Stanghellini et al. 1997; Meléndez, 2002). Furthermore, on the same plant, some bee species have been shown to be more efficient pollinators than others (Stanghellini et al. 2002). Therefore knowledge on appropriate pollinators of a plant has become important especially in the management and conservation of both the pollinators and the plants.

One of the factors determining pollinator effectiveness is the rate of pollinator visitation (Fishbein & Venable 1996). Measurements of visitation rates can identify the linkages amongst pollinators, plants and subsequent fruit set. Additionally, temporal variation in production of nectar may influence the rate of visitation (Thomson et al. 1989). Nectar volume and concentration are the basis upon which nectar energetics are calculated, and the abundances of the dominant species of flower visitors within some ecosystems are linked to the amount of energy provided by nectar (Roubik 1989). Daily changes in available nectar clearly affect the identity and abundance of flower feeders (Potts et al. 2001; 2004), as do seasonal changes (Petanidou & Ellis 1996; Bosch et al. 1997).

In an earlier study, the importance of *Apis mellifera adansonii* Linnaeus and *Xylocopa* species to pollination of *L. aegyptiaca* was demonstrated. No fruits were formed when flowers were bagged to exclude visits by bees. A single visit from *Xylocopa* species was enough to cause pollination while more than one visit of *A. mellifera* was needed (Mensah & Kudom 2010). That study, however, failed to demonstrate whether the single visit that resulted in pollination was enough to set fruit. In this study, pollinating efficiency of both *A. mellifera* and *X. olivacea* (Fabricius) were assessed. Furthermore, daily dynamics of nectar energetics were explored to explain temporal foraging behaviour of the bees on flowers of *L. aegyptiaca* and the effect of bee visits on fruit development. It is expected that the results will contribute to the knowledge of pollination ecology of *L. aegyptiaca* and to the improvement of fruit production among commercially grown vine crops.

METHODOLOGY

Study sites

The project was carried out in two contrasting patches of wild *L. aegyptiaca* in Biriwa (N05° 09.956', W01° 08.900) and Cape Coast (N05° 06.473', W01° 17.431') in the

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southern coastal part of Ghana. At Biriwa, the study site was a small plot of *L. aegyptiaca* isolated from other vegetation by roads and buildings, with < 100 flowers produced daily. At Cape Coast, the study site was a larger plot with > 500 flowers of *L. aegyptiaca* produced per day. This site was swampy with other vegetation surrounding it. From June 2009 to September 2010, data were collected on the frequency of bee pollinators on female flowers and daily and seasonal nectar dynamics. In addition, pollination efficiency of *A. mellifera* and *X. olivacea* were assessed in terms of fruit set and size.

Nectar survey

Nectar was collected in the two major seasons in Ghana, from February to March 2010 (dry season) and July to September 2010 (rainy season). In each season, nectar was collected from 60 open flowers exposed to floral visitors at different times of the day between 0600hrs and 1400hrs. The time for nectar collection was chosen after a preliminary survey on the period of activity of floral visitors and the temporal pattern of opening and closing of flowers of *L. aegyptiaca*, as described in Mensah and Kudom (2010). Each observation day was divided into three sessions: early morning (0600-0700), mid morning (1000-1100) and afternoon (1300-1400) and nectar was collected from four flowers in each session for five weeks. Nectar was taken from the flowers with 1 μL micro capillary tube (Drummond, U.S.A) and nectar concentration was measured with a sugar refractometer modified for small volumes (Bellingham and Stanley, UK) as described in Kearns & Inouye (1993). Nectar volume was determined by measuring the length of the nectar column in the micro capillary tube with a veneer calliper. After each use, the refractometer was thoroughly washed with distilled water and dried with tissue paper. Temperature and relative humidity at the time of nectar collection were measured as close as possible to the flowers with a hand-held thermohygrometer (Kestrel, U.S.A). Any day with particularly aberrant weather (e.g. heavy rainfall) was skipped to ensure that all data were collected under 'typical' microclimatic conditions. Total amount of sugar in nectar and nectar energetics were calculated as described in Galetto & Bernardello (2005) and Kudom & Kwapong (2010). ANOVA was used to compare the difference in nectar concentration between the two seasons while Kruskal Wallis non parametric test was used to analyze the daily changes (SPSS, Version 16).

Temporal pattern of bee visitation

Number of bee visits per minute to a *L. aegyptiaca* flower was recorded between 0600 and 1400. A visit was counted when *X. olivacea* or *A. mellifera* made contact with the stigma of a flower. Data were collected at the two study sites for three days each week, during the peak flowering season between July and September 2010. As for nectar survey, each observation day was divided into three sessions; early morning (0600-0700), mid morning (1000-1100) and afternoon (1300-1400). Observations were made every 15 minutes in each session and visitation rate was calculated by dividing the number of bee visits by observation time. Again, any day with particularly aberrant weather (e.g. heavy rainfall) was skipped to ensure all data were collected under 'typical' microclimatic conditions.

Pollination efficiency per visit

At the Cape Coast study site, 30 bagged female flowers each were open to *A. mellifera* and *X. olivacea* for a single visit and the flowers were re-bagged and the numbers that set fruit were recorded. Female flower buds were bagged as described in Mensah and Kudom (2010). Fruits were harvested after two weeks and their length and weight measured.

RESULTS

Throughout the study period, female flowers at the Biriwa study site did not receive visits from any *Xylocopa* species. The only bee visitors to flowers at that study site were *A. mellifera*. However, *Xylocopa* species (*X. varipes* Smith, *X. olivacea* and *X. imitator* Smith), *Amegilla calens* (Lepeletier) and *A. mellifera* were the bee visitors to the Cape Coast study site. Among the *Xylocopa* species at this site, *X. olivacea* was the most abundant. Due to the absence of *Xylocopa* from the Biriwa site, data are presented and comparisons between *A. mellifera* and *X. olivacea* for the Cape Coast site only.

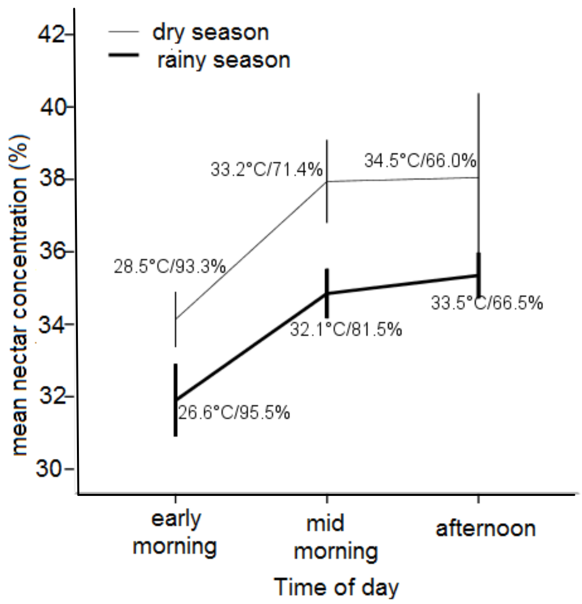

FIG. 1. Daily and seasonal variation of nectar concentration of *Luffa aegyptiaca*. Insert: average temperature (°C) and relative humidity (%). Error bars represent 2 SE

In the early mornings, *X. olivacea* was the most frequent visitor (0.47 min^{-1}) on the female flowers compared to *A. mellifera* (0.13 min^{-1}). However at mid-morning and afternoon, visitation rate of *A. mellifera* increased to 0.53 min^{-1} while visits from *X. olivacea* reduced to 0.03 min^{-1}.

Nectar survey

The mean nectar concentration (± SE) in the dry season was 36.58 ± 0.55 %, which was higher than the 34.03 ± 0.38 % in the rainy season (F = 14.986, df = 2, P < 0.0001). In both seasons, nectar concentration increased as temperature increased and relative humidity decreased through the day. In the dry season, nectar concentration in early morning was lower than in the mid morning ($\chi 2$ = 13.94, df = 1, P < 0.0001). However, nectar concentration at mid-morning was similar to nectar concentration in the afternoon, ($\chi 2$ = 0.38, df = 1, P = 0.54; Fig. 1). There was a similar trend during the rainy season, nectar concentration at mid morning was higher than the concentration in early mornings ($\chi 2$ = 12.05, df = 1, P = 0.001) but similar in the afternoon ($\chi 2$ = 1.93, df = 1. P = 0.17; Fig. 1).

As the concentration of nectar increased through the day, nectar volume decreased and it affected the amount of sugar in the nectar. Total amount of sugar in the early morning was 1.88 ± 0.37 mg which was higher than 0.28 ± 0.04 mg in the mid morning ($\chi 2$ = 14.33, df = 2, P < 0.0001). However the amount of sugar (mg) in nectar measured in the afternoon (0.26 ± 0.04 mg) was similar to amounts measured in the mid mornings ($\chi 2$ = 0.669, df = 2, P = 0.41). Nectar energetics were highest in the early mornings (Fig. 2).

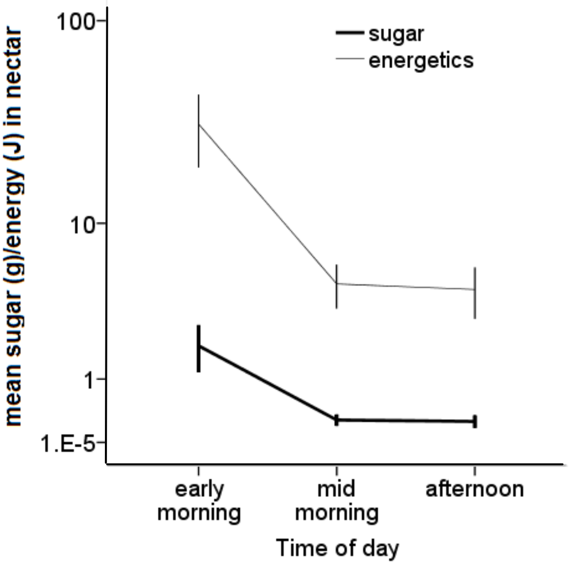

FIG. 2. Daily variation of sugar content (mg) in nectar and nectar energetic (J) of *Luffa aegyptiaca*. Error bars represent 2 SE

Pollination efficiency

All (100%) flowers visited by *X. olivacea* set fruit while only 55% of flowers visited by *Apis mellifera* set fruit. Fruits that developed from flowers that received a single visit from *X. olivacea* had a mean weight of 428.7 ± 47.76 g and were 1.5 times heavier than fruits from flowers visited by *A. mellifera* (286.76 ± 10.53 g). Furthermore, fruits developed from flowers pollinated by *X. olivacea* were longer (29.5 ± 2.5 cm) than fruits from flowers pollinated by *Apis mellifera* (22.9 ± 0.4 cm). The non overlapping standard error bars (Fig. 3) indicate that the differences in weight and length were significant. A Mann-Whitney U test, however, shows otherwise (P = 0.121)

DISCUSSION

This study showed that the daily foraging dynamics of bee pollinators of *L. aegyptiaca* were as a result of daily changes in nectar volume and energy. This change in nectar resources was also as a result of daily and seasonal changes in temperature and humidity. This is consistent with previous studies that have linked dynamics of floral visitors to daily changes in nectar volume and energy (Roubik 1989; Abrol 2005).

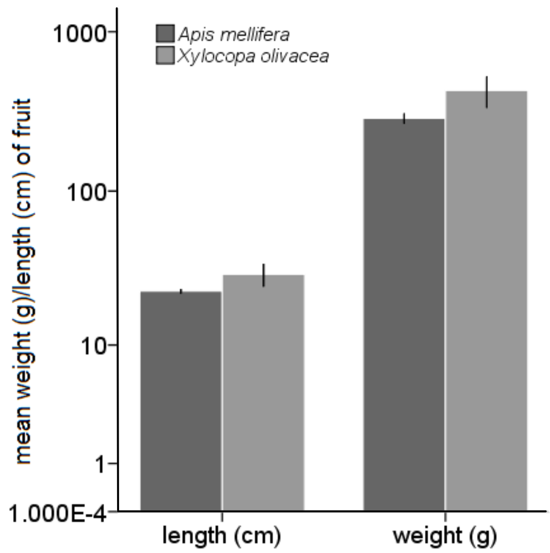

FIG. 3. The weight and length of fruits developed from a single visit of *Xylocopa olivacea* and *Apis mellifera*. Error bars represent 2 SE.

Weather is known to have marked effect on nectar concentration (Corbet et al. 1979), which may be a result of evaporation. Thus, daily and seasonal increase in temperature and decrease in relative humidity may have been the cause of the daily and seasonal variation in nectar concentration. The structure of a flower may also contribute to the degree of the effect of temperature and humidity on the nectar. Experimental studies have shown the direct effect of corolla depth on nectar concentration (Corbet et al. 1979; Galetto & Bernardello 2005). For instance, the long corolla tubes of *Ananas comosus* flowers reduced the effect of temperature and relative humidity on the nectar. Thus nectar concentration remained fairly constant even when temperature increased during the day (Kudom & Kwapong 2010). However, flowers of *L. aegyptiaca* have short corolla tubes, and are subject to greater effect of temperature and humidity.

The frequency of visits to female flowers by *X. olivacea* was high early in the morning which coincides with the time the plant produced high volumes of nectar and amounts of sugar, whereas visitation rate decreased as nectar volume and amount of sugar decreased. Large bees such as bumble bees have been shown to be dependent upon flowers providing relatively high volumes of nectar to support their foraging activities (Heinrich 1976) whereas smaller bees specialize on flowers with lower nectar volumes (Proctor et al. 1996). Hence, high volumes of nectar coupled with high nectar energy in early morning make the flowers more attractive to *X. olivacea* during that period. Though both pollinators were found at the same time at one of the study sites, the visit of *A. mellifera* to the flowers appeared to be impeded or the smaller bees were 'bullied' by the larger bees in early mornings. Furthermore, due to the high volumes of nectar in the early mornings, *A. mellifera* probably obtained the amount of nectar needed upon visiting few flowers. However, to increase the chance of a pollinator encountering a female flower, it may have to visit a lot of flowers, due to the high ratio of male to female flowers (Mensah & Kudom 2010). The increase in frequency of *A. mellifera* visits to female flowers in the late mornings and in the afternoons may be a result of low nectar volumes and low encounter rates with *X. olivacea.* During the period when nectar quantity was small, *A. mellifera* might have had to increase the number of flowers visited to get the amount of nectar needed.

A high visitation rate is essential for fruit set and optimum fruit size of *L. aegyptiaca,* especially for flowers visited only by *A. mellifera.* This became evident since only half of the virgin flowers were able to fruit after a single visit from *A. mellifera.* Moreover, fruits that developed from flowers pollinated by *A. mellifera* were comparatively smaller in size and weighed less than fruits developed from flowers pollinated by *X.* o*livacea*. Further investigation of this apparent difference in size is however needed, as it was not supported by the statistical test performed. This difference might be accounted for by a combination of behaviour and body size. *Xylocopa* bees are larger and by virtue of their size, they are exposed to a larger surface area of either the anther or the stigma. Therefore *Xylocopa* can either take more pollen from the anther or deposit more pollen on the stigma than *A. mellifera*. The behaviour of *A. mellifera* during nectar collection may also affect the number of pollen taken from anthers or deposited on stigmas of a flower. When honey bees stand on the petals to collect nectar, they do not make much contact with anthers or the stigma, which reduces efficiency in transferring pollen (Mensah & Kudom 2010).

It can be inferred from the results that *X. olivacea* was more efficient than *A. mellifera* as a pollinator of *L. aegyptiaca* in terms of fruit set resulting from a single visit. However, large bees such as *X. olivacea* may be attracted to forage in plots with large number of flowers so as to support their need for relatively high volumes of nectar (Heinrich 1976). There was an indication of this when no record was made of any *Xylocopa* species visiting female flowers at the Biriwa study site, where daily *L. aegyptiaca* flowers were less than 100. This observation supports an earlier submission for the need to maximize floral diversity in agro-ecosystems to maintain the abundance and diversity of pollinators for adequate pollination of crops (Steffan-Dewenter et al. 2006; Mensah and Kudom 2010). The result also suggests that in pollination management, especially in an agro-ecosystem, temporal foraging behaviour of pollinators must be considered so as to know the appropriate time to engage in some farm practices (e.g. insecticide application) that can affect activities of pollinators.

CONCLUSION

The daily foraging dynamics of the two important bee pollinators of *L. aegyptiaca* were a result of daily variation in nectar energetics. Seasonal and daily dynamics of nectar concentration were also due to effects of temperature and humidity. *X. olivacea* foraged early in the morning when nectar energetic was highest while *A. mellifera* still foraged effectively even at low nectar energetics. Although both *X. olivacea* and *A. mellifera* are pollinators of *L. aegyptiaca*, *X. olivacea* is more efficient than *A. mellifera* in terms of number of fruit set per single visit and probably the resulting fruit size. However, *X. olivacea* was attracted to plots with only large number of flowers. This study has provided some knowledge on pollination ecology of *L. aegyptiaca*, which can be exploited to improve fruit production in commercially grown vine crops. Also, the results showed that *L. aegyptiaca* provides an important nectar resource for its foragers throughout the year, and this finding can be useful in agro- and natural ecosystem management.

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