Int. j. adv. multidisc. res. stud. 2024; 4(4):392-399

Received: 02-06-2024
Accepted: 12-07-2024

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Pollination Efficiency of *Apis mellifera* L. (Hymenoptera: Apidae) on Flowers of *Phaseolus vulgaris* L. (Fabaceae) at Doyaba (Sarh, Chad)

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DOI: https://doi.org/10.62225/2583049X.2024.4.4.3050
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Abstract

To evaluate the impact of single visit of *Apis mellifera* on pod and seed yields of *Phaseolus vulgaris* Large White Seeds variety, the foraging and pollinating activities of the honey bee were studied in Sarh, during 2021 and 2022 rainy seasons. Treatments included unlimited flowers access by all visitors, bagged flowers, flowers limited visits by *A. mellifera* only and flowers bagged, opened and closed without insect or other organism visits. The foraging behavior of *A. mellifera* on flowers and its pollination efficiency were recorded. *Apis mellifera* was the most frequent visitor and it intensely and exclusively collected nectar. The fruiting rate of unprotected flowers is significantly higher than that of protected flowers. Through its pollination efficiency, *A. mellifera* had increase significally the fruiting rate by 52.27%, the number of seeds/pod by 30.79% and the percentage of normal seeds by 84.03%. The conservation strategies and installation of *A. mellifera* colony close to *P. vulgaris* fields is recommended to improve its pod production and seed quality in the province.

Keywords: *Phaseolus Vulgaris*, *Apis Mellifera*, Flowers, Yield, Pollination

Introduction

Phaseolus vulgaris is a plant that originated from South and Central America [1]. Bean plants are bushy or upright (40 to 60 cm); climbing stems are slightly branched; the leaves are stalked; alternate and compound trifoliate; green or purple [2]. Flowering starts 28-35 days after sowing; the flower is pink, but can vary from white to purple depending on the different varieties [3] and produces nectar/pollen which attract insects [4]. *Phaseolus vulgaris* flowers were reported to produce fewer seeds per pod in the absence of efficient pollinators in the United States of America [2]. In Doyaba (Sarh, Chad) the activities of *Xylocopa olivacea* on flowers of *P. vulgaris* (Large White Seeds variety) increase the fruiting rate by 52.27 %, the number of seeds/pod by 30.79 % and the normal seeds by 84.03 % [5]. Research conducted in Maroua by [4] has revealed that *Apis mellifera* visits *P. vulgaris* (Red and Small Seeds variety) flowers for nectar and pollen and increase the fruiting rate by 55.32 %, the number of seeds/pod by 19.10 % and the normal seeds by 7.71 %. Cross-pollination of *P. vulgaris* by insects is generally observed [6, 7] and this plant is autogamous/allogamous [8]. Prior to this studies, no previous research has been reported on the relationships between *P. vulgaris Large* White Seeds variety and its anthophilous insects, although, the activity and diversity of flowering insects of a plant species vary with varieties [7].

In Chad, *P. vulgaris* is consumed as vegetable, raw or cooked, or transformed into flour while the stems and leaves are used to feed livestock; the domestic production of edible fruits was about 138 088 and 144 070 tons annually in 2015 and 2016 respectively (Direction of the Agricultural Statistics in Chad, 2018), but the projections of production is more than

4500,000 tons [5]. Therefore, it is important to investigate on the possibilities of increasing the production of this plant in this country.

The main objective of this research was to gather data on the relationships between *P. vulgaris* and *A. mellifera* in Doyaba, for optimal management of pollination services in this country. Specific objectives were the registration of the activity of *A. mellifera* on *P. vulgaris* (Large White Seeds variety) flowers, the evaluation of the impact of visiting insects on pollination, pods and seeds yields of this Fabaceae, and the estimation of pollination efficiency of *A. mellifera* on this plant.

Materials and methods

Study site, experimental plot and biological material

The studies were conducted from July to Otober, in 2021 and 2022, in the locality at Doyaba (latitude of 09° 04.875' N, a longitude of 018° 25.721' E, an altitude 363.3 m.a.s.l.), a village located in the southern of the city of Sarh in the Moyen-Chari Province of Chad. The climate is of Sudanian type, characterized by two annual seasons: A long dry season (November to April) and a short rainy season (May to October); August is the wettest month of the year; the average annual rainfall is 1100 mm. The average temperature is 28 °C with a maximum of 33 °C and a minimum of 22 °C [5]. The humidity, very low in February and March, increases gradually from April with the rise of the Intertropical Front, peaking in August [9].

The experimental plot was an area of 437 m^2. The animal material was mainly represented by insects naturally present in the environment and 15 colony of *Apis mellifera* (Hymenoptera: Apidae) located close to the experimental field. The plant material was *P. vulgaris* Large White Seeds variety (Fig 1) collected in the surrounding of the University Institute of Agricultural Sciences and Environment of the University of Sarh, Chad.

Fig 1: Seeds of *Phaseolus vulgaris* Large White Seeds variety collected in the surrounding of the University of Sarh, in 2021

Sowing and weeding

On July 6th, 2021 and July 4th, 2022, the experimental plot was delimited, ploughed and divided into eight subplots, each measuring 8*4.5 m2. On July 8th 2021 and July 6th 2022, sowing was done on six lines per subplot, each of which had 32 holes per line. Three seeds were sown per hole. Holes were separated 25 cm from each other, while lines were 75 cm apart [10]. From germination (July 14th 2021 and July 12th 2022) to the blooming (September 9th 2021 and September 6th 2022), the field was regularly weeded with hoe and was performed manually as necessary to keep plots weed-free until the maturation of pods. A week after germination, the plants were thinned and only two were left per hole.

Determination of the reproduction mode of Phaseolus vulgaris

On September 10th 2021, 240 flowers at bud stage were labeled and divided in two treatments: 120 unprotected flowers (treatment 1) and 120 bagged flowers using gauze bags net to avoid all visits (treatment 2) [11]. Similarly, on September 7th 2022, 240 flowers at the budding stage were labeled of which 120 were left unprotected (treatment 5), while 120 were bagged (treatment 6). For each cropping year, a week after shedding of the last labeled flower, the number of pods was assessed in each treatment. The podding index (*Pi*) was then calculed as described by [10]: $Pi = Fb / Fa$, where *Fa* is the number of viable flowers initially set and *Fb* the number of formed pods. The allogamy rate (*Alr*) from which derives the autogamy rate (*Atr*) was expressed as the difference in podding indexes between treatment *X* (unprotected flowers) and treatment *Y* (bagged flowers) [12]: $Atr = \{[(PiX - PiY) / PiX] * 100\}$, where *PiX* and *PiY* are the podding indexes in treatments *X* and *Y* respectively; $Alr = 100 - Atr$.

Study of the foraging activity of Apis mellifera on Phaseolus vulgaris flowers

Obsevations were conducted on flowers of treatments 1 and 5, every day, from 11th to 17th September 2021 and from 8th to 14th September 2022. During each observation day, before starting visit counts, the number of open flowers in each treatment was counted. Data were taken according to six daily time frames: 6 - 7 am, 8 - 9 am, 10 - 11 am, 12 - 13 pm, 14 - 15 pm and 16 - 17 pm. In a slow walk along all labeled flowers of treatments 1 and 5, the identity of insects that visited *P. vulgaris* flowers was recorded [10]. All insects encountered on flowers were registered [13] and the cumulated results expressed as the number of visits to determine the relative frequency of each insect species in anthophilous entomofauna of *P. vulgaris* [10]. Data obtained were used to determine the frequency of visits (*Fi*) of each insect species on *P. vulgaris* flowers. For each study period, $Fi = [(Vi / Vt) * 100]$, with *Vi* the number of visits of insect *i* on treatment with unprotected flowers and *Vt* the total number of insect visits of all recorded insect species on these flowers [14]. Specimens (3 to 5) for all insect taxa, excluded *A. mellifera* were caught using insect net on unlabeled flowers and conserved in 70 % ethanol, excluding butterflies that were preserved dry [15] for subsequent taxonomic identification.

Study of the foraging activity of *Apis mellifera* on *Phaseolus vulgaris* flowers floral product harvested

The floral products (nectar or pollen) harvested by *A. mellifera* during each floral visit were recorded based on its foraging behavior. Nectar foragers were expected to extend their proboscis in the corolla, while pollen gatherers were supposed to scratch anthers using mandibles and legs [16]. During the same time that *A. mellifera* visits on flowers were registered, the type of floral product collected by this bee was noted [12].

Duration of visits and foraging speed

During the same days as for the frequency of visits, the duration of individual flower visits was recorded (using stopwatch) according to six daily time frames: 7 - 8 am, 9 - 10 am, 11 - 12 am, 13 - 14 pm, 15 - 16 pm and 17 - 18 pm. Moreover, the number of visits during which the bee came

into contact with the stigma [17] was registered. Regarding the foraging speed (*Fs*) which is the number of flowers visited by an individual bee per minute [18], data were registrated during the same dates and according to same time frames and daily period as for duration of visits. The stopwatch, previously set to zero was switched on as soon as an individual landed on a flower and the number of visited flowers was concomitancy counted. The stopwatch was stopped as soon as the visitor was lost to sight or when it left *P. vulgaris* flower for another plant species. The foraging speed (*Fs*) was calculated using the following formula: $Fs = (Nf / dv) * 60$, where *dv* is the time (sec) given by a stopwatch and *Nf* the number of flowers visited during *dv*. During the observation, when a forager returns to previously visited flower, counting is performed as two different flowers [10].

Abundances per flower and per 1000 flowers

The abundances of foragers (highest numbers of individuals foraging simultaneously) per flower and per 1000 flowers (*A1000*) were recorded on the same dates and daily time frames as for the registration of duration of visits. Abundance per flower was recorded as a result of direct counting. For determining the abundance per 1000 flowers, foragers were counted on a known number of opened flowers and *A1000* was calculed using the following formula: $A1000 = [(Ax / Fx) * 1000]$ (6), where *Fx* and *Ax* are respectively the number of flowers and the number of foragers effectively counted on these flowers at time *x* [18].

Foraging ecology

The disruption of the activity of foragers by competitors or predators and the attractiveness exerted by other plant species on *A. mellifera* was assessed by direct observations [12]. For the second parameter, the number of times that the bee left *P. vulgaris* flowers to other plant species and vice versa was noted through the investigation period [12]. During each daily period of investigation, ambient temperature and relative humidity in the station were registered every 30 minutes using a mobile thermo-hygrometer (Technoline WS9119) [12] installated in the shade.

Evaluation of the impact of the flowering insects including *Apis mellifera* on *Phaseolus vulgaris* yields

Parallel to the constitution of treatments 1, 2, 5 and 6, 600 flowers at bud stage were protected in 2021 and 2022 to form two treatments:

- Treatments 3 in 2021 and 7 in 2022: 200 flowers protected using gauze bag nets to prevent insect visits and destined to receive one visit of *A. mellifera*. As soon as the flowers were opened, each flower of treatments 3 and 7 were inspected. Hence, gauze bag was delicately removed and this flower was observed for up to 10 minutes; the flowers visited by *A. mellifera* were marked and then reprotected. Unvisited flowers by this bee were included in treatment 4 and 8.
- Treatments 4 in 2021 and 8 in 2022: 100 flowers protected using gauze bag nets and destined to be uncovered then rebagged without the visit of insects or any other organism. As soon as each flower of treatments 4 and 8 was opened, the gauze bag was removed and the flower was observed for up to 10 minutes while avoiding the visit by *A. mellifera* or any other organism.

At maturity, pods were harvested and counted from each treatment. The mean number of seeds per pod and the percentage of normal (well developed) seeds [19] were then evaluated. The estimation of the effect of insects including *A. mellifera* on *P. vulgaris* production was based on the impact of flowering insects on pollination, the impact of pollination on *P. vulgaris* podding and the comparison of yields (podding rate, number of seeds per pod and the percentage of normal seeds) of treatments 1, 2, 4, 5, 6 and 8. For each observations year, the podding rate due to the flowering insects including *A. mellifera* (*Pri*) was calculated using the following formula: $Pri = \{[(PX - PZ) / (PX + PY - PZ)] * 100\}$ [20], where *PX*, *PY* and *PZ* are the podding rates in treatment *X* (flowers left in free pollination), treatment *Y* (flowers protected from all insect visits) and treatment *Z* (flowers bagged then uncovered and rebagged without insect or any other organism visit). The podding rate of a treatment (*Pr*) is giving by the following formula: $Pr = [(b / a) * 100]$, where *a* is the number of viable flowers initially set and *b* the number of formed pods [21]. The impact of flower visiting insects including *A. mellifera* on the number of seeds per pod and the percentage of normal seeds were evaluated using the same method as mentioned above for the podding rate.

Assessement of the pollination efficiency of *Apis mellifera* on *Phaseolus vulgaris*

The contribution of *A. mellifera* on the podding rate, the number of seeds per pod and the percentage of normal seeds was calculated using the data of treatments 3 and 4 for 2021 and those of treatments 7 and 8 for 2022. For each observation year, the contribution of *A. mellifera* on the podding rate (*PrX*) was calculated using the following formula: $PrX = \{[(PC - PZ) / PC] * 100\}$, where *PC* is the podding rate in treatment *C* (flowers visited exclusively by the bee, *A. mellifera*) [20]. The impact of *A. mellifera* on the number of seeds per pod and the percentage of normal seeds were evaluated using the same method as mentioned above for the podding rate.

Statistical analysis

Data were subjected to descriptive statistics, student's *t*-test for the comparison of means of the two samples, Pearson correlation coefficient (*r*) for the study of the association between two variables, and chi-square ($\chi 2$) for the comparison of percentages, using Microsoft Excel 2013 software.

Results

Reproduction mode of *Phaseolus vulgaris*

The podding indexes of *P. vulgaris* were 0.86, 0.12, 0.85 and 0.14 for treatments 1, 2, 3 and 4 respectively (Table 1). Thus, in 2021, the autogamy rate was 14.42 %, whereas the allogamy rate was 85.58 %. In 2022, the corresponding figures were 16.51 % and 83.49 %. For the two cu

Table 1: Allogamy and autogamy rates of *Phaseolus vulgaris* in 2021 and 2022

Years	Treatments	Number of flowers	Number pods	Podding indexes	Autogamy rate	Allogamy rate
2021	1 (unprotected flowers)	120	104	86.67	14.42	85.58
	2 (bagged flowers)	120	15	12.5		
2022	3 (unprotected flowers)	120	103	85.83	16.51	83.49
	4 (bagged flowers)	120	17	14.17		
2021 /2022	**Total**	**480**	**239**	**49.79**	**15.47**	**84.54**

Mulative years, the autogamy rate was 15.47 % and the allogamy rate was 84.54 %. It appears that *P. vulgaris* Large White Seeds variety has a mixed reproduction mode with the predominance of allogamy over autogamy.

Activity of *Apis mellifera* on *Phaseolus vulgaris* flowers
Frequency of visits

Amongst the 589 and 658 visits of 10 and 12 insects species recorded on the flowers of *P. vulgaris* in 2021 and 2022 repectively, *A. mellifera* was the most represented insect with 143 visits (24.28 %) and 153 visits (23.25 %) in 2021 and 2022 respectively (Table 2). The difference between the percentages of *A. mellifera* visit for the two years is highly significant ($\chi 2 = 7.05$; $df = 1$; $P < 0.001$). This difference could be the consequence of climatic factors and seasonal variations in flower resources availability. It can also be attributed to the variation of the number of *A. mellifera* colony in the study site from one year to another (7 colony in 2021 and 15 in 2022). Other observations have revealed that *A. mellifera* is one of the most frequent insect visitors on flowers Of *Luffa aegyptiaca* [21], *P. coccineus* [22], *P. vulgaris* Black Seed variety [7], *Vigna unguiculata* [23], *Vitellaria paradoxa* [24], *P. vulgaris* Large White Seeds variety [5] and *Cajanus cajan* [25].

Floral products harvested

From our field observations and during the two flowering periods, *A. mellifera* were found to intensively and regularly collect only nectar on flowers from *P.vulgaris* (Fig 2).

Fig 2: *Apis mellifera* collecting nectar in a *Phaseolus vulgaris* Large White Seeds variety flower at Doyaba in 2021

Table 2: Diversity of insects on *Phaseolus vulgaris* flowers in 2021 and 2022 at Doyaba, number and percentage of visits of different insects

		Insects		2021		2022		2021/2022	
Order	**Family**	**Genus and species**		n_1	p_1 (%)	n_2	p_2 (%)	n_T	p_T (%)
Coleoptera	Meloidae	*Coryna* sp. (fc)		46	7.81	32	4.86	78	6.25
Hymenoptera	Apidae	*Apis mellifera* (ne)		143	24.28	153	23.25	296	23.74
		Amegilla sp. (ne)		24	4.07	19	2.89	43	3.45
		Xylocopa inconstans (ne)		43	7.30	21	3.19	64	5.13
		Xylocopa olivacea (ne)		106	18	123	18.69	229	18.36
		Xylocopa sp. 1 (ne)		-	-	30	4.56	30	2.40
	Formicidae	*Camponotus flavomarginatus* (ne)		29	4.92	21	3.19	50	4.01
	Megachilidae	*Chalicodoma cincta* (ne)		78	13.24	82	12.46	160	12.83
		Chalicodoma rufipes (ne)		45	7.64	51	7.75	96	7.69
		Megachile torrida (ne)		17	2.89	22	3.34	39	3.13
	Vespidae	*Belonogaster juncea* (ne)		-	-	39	5.93	39	3.13
Lepidoptera	Pieridae	*Eurema* sp. (ne)		58	9.85	65	9.88	123	9.86
		Total	**visits**	**589**	**100**	**658**	**100**	**1247**	**100**
			species	**10**		**12**		**12**	

n_1 and n_2: Number of visits on 120 flowers in 12 days, p_1 and p_2: Percentages of visits, $p_1 = (n_1/589) * 100$; $p_2 = (n_2/658) * 100$. Comparison of percentages of *A. mellifera* visits (2021/2022): $\chi 2 = 0.00$; $df = 1$; $P > 0.05$; fc: consumption of flowers; ne: Collection of nectar; sp.: unidentified species.

Relationship between visits and flowering stages

Apis mellifera visits were more numerous on treatments 1 and 5 when their number of opened flowers was highest (Fig 3). Moreover, we found a positive and highly significant correlation between the number of *A. mellifera* visits and the number of *P. vulgaris* opened flowers in 2021 ($r = 0.97$; $df = 4$; $P < 0.01$) (Fig. 3 A) as well as in 2022 ($r = 0.99$; $df = 4$; $P < 0.01$) (Fig. 3 B). This result highlights the good attractiveness of the nectar of *P. vulgaris* towards *A. mellifera*. In Cameroon, [4] have also found a positive and highly significant correlation between the number of *A. mellifera* visits and the number of *P. vulgaris* opened flowers.

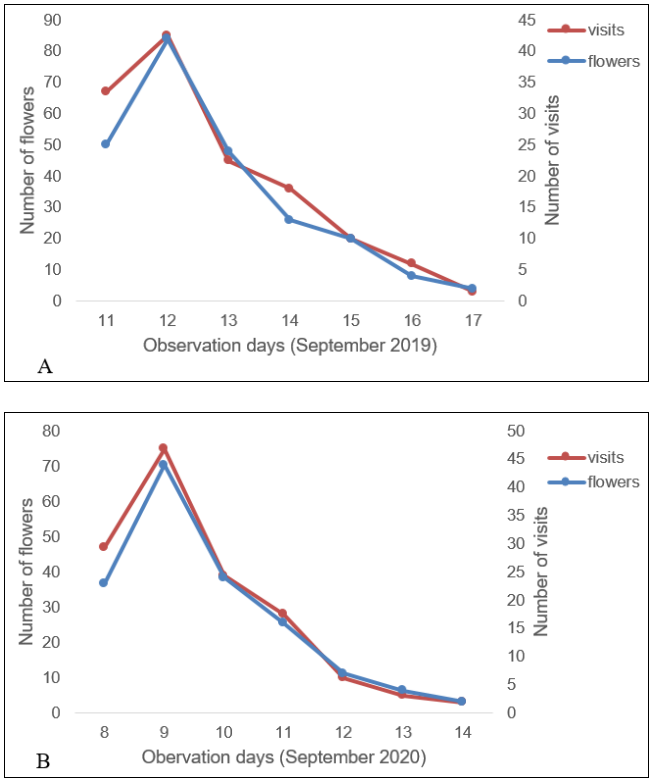
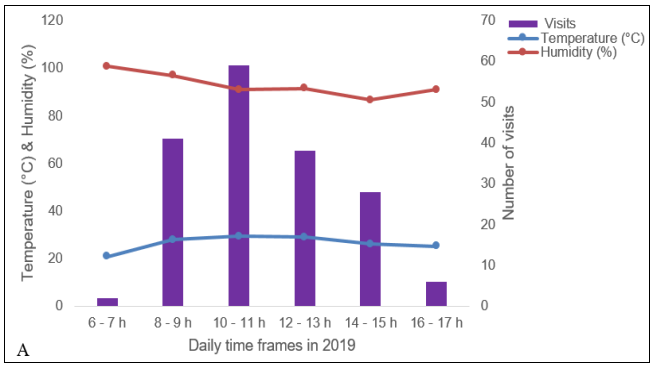


Fig 3: Seasonal variations of the number of *Phaseolus vulgaris* opened flowers and the number of *Apis mellifera* visits on these organs in 2021 (A) and 2022 (B) at Doyaba

Diurnal flower visits

The bee was active on *P. vulgaris* flowers from 6 am to 5 pm in 2021 and from 6 am to 5pm in 2022. The peak of acti



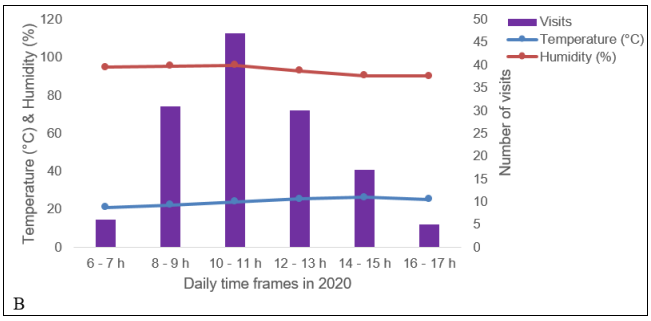


Fig 4: Variation of the temperature, the humidity and the number of *Apis mellifera* visits on *Phaseolus vulgaris* flowers according to the daily frames time in 2021 (A) and 2022 (B) at Doyaba

Vity was situated between 10 and 11 am in 2021 as well as in 2022 (Fig 4).

Ambiant temperature and relative humidity did not influenced the activities of *A. mellifera* on *P. vulgaris*. In 2021 (Fig. 4 A), the correlation was not significant between the number of *A. mellifera* visits and the temperature ($r = 0.88$; $df = 3$; $P > 0.05$), and between the same number of visits and the relative humidity ($r = - 0.62$; $df = 3$; $P > 0.05$). Equally, in 2022 (Fig. 4 B), the correlation was not significant between the number of *A. mellifera* visits and the temperature ($r = 0.07$; $df = 2$; $P > 0.05$), and beetwen the same number of visits and the relative humidity ($r = 0.31$; $df = 2$; $P > 0.05$).The peak of activity could be linked to the period of highest availability of nectar on the *P. vulgaris* flowers. The same result have been obtained at Maroua (Cameroon) by [26] on the same plant species indicating that the peak of activity of *A. mellifera* was situated between 10 and 11 am.

Duration of a visit per flower

In 2021 and 2022 the mean duration of *A. mellifera* visit per flower was 7.80 sec ($n = 66$; $s = 3.62$; $maxi = 16$) and 5.08 sec ($n = 60$; $s = 1.66$; $maxi = 10$) respectively. The difference between these two means is highly significant ($t = 6.46$; $df = 124$; $P < 0.001$). This difference could be explained by the availability of nectar in the visited flowers or the variation of diversity of flowering insects from one year to another. For the two cumulated years the mean duration per flower was 7.13 sec. In Cameroon, according to [26], the mean duration of *A. mellifera* visit per flower was 1.95 sec on *P. vulgaris* var. small red seeds. The difference between these two means is highly significant ($t = - 13.84$; $df = 120$, $p < 0.001$). This difference could be explained by the availability of nectar on flowers of each variety of *P. vulgaris* studied.

Abundance of *Apis mellifera*

In 2021, the highest mean number of *A. mellifera* simultaneously in activity was 1 per flower (n = 86; s = 0) and 208.61 per 1000 flowers ($n = 56$; $s = 125.67$; $maxi = 450$). In 2022, the corresponding figures were 1 per flower ($n = 83$; $s = 0$) and 220 per 1000 flowers ($n = 53$; $s = 117.04$; $maxi = 450$). There is no difference between these two means ($t = 0.43$; $df = 77$; $P > 0.05$). For the two cumulated years, the highest mean number of *A. mellifera*

simultaneously in activity per 1000 flowers was 214.55. This last result is higher than that pointed out at Maroua by [26] who observed that the abundance of this bee was 152.69 per 1000 flowers on *P. vulgaris* small red seeds variety. The difference between these two means is highly significant (t = 12.36; df = 85, p < 0.001). This difference could be explained by the variation of the number of *A. mellifera* colony over the years. Indeed, during the two years of observation, we registrated 15 colony compared to 3 noted by these authors.

Foraging speed of *Apis mellifera* on *Phaseolus vulgaris* flowers

In *P. vulgaris* field, the mean foraging speed of *A. mellifera* was 8.90 flowers per minute (n = 79; s = 5.45; *maxi* =30) in 2021 and 7.07 flowers per minute (n = 59; s = 2.85; *maxi* =13) in 2022. The difference between these two means is significant (t = 2.35; df = 116; P < 0.05). For the two cumulated years, the mean foraging speed was 8.14 flowers per minute. The later difference could be explained by the accessibility and availablility of nectar or the distance separating the flowers visited during the various foraging trips. This foraging speed is smaller than that by [26] on *P. vulgaris* small red seeds variety. These authors noted that the mean foraging speed of *A. mellifera* was 27.98 flowers/min. The difference between these two means is highly significant (*t = 8.68; df = 95, p < 0.001*). This difference could be explained by the availablility and accessibility of nectar on each plant species.

Influence of the fauna

A. mellifera were disturbed in their foraging activity by other individuals of the same species or those from other especies, which were competitors for *P. vulgaris* nectar.

In 2021, for 76 visits, two (2.32 %) were interrupted by *X. olivacea* and four (2.74 %) by *C. rufipes.* In 2022, for 69 visits, three (1.9 %) were interrupted by *X. olivacea*, five (3.2 %) by *C. rufipes* and three (1.8 %) by *X. inconstans.* In order to obtain their optimal nectar load, *A. mellifera* who suffered from such disturbances were forced to visit more flowers during the corresponding foraging trip. The perturbation of *A. mellifera* in their foraging activity by other insect species have been observed by [26] on *P. vulgaris* in Maroua (Cameroon).

Influence of neighboring floral

During each observation periods, flowers of many other plant species growing in the study area were visited by *A. mellifera*, for nectar (ne) and/or pollen (po). Among these plants were: *Abelmoschus esculentus* (po), *Arachis hypogaea* (ne), *Bidens pilosa* (ne and po), *Cajanus cajan* (ne), *Gossypium hirsutum* (ne and po), *Helianthus annuus* (ne and po), *Phaseolus coccineus* (ne), *Psidium guajava* (ne and po), *Sesamum indicum* (ne), *Vigna unguiculata* (ne and po) and *Zea mays* (po). During the whole observation periods bee foraging on *P. vulgaris* were not observed moving to a neighboring plant species and vice versa.

Impact of anthophilous insects including *Apis mellifera* on the pollination, pod and seed yields of *Phaseolus vulgaris*

The podding rate, the mean number of seeds per pod and the percentage of normal seeds in the different treatments of *P. vulgaris* are shown in Table 3. This table shows that:

a) The podding rates were 56.16 %, 43.33 %, 56.92 %, 47.64 %, 85 %, 65 %, 68.5 % and 48.89 % in treatments 1 to 8 respectively. The differences between these eight percentages are globally highly significant ($\chi 2$ = 140.02; df = 7; P < 0.001). The two-by-two comparisons showed that the difference observed is highly significant between treatments 1 and 2 ($\chi 2$ = 6.02; df = 1; P < 0.001) and between treatments 5 and 6 ($\chi 2$ = 12.80; ddl = 1; P < 0.001). Consequently in 2021 and 2022, the podding rate of unprotected flowers (treatments 1 and 5) was higher than that of protected flowers (treatments 2 and 6).
b) The mean numbers of seeds per pod were 4.42, 3.487, 5.09, 3.88, 4.80, 3.66, 4.45 and 3.63 in treatments 1 to 8 respectively. The differences between these eight means are globally highly significant (F = 7.11; $df1$ = 7; $df2$ = 547; P < 0.001). Two-to-two comparisons showed that the difference observed is highly significant between treatments 1 and 2 (t = 8.67; df = 121; P < 0.001) as well as between treatments 5 and 6 (t = 6.57; df = 138; P < 0.001). Consequently in 2021 as well as in 2022, the mean number of seeds per pod of unprotected flowers was higher than that of protected flowers.
c) The percentages of normal seeds were 76.75 %, 66.33 %, 72.79.84 %, 69.15 %, 86.47 %, 76.59 %, 91.22 % and 76.22 % in treatments 1 to 8 respectively. The differences between these eight percentages are globally highly significant ($\chi 2$ = 106.30; df = 7; P < 0.001). Pairewise comparisons showed that the difference observed is highly significant between treatments 1 and 2 ($\chi 2$ = 6.71; df = 1; P < 0.001) as well as between treatments 5 and 6 ($\chi 2$ = 12,28; df = 1; P < 0.001). Hence in 2021 as well as in 2022, the percentage of normal seeds of unprotected flowers was higher than that of protected flowers.

In 2021, the contribution of anthophilous insects in the podding rate, the mean number of seeds per pod and the percentage of normal seeds were 26.75 %, 21.26 %, and 13.58 % respectively. In 2022, the corresponding figures were 23.53 %, 23.75 %, and 11.43 %. For the two cumulated years, the numeric contribution of anthophilous insects were 25.14 %, 22.51 % and 12.51 % for the podding rate, the mean number of seeds per pod and the percentage of normal seeds respectively.

Pollination efficiency of *Apis mellifera* on *Phaseolus vulgaris*

During the nectar harvest, *A. mellifera* always came into contact with anthers and stigma. Thus they increased self-pollination or cross-pollination possibilities of visited flowers.

The podding rates due to *A. mellifera* were 56.92 % in 2021, 68.5 % in 2022 and 62.71 % for the two cumulated years. The difference was not significant between treatments 3 and 4 ($\chi 2$ = 2,54; df = 1; P < 0.05) as well as between treatments 7 and 8 ($\chi 2$ = 0,42; df = 1; P < 0.05). Therefore, in 2021 and 2022, the podding rate of flowers visited by *A. mellifera* was higher than that of flowers protected, uncovered and rebagged without the visit of insect or any other organism.

The comparison of the mean number of seeds per pod (Table 3) shows that the difference was highly significant between treatments 3 and 4 (t = 13.58; df = 59; P > 0.001) as well as between treatments 7 and 8 (t = 5.40; df = 146; P >

0.001).

The comparison of the percentage of normal seeds (Table 3) shows that the difference was highly significant between treatments 3 and 4 ($\chi 2$ = 9.91; *df* = 1; *P* < 0.001) as well as between treatments 7 and 8 ($\chi 2$ = 42.43; *df* = 1; *P* < 0.001). Hence, in 2021 and 2022, the percentage of normal seeds of flowers visited by *A. mellifera* was higher than that of flowers protected, uncovered and rebagged without visit of insect or any other organism.

Table 3: Podding rate, mean number of seeds per pod and the percentage of normal seeds according to the different treatments of *Phaseolus vulgaris* in 2021 and 2022 at Doyaba

Years	Treatments	NF	NP	PrR (%)	Number of seeds / pod		TNS	NS	% NS
					m	*df*			
2021	1 (UF)	120	71	59.16	4,42	0,79	314	241	76,75
	2 (Pf)	120	52	43.33	3,48	0,38	202	134	66,33
	3 (FPvX)	130	74	56.92	5,09	0,44	377	301	79,84
	4 (Fpwv)	170	81	47.64	3,88	0,65	282	195	69,15
2022	5 (UF)	120	102	85	4.80	1.03	488	422	86.47
	6 (Pf)	120	78	65	3.66	0.84	282	216	76.59
	7 (FPvX)	200	137	68.5	4.45	0.86	501	457	91.22
	8 (Fpwv)	180	88	48.89	3.63	0.58	265	202	76.22

NF: Number of flowers; NP: Number of pods; PrR: Podding rate; TNS: Total number of seeds; NS: Number of normal seeds; %NS: Percentage of normal seeds; *m*: Mean; *df*: Standard deviation; Uf: Unprotected flowers; Pf: Protected flowers; Fpvx: Flowers visited exclusively by the bee, *A. mellifera*; Fpwv: Flowers bagged then uncovered and rebagged without visit by insect or any other organism.

In 2021, the podding rate, the mean number of seeds per pod and the percentage of normal seeds due to *A. mellifera* were 16.30 %, 23.77 %, and 13.39 % respectively. In 2022, the corresponding figures were 28.63 %, 18.42 % and 16.44 %. For the two cumulated years, the numeric contribution of *A. mellifera* via a single flower visit on the podding rate, the mean number of seeds per pod and the percentage of normal seeds 22.47 %, 21.09 % and 14.92 % respectively.

During the nectar harvest on *P. vulgaris* flowers, *A. mellifera* always shake flowers and come into contact with anthers and stigma. Similar observation was reported by Kingha *et al*. (2012) on *P. vulgaris* Black Seed variety at Dang (Cameroon). *Apis mellifera* could enchance self-pollination by applying pollen of a flower on its own stigma or on the stigma of another flower of the same plant (geitonogamy) [11]. This bee could provide allogamous pollination througt carrying a pollen on their hairs, legs and mouth accessories from a flower of one plant, which is consequently deposited on another flower belonging to a different plant of the same species (xenogamy) [11]. The contribution of *A. mellifera* to *P. vulgaris* production through its pollination efficiency was significantly higher than that of all insects on the exposed flowers. Douka & Tchuenguem (2013) have also found that, throughout its foraging and pollination activities, this bee increased significantly the podding rate, the number of seeds per pod and the percentage of normal seeds of *P. vulgaris* Red and Small Seeds variety by 55.76 %, 19.1 % and 7.72 % respectively. In fact, by laying on flowers, *A. mellifera* could facilitate the release of pollen for the optimal occupation of the stigma. According to [27], the fruiting is maintly depend on pollination intensity. Moreover, studies made by [28, 29] and [5] in Kenya, Burundi and Chad (Doyaba) respectively revealed that *P. vulgaris* pod and seed yields were low in the absence of pollination by this bee. These studies show that *A. mellifera* is an efficient pollinator of *P. vulgaris*.

Conclusion

The results obtained from this study reveal that *P. vulgaris* White and Large Seeds variety is a plant that benefits from the pollination by insects, among which *Apis mellifera* is one of the most important and harvest exclusively nectar. The comparison of pod and seed sets of flowers visited once exclusively by *A. mellifera* with those of flowers bagged then uncovered and reprotected without the visit of this bee or any other organism underscores the value of this bee in increasing the podding rate, the mean number of seeds per pod and the percentage of normal seeds of *P. vulgaris*. Thus conservation and installation of *A. mellifera* close to *P. vulgaris* White and Large Seeds variety is recommended to improve its pod production as well as its seed quality and to favor the population of this bee in the Moyen-Chari province.

Acknowledgements

We thank the staff of Sarh University, for granting us the experimental plot.

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