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RESEARCH ARTICLE

Pollination Efficiency of Abundant Insect Species of Lentil *Lens culinaris* Medik. in the Northeastern Algeria (Constantine)

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Abstract This study was conducted in the Baaraouia region (Constantine, northeastern Algeria) during the 2022 flowering season. The objective was to examine the variety of insect pollinators in the lentil crop during its flowering phase. The Hymenoptera order was the predominant insect group recorded, comprising six families and twelve species, notably including two principal pollinators: *Apis mellifera* (Linnaeus, 1758) and *Osmia ferruginea* (Latreille, 1811). The findings indicate that the honey bee (*Apis mellifera*) forages at a quicker pace and transports a greater quantity of pollen grains, while the mason bee (*Osmia ferruginea*) conducts more efficient visits. Flora, with unrestricted access to pollinating insects yielded a greater quantity and superior quality of seeds compared to those enclosed in bags.

Keywords: Fabaceae, Hymenoptera, Lentil, Pollination.

Introduction

Pollination is a critical ecosystem service that underpins the productivity of many agricultural systems [1]. It is estimated that around 75% of the world's leading crop species depend at least partially on animal pollination for successful fruit and seed production [2]. Pollination by insects is a fundamental biological interaction that facilitates the sexual reproduction of over 85% of all flowering plants, including a significant portion of the world's agricultural crops [3].

Grain legumes belong to the Leguminosae or Fabaceae family, encompassing a variety of species cultivated globally, primarily for their grains. These are collected at full maturity and marketed in the commercial and industrial sectors as desiccated products referred to as legumes [4]. Lentils (*Lens culinaris* L.) are predominantly cultivated in arid, low-precipitation agricultural systems in conjunction with cereals like wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) [5].

Lentil serves as a principal source of dietary protein in numerous developing nations with vegetarian diets [6]. It ranks among the most prevalent legume crops in Algeria, following fava beans, chickpeas, and peas in consumption [7]. Despite efforts to expand agricultural land and improve Fabaceae crop production in Algeria, yields have remained moderate [8]. A contributing factor may be the lack of understanding regarding the role of insect pollinators in legume productivity. In particular, there is limited information on the pollination ecology of lentil crops, which may hinder yield optimization.

[9] emphasized the pivotal role of both wild bees and *Apis mellifera* in the pollination of legume crops in Algeria, suggesting their potential contribution to lentil pollination. Other studies have shown that diverse and abundant pollinator communities can significantly increase crop yields by promoting more effective and consistent pollination services [10-11]. These findings underscore the importance of conserving pollinator diversity to sustain and optimize legume crop production.

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These insights bring attention to the need to better recognize the role of insect pollinators in enhancing lentil yields and to promote targeted conservation strategies within diverse agricultural systems. Accordingly, the present study aims to investigate the pollinator community associated with lentil crops and to assess their interactions with flowers during the blooming period. To achieve this, field observations were conducted on a lentil plot for 14 days during the 2022 flowering season in the Constantine region of northeastern Algeria. The attendance rates of prevalent pollinator species on flowers were recorded to characterize their foraging activity, and the number of pollen grains deposited by dominant visitors was quantified to evaluate their pollination efficacy.

Materials and Methods

Study Site

Baaraouia is situated approximately four kilometers from El Khroub, seven kilometers from the new town of Ali Mendjeli, and eleven kilometers from the center of Constantine. The crop was cultivated in proximity to the ITGC Technical Institutefor Large-Scale Crops. The plot area was assessed at one hectare, geographically defined by four delimiting points. Two points located to the north: 36°16'09"N, 6°40'17"E and 36°16'10"N, 6°40'22"E; and two points situated to the south: 36°16'07"N, 6°40'17"E and 36°16'07"N, 6°40'23"E.

Wheat fields and herbaceous vegetation, predominantly consisting of Asteraceae species like *Silybum marianum*, surrounded it, the forest included a small section dominated by Aleppo pine (*Pinus halepensis*), occupying a limited surface area. Our research area is situated at an elevation exceeding 610 meters, with altitude variation from 558 meters along the rivers to 750 meters at the mountain summits. The area is characterized by sandy loam soil, fluctuating precipitation, and a semi-arid climate.

Diversity of Lentil Pollinators

Five 1 m² frames were set up to facilitate the observation and enumeration of pollinators. Pollinator counts were conducted per frame at 10-minute intervals during the crop's flowering period, totaling 50 minutes. The operation was conducted hourly from 9 am to 4 pm during the flowering period, which extended from mid-March to the end of April 2022. Using a sweep net and plastic vials, insects collected from the crop were transported to the laboratory for identification utilizing reference collections of various insect groups and specific identification keys mentioned in [12].

Behaviour of Abundant Pollinators

Lentil-abundant pollinators were selected based on their abundance in the crop during the flowering period. Their foraging rhythm was quantified by timing one minute and tallying the flowers visited. The duration of time spent on flowers by each principal pollinator was documented. A total of fifty individuals were assessed for each primary pollinator.

Pollination Efficiency of Abundant Pollinators

To prevent self-pollination, we encased 50 buds in bags to obstruct pollen transfer by insects. Thereafter, upon the flowers reaching full bloom, the tulle was removed. We then awaited one effective pollinating visit by an abundant pollinator before promptly collecting the stigma. The procedure was conducted on a collection of 15 flowers for each main pollinator. To maintain the freshness of the stigmas collected for analysis, they were transported to the laboratory the following day.

In the laboratory, the contents of the stigmas were dispersed onto a slide using an insect pin. The pollen grains were degreased by applying several drops of 100% ethanol and subsequently rinsing the slides after the solvent evaporated. A colored glycerin solution was applied to the pollen grains. A stereoscopic microscope was used to examine and quantify the pollen grains at 40x magnification.

Nectar Measurement

After a 24-hour bagging period, the nectar volume of 40 flowers was quantified using a 5 µl microcapillary. To prevent insect infiltration, the flowers were swiftly re-covered following each sampling. This study examines the correlation between the density of primary pollinators throughout the day and the volume of nectar produced.

Impact of Pollinating Insects on Yield and Quality

To evaluate the influence of pollinators, specifically insects, on crop yield and quality, fifty buds were enclosed in bags (self-pollination), while fifty others were marked with colored string and left exposed (open pollination). Upon grain maturation, the grains from the covered inflorescences were collected and compared to those from open-pollinated flowers. Quantitative performance was evaluated based on the number of grains produced, whereas qualitative performance was determined by the fruit's developmental stage, specifically its average weight.

Statistical Analysis

Statistical analysis was conducted using PAST software version 4.03. A one-way ANOVA was performed to assess differences in the number of flowers visited among the most abundant pollinator species. To compare how much time each species spent on the flower's stigma, we used the non-parametric Mann-Whitney U test. The Kruskal–Wallis test was used to assess differences in the number of pollen grains deposited on flower stigmas by each of the three main foragers. The Pearson correlation test was applied to evaluate the relationship between the volume of nectar secreted by flowers and the number of attracted specimens. To compare the quantitative yield results with and without pollinating insects, we applied Student's t-test. Statistical significance was determined as ($p \leq 0.05$).

Results

Lentil Pollinator Fauna

Various insect groups were observed, collected, and identified in the crop; however, their diversity and abundance varied, as shown in (Table 1).

Table 1. Entomofauna, percentage and type of insect visits observed in chickpea and lentil crops during their 2022 flowering periods in Baaraouia

Order	Family	Species	Type of visit	Relative abundance (%)
Diptera	Syrphidae	*Eupeodes corollae* (Fabricius, 1794)	+	7.77
		Episyrphus balteatus (De geer, 1776)	-	10.36
Hymenoptera	Apidae	*Apis mellifera* Linnaeus, 1758	+	60.88
		Eucera eucnemidae Dours, 1873	+	6.99
		Bombus terrestris (Linnaeus, 1758)	+	0.64
	Megachilidae	*Osmia heteracantha* Pérez, 1896	+	0.9
		Osmia tingitana Benoist, 1969	+	2.07
		Osmia ferruginea Latreille, 1811	+	27.46
		Megachile pilidens (Alfken 1924)	+	4.14
		Megachile ericetorum Lepeletier, 1841	+	0.25
	Andrinidae	*Andrena* sp Fabricius, 1775	+	0.64
	Vespidae	*Polistes dominula* (Christ, 1791)	-	1.03
	Scoliidae	*Dasyscolia ciliata* (Fabricius, 1787)	+	0.12
	Halictidae	*Lasioglossum* sp Curtis, 1833	+	1.16
Lepidoptera	Pieridae	*Pieris rapae* (Linnaeus, 1758)	+	6.34
	Noctuidae	*Autographa gamma* (Linnaeus, 1758)	-	0.25
	Nymphalidae	*Vanessa cardui* (Linnaeus, 1758)	+	0.12
Coleoptera	Coccinelidae	*Coccinella septempunctata* (Linnaeus, 1758)	-	2.84

(+): pollinating visits, (-): non-pollinating visits

The Hymenoptera group was notable for its substantial abundance, consisting of six families and twelve species. The Lepidoptera group included three species, Diptera contained two species, and the Coleoptera group had one species noted for ineffective visitation. The visit modalities varied by species. Hymenoptera have once more demonstrated their efficacy in pollination, as the majority of their species provided beneficial visits to lentil flowers, thereby facilitating cross-pollination.

Foraging Behaviour and Pollination Efficiency of Pollinator Species

During the 2022 flowering season, *Apis mellifera* (470 individuals) and *Osmia ferruginea* (212 individuals) emerged as the two dominant foragers of lentil flowers. *Apis mellifera* exhibited a superior foraging speed in comparison to *Osmia ferruginea*. Additionally, this superiority was associated with a substantial transfer of pollen grains on the flower stigmas (Table 2). No notable difference was detected in the frequency of flowers visited per minute between the two taxa ($F = 1.33$; $df = 29.25$; $p = 0.25$). A notable disparity was noted in the duration primary pollinators allocated to the flower, with wild bees exhibiting a markedly slower foraging velocity compared to honey bees ($U = 758.8$; $p = 000.6$). In addition, honey bees demonstrated significantly greater pollination efficiency by depositing a higher number of pollen grains on the stigma of lentil flowers ($H = 9.41$, $p = 0.002$).

Table 2. Foraging speed, time spent on the flower, and number of pollen grains deposited by abundant species on lentil flowers during the 2022 flowering period

Species	Foraging speed (flowers/minute)	Time spent on flower (s)	N° of pollen grains
Apis mellifera	4.5 ± 1.04	5.84±5.17	42.5±9.43
Osmia ferruginea	4.21 ± 1.25	4.56±1.93	37.5±8.81

During the flowering phase, high foraging activity was exclusively observed in the most prevalent species on lentil flowers, *Apis mellifera* and *Osmia ferruginea*. The honey bee participates in efficient foraging on approximately 96% of its visits, primarily when gathering pollen from the upper section of the flower (Table 3). Nevertheless, they alight on the flower's side and penetrate the calyx at the corolla's base to obtain nectar (with a minimal frequency of visits), thereby obstructing flower fertilization.

A. mellifera exhibited inconsistent pollination behaviour, especially concerning the type of visits for pollen or nectar acquisition. Throughout the flowering phase, the species exhibited an augmentation in pollen acquisition. During the flowering phase, it consistently produced a combination of pollen and nectar. The mason bee primarily consumes the nectar of lentil blossoms. This last extends its long tongue into the flower's corolla to gather pollen, nectar, or both. This establishes contact between the staminal column and the stigma. Consequently, nearly all her visits possess the potential to be productive.

Table 3. Distribution of visits (in %) by the main foragers to lentil flowers and the effectiveness of their visits during the 2022 flowering period

Species	*Apis mellifera*	*Osmia ferruginea*
Number of visits observed	470	212
P^+	28%	30%
N^+	10%	45%
N^- (Side visit)	4%	1%
$(P+N)^+$	60%	24%
Pollinating visits	96%	99%

P: pollen; N: nectar; +: pollinating visit; -: non-pollinating visit

Study of the Activity Rhythm and Nectar Secretion of Abundant Species

In the morning hours throughout the lentil flowering period in 2022, we observed a substantial increase in nectar volume, peaking around midday (Figure 1), accompanied by a simultaneous rise in the number of main pollinators. In the afternoon, nectar secretion gradually declined, reaching lower levels by approximately 4:00 PM; this decrease was also Associated by a reduction in the number of main pollinators. The Pearson correlation analysis revealed a significant positive relationship between the volume of nectar secreted by lentil flowers and the number of abundant foragers with *Apis mellifera* ($r = 0.88$, $p = 0.008$) and *Osmia ferruginea* ($r = 0.91$, $p = 0.005$) both showing strong correlations. In terms of individual count, *honey bee* was consistently more abundant than mason bee during daylight hours.

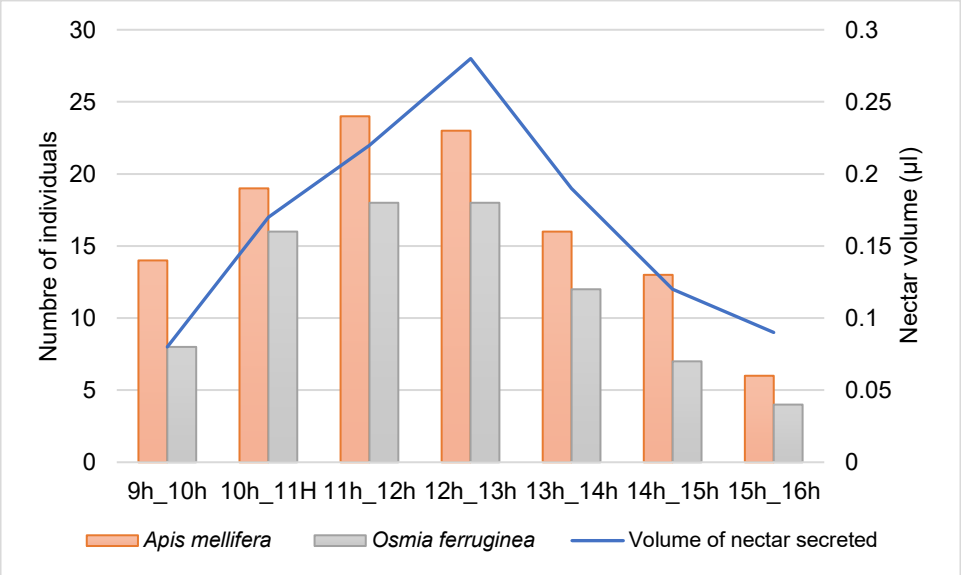

Figure 1. Relationship between volume of nectar secreted and density of abundant species in lentil culture

Effects of Insect Pollinators on the Quantity and Quality of Lentil Yield

The self-pollination resulted in 34 pods, whereas the yield from 50 flowers undergoing open pollination was 45 pods. The weight was remarkably greater, as indicated in (Table 4).

Table 4. Yield formed in bagged and freely pollinated chickpea flowers. Mean ± SD

Pollination	Pod weight (g) (N=50)	Seed weight (g) (N=50)	Wrinkled seeds
Free	0.18 ± 0.02	0.07 ± 0.02	1
Bagged	0.10 ± 0.03	0.05 ± 0.01	7

A significant difference in seed weight was noted between open-pollinated and self-pollinated lentil (*Lens culinaris*) flowers. Specifically, the weight of 50 seeds from open-pollinated flowers averaged 3.56 g, compared to 2.73 g for seeds from bagged (self-pollinated) flowers. This difference was statistically significant (Student's t-test: $t = 30.97$, $p < 0.001$). In comparison to open pollination, self-pollination led to a higher yield of wrinkled seeds. These seeds were small, exhibited deformities, and some were unfit for human consumption, as shown in (Figure 2).

Figure 2. A Pre-harvest lentil pod; **B** Open-pollinated and bagged lentil seeds.

Discussion

Various insect taxa were documented in lentil crops throughout the day during the 2022 season at Baaraouia (Constantine). The Hymenoptera group was the most prevalent, followed by the Diptera, Lepidoptera, and Coleoptera groups, respectively. The high insect density in the crop resulted in a diverse Hymenoptera population comprising 12 species from six different families. This collection of pollinators, including honey bees, wild bees, and wasps, facilitated an increased frequency of beneficial pollination visits. The primary lentil pollinators identified in Algeria are *Apis mellifera* and *Osmia ferruginea*. The honey bee exhibited a broader distribution across diverse locales compared to the wild bee. It has already been identified as the primary pollinator of several crops in Algeria, including cucumber, lavender, and bean.

The two primary pollinators exhibited differences in pollen collection efficacy. *A. mellifera* deposited a larger volume of pollen compared to *O. ferruginea*, despite the latter possessing a distinctive structure that enables the transport of substantial amounts of pollen. The disparity can be attributed to the enhanced pollen transfer facilitated by the honey bee's dense thoracic hairs, while the small flower size could limit full contact with the wild bee's scopa hairs, leading to a reduced deposition of a substantial quantity of pollen grains.

Episyrphus balteatus was the principal representative of the extensively distributed Syrphidae family. Despite its prevalence among Diptera, this species has little preference for positive floral visits, severely limiting its effectiveness as a lentil pollinator. Some Syrphidae deposit half as much pollen per unit of time as bumblebees. Furthermore, they are inefficient due to their simple silk type and scarcity of hairs. Apoidea, such as honey bees and bumblebees, are characterized by high hair density, which makes them more effective pollinators [15].

Pollinators' nectar consumption is influenced by several factors, including the presence of alternative food sources, interspecific competition among plants for pollinator visits, and the specific preferences of different pollinator species. Increasing nectar availability, a critical nutritional resource for many pollinators, typically attracts more visitors, thereby boosting the plant's reproductive success. Conversely, reduced nectar supply is often associated with a decline in key pollinator populations, a trend well-documented in ecological studies. Both the quantity and quality of nectar play a crucial role in influencing pollinator foraging behavior and visitation frequency [9-16].

The greater abundance of *Apis mellifera* compared to *Osmia ferruginea* during daylight hours may be attributed to the honey bee's highly organized foraging behaviour, larger colony size, and efficient communication through the waggle dance [17-2], which enhances resource exploitation. In contrast, solitary bees like *Osmia ferruginea* exhibit more individualistic foraging patterns and lower overall abundance, making them less competitive in high-reward environments.

The observed disparity in seed weight and quality between open-pollinated and self-pollinated lentil (*Lens culinaris* Medik.) flowers underscores the crucial role of insect-mediated pollination in enhancing reproductive success and seed viability. Cross-pollination facilitated by pollinators improves both the quantity and quality of seed output. These results are consistent with previous research showing that

insect pollination in legumes can increase seed set, weight, and uniformity due to the genetic diversity introduced through outcrossing [18-19].

Furthermore, the higher occurrence of wrinkled, deformed, and non-viable seeds under self-pollination conditions may reflect limited pollen quantity, which often leads to poor fertilization and incomplete embryo development [20-21]. In lentils, although self-pollination is possible due to their hermaphroditic flowers, the contribution of insect pollinators has been shown to significantly enhance seed morphology and development [9]. An essential element of pollinator management is the preservation and protection of their habitat [22-23].

The installation of artificial trap nests in some crops results in both quantitative and qualitative yield enhancements, as noted by [24]. Recently, humans have started utilizing wild bees as pollinators in commercial agriculture because most honey bees are susceptible to numerous natural predators [25]. [26] assert that the management of wild bee populations may serve as an effective strategy for enhancing the pollination of certain crops.

Conclusions

Chickpea flowers are visited by numerous insects, such as bees, wasps, flies, and butterflies; however, not all serve as effective pollinators. Bees constituted the predominant group of floral visitors compared to all other categories, according to the maximum values of positive visit rate and visit frequency. The results indicate that the frequent foragers of *Lens culinaris* engage in diverse quantitative and qualitative interactions with this plant. This study indicates that the mason bee (*Osmia ferruginea*) and the honey bee (*Apis mellifera*) may serve as potential pollinators for lentils.

This research, encompassing open pollination and bud bagging, illustrated the essential contribution of pollinators to enhancing lentil yield. Consequently, it is imperative to conserve local pollinators to meet the pollination requirements of crops. This can only be accomplished if the habitat of this entomofauna is safeguarded from the significant pressures imposed by human activities. A comprehensive understanding of their biology and nesting behaviour may enhance the conservation of these species, thereby ensuring crop pollination.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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