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Effectiveness of wild bees in the pollination of *Citrullus lanatus* in the Algerian Sahara

Cezayir Sahrası'nda *Citrullus lanatus* 'un tozlaşmasında yabani arıların etkinliği

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ABSTRACT

This study was carried out at an experimental site in Laghrouse, province of Biskra (Algeria), on a Watermelon crop (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) during the 2024 flowering period. Among the inspected insect groups, Hemiptera and Coleoptera are considered as visitors; Hymenoptera, Diptera, and Lepidoptera are considered as pollinators of watermelon. The statistical analysis showed that Hymenoptera is the most abundant group and the main pollinators in this crop. It was found that seven species of wild bees- *Halictus rubicundus* (Christ, 1791), *Lasioglossum pallens* (Brullé, 1832), *Lasioglossum sisymbrii* (Cockerell, 1895) (Hymenoptera: Halictidae), *Hylaeus hyalinatus* (Smith, 1842) (Hymenoptera: Colletidae), *Megachile rotundata* (Fabricius, 1787) (Hymenoptera: Megachilidae), *Epeolus cruciger* (Panzer, 1799), and *Anthophora bimaculata* (Panzer, 1798) (Hymenoptera: Apidae) were their most effective pollinators, although watermelon is a self-compatible plant. The intervention of pollinators in this culture by xenogamy improves the quantitative yield of the watermelon by a percentage of 94,27% and qualitatively by increasing the market value of the fruits by a percentage of 100%, compared to self-pollination by geitonogamy. The study also identified five species of wild flowering plants: *Reseda lutea* L. (Resedaceae); *Convolvulus cantabrica* L. (Convolvulaceae); *Carduus nigrescens* Vill. (Asteraceae); *Sinapis pubescens* L. (Brassicaceae); and *Torilis arvensis* (Huds.) Link. (Apiaceae), at the edges of the greenhouse, which attract these wild bee species pollinating watermelons.

INTRODUCTION

Pollination is crucial for the reproduction of numerous crops and guarantees human food security (Klein et al. 2006, Van der Sluijs and Vaage 2016). Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) (Cucurbitaceae) is a crop

characterized by its unisexual flowering system (Delgado-Carrillo et al. 2024). Comprehending the pollinator groups and their efficacy in sustaining watermelon cultivation is essential (Sawe et al. 2020). Watermelon is a significant

economic horticulture crop, with global production surpassing 90 million tons each year (Anonymous 2020). In Algeria, 2.5 million tons are produced on 62.949 hectares (Anonymous 2024). In Algeria, the Saharan honeybee, *Apis mellifera sahariensis* (Hymenoptera: Apidae), exhibits remarkable adaptation to arid environments (Khedidji et al. 2025). Nonetheless, its use in agricultural systems is fraught with challenges stemming from the dangers of pesticide contamination, colony collapse, and the financial burdens linked to colony management in isolated desert regions (Smith et al. 2013). Consequently, wild bees serve as a significant alternative and an auxiliary force for pollination services in desert agriculture.

Desert ecosystems are defined by severe environmental conditions, where elevated temperatures, low humidity, and water scarcity adversely affect plant reproduction and pollinator populations. Bee behavior and plant-pollinator interactions in these environments markedly differ from those in temperate agricultural systems (Chacoff et al. 2012, Descamps et al. 2021). The Algerian Sahara, encompassing the Biskra region, constitutes roughly 85% of Algeria's territory (Sahabi-Abed 2022) and represents one of the most arduous agricultural settings globally, marked by extreme temperatures, scarce water resources, and sparse vegetation (Bachir et al. 2024). The Biskra region serves as a significant hub for the cultivation of cucurbit crops (Allache et al. 2020). This dry ecosystem relies significantly on effective pollination services (Bendifallah et al. 2012).

Research indicates that multiple bee species facilitate watermelon pollination (Arachchige et al. 2023, Campbell et al. 2019). Insect pollination is a vital determinant in enhancing watermelon crop yields and fruit set by augmenting pollinator visitation to watermelon flowers (Fekadie et al. 2023, Karamaouna et al. 2024, Leach and Kaplan 2022, Sawe et al. 2020). The investigation of field edge management to create habitats for pollinators and its potential effects on watermelon harvests was also conducted (Karamaouna et al. 2024). The shape of watermelon is rigorously evaluated regarding quality requirements, as it affects market pricing (Sawe et al. 2020). The role of insects in watermelon pollination remains inadequately researched (Arachchige et al. 2023, Leach and Kaplan 2022). In North Africa, only two studies have been conducted: one in Egypt, specifically in the Kafr El Sheikh Governorate, which directly examined the impact of insect pollination on fruit set and seed production (Taha and Bayoumi 2009). The second study, conducted in the Tizi Ouzou region of Algeria, investigated bee diversity, abundance, behavior, and flower visitation rates but did not compare watermelon

yield between open-pollination and pollinator-exclusion treatments (Korichi et al. 2025). Moreover, no Algerian study has directly examined regarding the movement of wild bees from field edges to watermelon flowers and their impact on fruit set, weight, or quality. Accordingly, investigating the effects of wild bees on crop yield, as well as the extent to which field edges influence these effects, represents an important knowledge gap, particularly in arid regions of Algeria.

This study investigates the efficacy of wild bee species in pollinating watermelon in the Biskra region of the Algerian desert. The objective is to assess the impact of pollinators on production quality by comparing watermelon yields resulting from self-pollination and insect-mediated cross-pollination. The following objectives were established: (i) to document the insect species that visit watermelon flowers in this desert agricultural environment; (ii) to analyze the temporal dynamics of pollinator activity and its correlation with watermelon flower phenology; (iii) to assess the impact of species on pollination efficiency and, subsequently, on fruit set rates; (iv) to compare the pollination efficiency of wild bees with that of other pollinator species; and (v) to investigate the relationship between wild bees and plants in a protected agricultural ecosystem by contrasting wild bee visits to watermelon flowers within the greenhouse with visits to wild flowering plants at the greenhouse's periphery to identify the principal wild plant species linked to their foraging behavior.

Assuming that wild bee populations in this arid environment substantially enhance watermelon production, and that the adjacent wild flowering plants serve as crucial resources for these bees, the findings of this research will deepen our comprehension of the role of native pollinators in desert agriculture and inform strategies for sustainable crop production in arid regions.

MATERIALS AND METHODS

Study site

The study area, Biskra Province, is located in the northern part of the Great Algerian Sahara (34°51'N, 5°44'E) (Merabti et al. 2020) (Figure 1). Biskra is a Saharan region (drought, severe aridity of the climate, etc.) (Benabdelkader et al. 2021), and extreme drought conditions were experienced particularly in 2023 and 2024. This is the region with the highest temperatures in Algeria, where the temperatures can exceed 45°C, with an average annual rainfall of only 141 mm (Hamel et al. 2024).

Watermelon (*C. lanatus*) is a popular crop in the municipality of El Ghrous, Biskra province. As an important summer

fruit, it is planted twice in early spring to produce two crops. The unique characteristics and warm climate make it one of the most productive agricultural areas in Algeria.

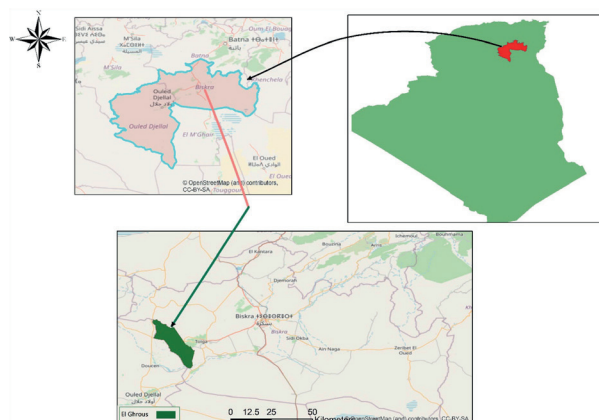


Figure 1. The study site in the Biskra region (ArcGIS 1.8-1, 2024)

Trial area design

Gardening practice

Our research on watermelon pollinators was conducted from February to April. The watermelons were planted on February 13, 2024. The row planting system was used. The study fields were irrigated using a drip irrigation system. The distance between watermelon plants was 1 m along the row and 0.44 m between the rows, with a density of 2.25 plants/m². The watermelon variety used was the hybrid F1 Top Gun. The Top Gun variety is an early variety, with high fruit quality, high yield, and resistance to diseases. The fruit is dark green and stores well after harvest. Details related to the flowering period are provided in Table 1.

Table 1. Gardening practices and the different characteristics of the variety studied

Plant studied	<i>Citrullus lanatus</i> L.
Variety	Top Gun
Sowing date	13 February 2024
Germination date	19 February 2024
Density of plants studied	2.25 plants/ m ²
Flowering start date	20 March 2024
Flowering duration	40 days
Total number of flowers/m ²	72 flowers/ m ²
Density of blooming flowers (max.)	20 blooming flowers/ m ²
Total number of male flowers/ m ²	63 male flowers/ m ²
Total number of female flowers/ m ²	9 female flowers/ m ²

In this variety of watermelon, "Top Gun," the flowers appear unisexual and monoecious: the plant bears both male and female flowers (Figure 2). The flower is small in size with a pale yellow corolla. The female flowers are distinguished from the male flowers by a mini-fruit-shaped ovary at the base of each female flower (mini-watermelon). The male flowers appear in remarkably large numbers compared to the female flowers, with 28 male flowers and 4 female flowers for each plant. The watermelon plants started flowering 37 days after planting, with the male flowers blooming first, followed by the female flowers 10 days later. The latter were in full bloom after 15 days. The flowering period of the watermelon lasted 40 days. It began on March 20, 2024, and the flowering of the plant evolved slowly, and after March 30, 2024, it increased rapidly to reach a peak on April 9 (20 flowers bloomed/m²), then it gradually declined and ended on April 29, 2024.



Figure 2. The female and male flowers of the variety of watermelon "Top Gun"

Greenhouse characteristics and pollinator access

The research was carried out in a naturally ventilated, unheated, semi-cylindrical plastic tunnel greenhouse situated in El Ghrou, Biskra area, Algeria. Plastic greenhouse horticulture is prevalent in the research area, noted for its elevated temperatures and heavy sun radiation. The experimental construction was 50 m in length and 9 m in breadth, encompassing a total area of approximately 450 m². The ceiling and lateral sides were enveloped in transparent plastic film. The greenhouse lacked insect-proof screening. Under typical weather circumstances, the lateral sidewalls, ventilation apertures, and the expansive entrance were maintained in an open position to facilitate natural ventilation. The apertures were temporarily sealed during instances of high winds. Throughout the watermelon flowering phase and pollinator observations, the primary entry and ventilation apertures were kept ajar, facilitating the natural ingress and egress of pollinators.

Initial observations of pollinators were performed on watermelon blossoms within the greenhouse to determine the wild bee taxa visiting and potentially pollinating the crop. The adjacent spontaneous flowering plants were subsequently examined to determine which ones were visited by the same species of wild bees, to elucidate bee-plant interactions and the utilization of both crop and non-crop floral resources within the greenhouse agroecosystem.

Field trips

To conduct an inventory of watermelon pollinating insects, 20 sampling trips were conducted from March 20, 2024, to April 9, 2024, coinciding with the flowering period of the crop under study. The census was always conducted during the watermelon blossoming period in the morning, from 7:30 a.m. to 12:30 p.m. (Figure 3).

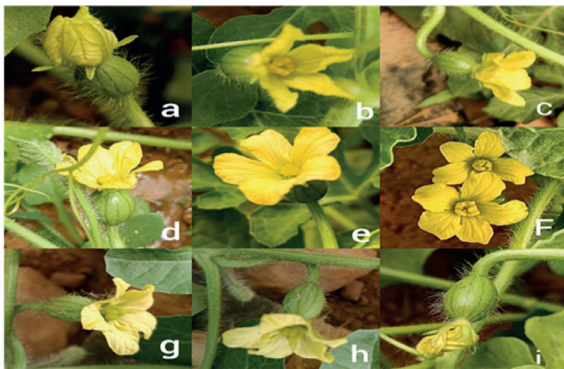


Figure 3. Flower opening behavior of *Citrullus lanatus* L.: (a) 7:30 a.m. (b) 8:00 a.m. (c) 8:30 a.m. (d) 9:00 a.m. (e) 10:00 a.m. (f) 11:00 a.m. (g) 12:00 p.m. (h) 12:15 p.m. (i) 12:30 p.m.

Pollination treatments

Two treatments were conducted to determine the role of insects in watermelon pollination:

1. Self-pollination: In the experimental area, watermelon plant buds within one square meter were covered with an insect-proof mesh bags.
2. Cross-pollination: 1 m² of the experimental area was allocated for cross-pollination. Here, the buds were not enclosed in the bag and were exposed to insect pollination (Figure 4).

Pollinating insect survey

The study generally took place in dry, warm, and bright conditions. The systematic transect sampling technique, also known as the "quadrat method," was employed. 1 m² square area was defined (Goslee 2006). Four iron pillars were driven into the ground, and a string was wrapped around the top

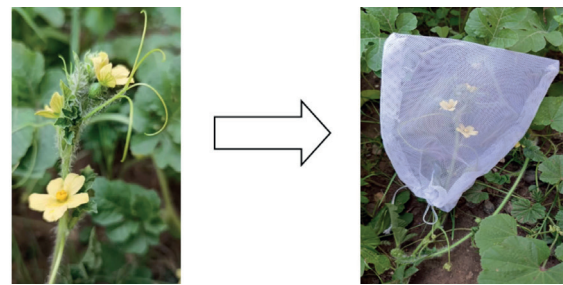


Figure 4. Treatment 1: Self-pollination, watermelon flower buds covered with an insect-proof mesh bag.

four, delimiting this study area. To specify the coverage of the cultivated plants to be studied and count the pollinating insects to estimate their density and biodiversity (O'Connor et al. 2019), their location was changed randomly each time (Vinatier et al. 2011). This method was repeated seven times on each day of the field visits in the greenhouse. So, the quadrats did not overlap each time. They were put as far away as possible (Vinatier et al. 2011), with almost 2 meters between each square and the other. In each quadrat, the density of blooming flowers was first counted, and then the insects foraging on the watermelon flowers were monitored by observing for 10 minutes in each quadrat of the seven quadrats daily.

The movement of wild bees visiting the watermelon field was tracked along the edges of the greenhouse, as they have the same flowering period. The species of wild bees that pollinate the watermelon move between inside and outside the greenhouse, ultimately to identify the species of wild flowering plants that attract them.

All foraging insects on watermelon flowers observed during field work were recorded to the lowest possible taxonomic level. Identification was first made in the field based on visible morphological characters (body size, color patterns, wing shape, and general behavior on the flowers of watermelon). To confirm identification, representative samples from each group (bees, flies, butterflies, beetles, and hemipterans) were collected using an insect net and sent to the laboratory. Bee specimens were identified using standard taxonomic keys for Western Palaearctic bees (Amiet et al. 2001, 2004, 2007, 2014), supplemented by comparison with authenticated reference images from the U.S. Geological Survey Bee Inventory and Monitoring Laboratory and the Discover Life Bee Species Guide (Anonymous 2025). The visiting insects were noted and counted to estimate their biodiversity and measure their density. Flowering plant species were identified by the authors using regional floras and botanical reference sources.

As far as possible, foraging speed was calculated (number of flowers visited/min) on the watermelon flowers, and at the

same time, the type of positive or negative visits was noted (depending on whether there is contact with the stigma or not, respectively), as well as the object of the insect's visit (collecting pollen, nectar, or both products together). In nectar feeding, the insect inserts its proboscis or mouth into the base of the watermelon flower where the nectar is located. It often remains stationary inside the flower, moving slowly, not touching the stamens (pollen-bearing) or stigmas much, and as a result, no pollen grains are visible on its body or legs.

When collecting only pollen, the insect moves quickly inside the flower, using its legs or mandibles to rub the stamens so that the pollen on its body is clearly visible, especially on the hind legs of bees. There are yellow/orange balls on the hind legs or on the abdominal hairs (in Megachilidae). When we notice the insect moving frequently between the center of the flower and the stamens, it is often collecting nectar and pollen together.

Statistical analysis

Pollinator diversity was assessed using species richness (S) and the Shannon diversity index (H'). The Shannon index was calculated according to the formula of the Shannon diversity index based on the relative visitation frequency of each pollinator species.

To evaluate the effect of pollination on watermelon yield and fruit quality, two treatments were compared: self-pollination (absence of pollinators) and cross-pollination (presence of pollinators). Fruit weight, length, width, and number of seeds per fruit were recorded.

Fruiting rate

This calculation represents the percentage of female flowers that successfully mature (Sutherland 1986).

$$\text{Fruiting rate} = \frac{\text{Average number of fruits produced}}{\text{Number of female flowers}} \times 100$$

Yield

It is a standard measurement of the amount of agricultural production harvested per unit of land area (Hayes 2025).

$$\text{Yield (per square meter)} = \frac{\text{Total amount of watermelon harvested}}{\text{Surface area of the study plot}}$$

Yield increase due to pollinator effects

The intervention of pollinators shows a clear increase in yield.

$$\text{Yield increase} = \frac{(\text{Free square yield} - \text{Hidden flower square yield})}{\text{Free square yield}} \times 100$$

Commercial sizing

All fruits were taken into account, regardless of their size, and the percentage of fruits that did meet and did not meet the commercial size was calculated.

$$\text{Commercial sizing} = \frac{(\text{Number of fruits in the size / out of size})}{\text{Total number of fruits harvested}} \times 100$$

Mean values and standard deviations were calculated for each treatment. Differences between treatments were tested using Student's t-test. Statistical significance was considered at $p < 0.05$.

RESULTS

Abundance of pollinator insects during watermelon flowering

Data collected during sampling showed seven different groups of insects visiting watermelon flowers (Table 2). Observations conducted at an experimental site in EL Ghrous, Biskra province, on a watermelon crop during the 2024 flowering period allowed the identification of five orders of insects pollinating watermelon flowers: Hymenoptera (honeybees and wild bees, hornets), Diptera (flies), Lepidoptera, Coleoptera, and Hemiptera. It appears that wild bees are the most abundant and the main pollinators, with a percentage of 62.62% (Figure 5).

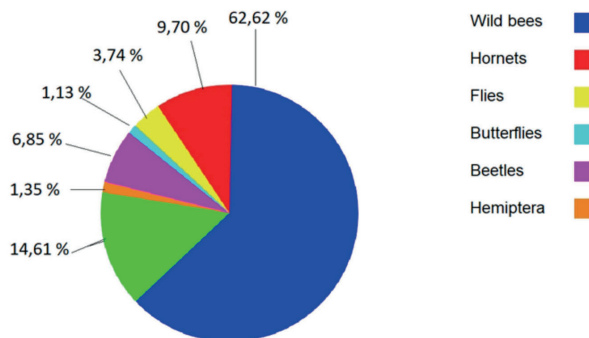


Figure 5. Distribution of watermelon forager visits during flowering 2024

Flower visitation time of visitors on watermelon flower

According to the observations, no foraging was observed before 7:30 a.m. The visitation rate was low early in the morning (honeybees are the first foragers), but it increased steadily later, reaching a peak from 9:00 a.m. to 11:30 a.m. This is the period of high receptivity of watermelon flowers, which coincides with the foraging time of all watermelon pollinators. After that, the visitation rate decreased until 12:30 p.m., the time when they had practically stopped visiting (the time of flower closure); at 11:30 a.m., the watermelon flowers began to close and remained closed

Table 2. Average overall density of different visitors in greenhouse watermelon crop

Field trip date	The average density of visitors /1m ²	Hymenoptera			Diptera (%)	Lepidoptera (%)	Coleoptera (%)	Hemiptera (%)
		Honeybee (%)	Wild bees (%)	Hornets (%)				
20/03/2024	2.71	20	73.80	6.20	-	-	-	9.22
21/03/2024	3.08	32.46	35.06	20	-	-	12.46	
22/03/2024	4	-	50	15	25	-	10	-
23/03/2024	5.28	18.04	50.82	6.90	18.94	-	5.30	
24/03/2024	5.71	17.51	70.05	12.43	-	-	-	-
25/03/2024	6	16.06	50	16.60	6.66	-	10.66	
26/03/2024	6.43	15.55	62.21	15.33	6.69	-	-	
27/03/2024	6.85	-	72.47	12.52	-	7.30	12.41	7.30
28/03/2024	7.43	13.46	70.50	10.25	-	-	-	5.79
29/03/2024	6.85	14.60	72.99	10.22	-	-	-	2.33
30/03/2024	8	25	62.5	-	-	-	12.5	-
31/03/2024	7.4	13.51	81.08	14.28	-	14.28	-	
01/04/2024	8.85	20.90	69.03	10.07	-	-	5.40	-
02/04/2024	8	-	82.34	17.66	-	-	-	-
03/04/2024	12.71	15.70	60.81	10.10	5.57	-	7.84	-
04/04/2024	14.14	10.14	70.52	6.19	0.9	-	12.14	-
05/04/2024	15	19	63.33	11.10	-	-	6.57	-
06/04/2024	13.14	14.92	53.27	-	3.80		24.73	2.97
07/04/2024	14.85	13.07	67.34	2.40	5.72	-	11.47	-
08/04/2024	15.42	19.46	64.85	1.62	3.24	1.62	9.21	-

Table 3. Peak activity of visitors in watermelon flowers according to morning time slots during the 20 days of observations

Pollinators	Visits by time slot			
	Before 7:30	7:30-9h	9-11:30 h	11:30 -12:30h
Honeybee	-	+	+	+
Wild Bee	-	-	+	+
Diptera	-	-	+	-
Lepidoptera	-	-	+	-
Hornet	-	-	+	+
Coleoptera	-	-	+	+
Hemiptera	-	+	+	+

until 12:30 p.m., except that beetles, Hemiptera, can be found at any time, even when the flower is closed (Table 3).

Pollination efficiency of watermelon flower visitors

The pollination efficiency of watermelon flower foraging insects was measured by the flower visit speed and the number of pollinating visits. Monitoring the daily activity of foragers shows that each pollinator during foraging has its own preferred product to harvest and contributes more or less to pollination.

Based on the information above, we observed that hornets, butterflies, and Hemiptera visit only for nectar, while beetles visit only for pollen. Although flies, honeybees, and wild bees collect nectar and pollen at different rates, the rate of nectar collected was always higher than the rate of pollen (Table 4).

The results of observations recorded that more pollinator visits occur to male (staminate) flowers (72.42%) than to female (pistillate) flowers (27.58%). It was determined that most visits by honeybees, wild bees, and wasps to female flowers resulted in fertilization because they contacted the stigma during their visits (Table 5). According to the comparison between biodiversity and abundance, it was noticed that the greatest number of visits is from the wild bees (857 visits), and they contribute in a major way to pollination; this group records the greatest number of visits, of which most of the visits are pollinating (57.75%) with honey bees (21.97%) and hornets (14.08%). Those that contribute to pollination but in a minor way: butterflies (occasional visits but all pollinating 3.38%), flies (2.82%), beetles, and Hemiptera (several visits but no pollination visits recorded) (Table 5).

Table 4. Watermelon visitors, their number of visits and their preferences for products to be harvested during foraging

Visitors	Visits by time slot			
	Nectar		Pollen	
	N	%	N	%
Honeybee	215	84.64	24	15.36
Wild Bee	722	84.25	135	15.75
Diptera	39	90	3	10
Lepidoptera	12	100	-	-
Hornet	59	100	-	-
Coleoptera	-	-	66	100
Hemiptera	9	100	-	-

N: Number of visits

?: Percentage of visits

Table 5. Distribution of visits according to the floral product harvested and pollinating efficiency of these visits during flowering 2024

	Visitors							Total
	Honeybee	Wild Bee	Diptera	Lepidoptera	Hornet	Coleoptera	Hemiptera	
NTV	254	857	59	30	12	66	9	1287
N+	78	205	50	10	12	-	-	355
N+ (%)	21.97	57.75	14.08	2.82	3.38	-	-	100

NTV: Total number of visits

N+: Pollinating visits (the number of insects contacting the stigma during the visit)

N+ (%): Percentage of pollinated visits

Visiting speed of watermelon wild bees pollinators

In this study, seven species of wild bees were identified as pollinating the watermelon. These species were *Anthophora bimaculata* (Panzer, 1798), *Epeolus cruciger* (Panzer, 1799) (Hymenoptera: Apidae); *Hylaeus hyalinatus* (Smith, 1842) (Hymenoptera: Colletidae); *Halictus rubicundus* (Christ, 1791), *Lasioglossum pallens* (Brullé, 1832), *L. sisymbrii* (Cockerell, 1895) (Hymenoptera: Halictidae), and *Megachile rotundata* (Fabricius, 1787) (Hymenoptera: Megachilidae) (Figure 6). Of these, the Halictidae family represents the main family of wild bees pollinating the watermelon, with a rate of 42.86%.

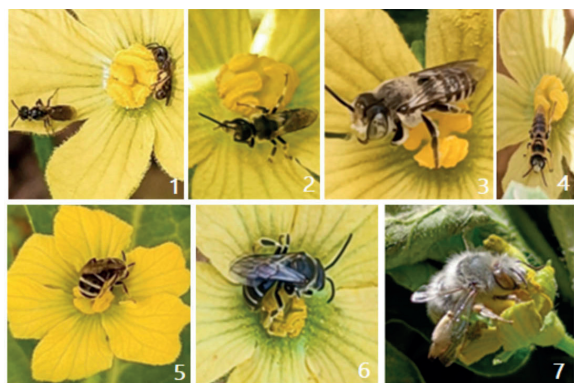


Figure 6. Wild bees the most effective pollinators for watermelon: (1) *Lasioglossum pallens*, (2) *Hylaeus hyalinatus*, (3) *Megachile rotundata*, (4) *Epeolus cruciger*, (5) *Lasioglossum sisymbrii*, (6) *Halictus rubicundus*, (7) *Anthophora bimaculata*

According to the comparison of biodiversity, abundance, and speed of visits, the wild bee *Lasioglossum pallens* had the highest number of visits, totaling 726, most of which were for pollination. This confirms that watermelon makes a significant contribution to pollination (Table 6). It was found that the visiting speed of wild bees to watermelon flowers and the harvested product varied by species. The fastest-visiting species, with a visiting speed of more than 10 flowers/min, were *Anthophora bimaculata*, *Megachile rotundata*, and *Epeolus cruciger*. Species with an average visiting speed of less than 10 flowers/min were *Lasioglossum sisymbrii* and *Halictus rubicundus*. Slow-visiting species, with a visiting speed of less than 1 flower/min, were *Hylaeus hyalinatus* and *L. pallens* (Table 6).

A total of seven wild bee species were recorded visiting watermelon flowers in the study area, with a species richness of $S = 7$ and a Shannon diversity index of $H' = 0.67$. Effect of pollination on fruit characteristics. Cross-pollination significantly improved watermelon production and fruit quality compared with self-pollination. Fruit weight was significantly higher under cross-pollination (4.82 ± 0.99) than under self-pollination (0.69 ± 0.03) (t-test, $p < 0.001$). Similarly, fruit length increased significantly in the presence of pollinators (34.63 ± 2.54) compared with their absence (8.5 ± 0.35) ($p < 0.001$). Fruit width also showed a significant increase under cross-pollination (62.81 ± 5.22) compared with self-pollination (16.02 ± 0.67) ($p < 0.001$). In addition, the number of seeds per fruit was significantly higher in the presence of pollinators (478.75 ± 52.5) than in their absence (162 ± 1.4) ($p < 0.001$) (Table 6).

Table 6. Watermelon pollinating wild bees in the El Ghrous /Biskra region (their numbers and behaviors)

Wild bees	N	Pi	Pi *Ln(Pi)	Watermelon		Foraging speed (number of flowers visited/min)	Pollen (P)/ nectar (NC)
				Male flowers	Female flowers		
<i>Anthophora bimaculata</i>	5	0.006	- 0.031	+	-	14	P; NC
<i>Megachile rotundata</i>	34	0.04	- 0.129	+	+	10	P; NC
<i>Epeolus cruciger</i>	21	0.025	- 0.092	-	-	12	P; NC
<i>Lasioglossum sisymbrii</i>	17	0.020	-0.078	+	+	2	P; NC
<i>Halictus rubicundus</i>	11	0.013	- 0.056	+	+	3.75	P; NC
<i>Hylaeus hyalinatus</i>	39	0.046	- 0.142	+	+	1	P; NC
<i>Lasioglossum pallens</i>	726	0.85	- 0.138	+	+	0.28	P; NC

Besides, 23 plant species belonging to 14 families and 22 genera were recorded at the edges of the study greenhouse (Table 7). During the twenty field trips to our study site, higher interactions between pollinators and flowers were recorded near the experimental greenhouse compared to inside it, and five wild flowering plants were identified on the edges of the greenhouse as the most attractive flowering plants for watermelon pollinators at the study site. These were, in order: *Reseda lutea* L. (Resedaceae), most frequently visited by the species *Hylaeus hyalinatus*, *Epeolus cruciger*, and *Lasioglossum pallens*; *Convolvulus cantabrica* L. (Convolvulaceae), most frequently visited by *Lasioglossum pallens*; *Carduus nigrescens* Vill. (Asteraceae), most frequently visited by *Megachile rotundata*; *Sinapis pubescens* L. (Brassicaceae), most frequently visited by *Lasioglossum sisymbrii*, *Halictus rubicundus*, and *Anthophora bimaculata*; and *Torilis arvensis* (Huds.) Link. (Apiaceae), which had the most visits of the *Lasioglossum pallens* species (Figure 7).



Figure 7. Wild plants attractive to watermelon pollinators respectively: (1) *Reseda lutea* L., (2) *Convolvulus cantabrica* L., (3) *Carduus nigrescens* Vill., (4) *Sinapis pubescens* L., (5) *Torilis arvensis* (Huds.) Link.

The quantitative and qualitative effects of watermelon pollinators

To evaluate the quantitative effect of watermelon pollinators on production yield, we compared the fruiting rate, yield, and commercial calibration of watermelon production

Table 7. The plant species recorded at the edges of the watermelon greenhouse in El Ghrou / Biskra region

Site	Family	Species
El Ghrou	Apiaceae	<i>Torilis arvensis</i> (Huds.) Link
	Apocynaceae	<i>Pergularia tomentosa</i> L.
	Asteraceae	<i>Carduus nigrescens</i> Vill.
		<i>Echinops spinosissimus</i> Turra
		<i>Pulicaria burchardii</i> Hutch.
		<i>Reichardia tingitana</i> (L.) Roth
		<i>Sonchus oleraceus</i> L.
		<i>Sonchus tenerrimus</i> L.
		<i>Urospermum picroides</i> (L.) Scop. ex F.W.Schmidt
	Boraginaceae	<i>Echium trygorrhizum</i> Pomel
	Brassicaceae	<i>Farsetia occidentalis</i> B.L.Burt
		<i>Marcus-kochia triloba</i> (L.) Al-Shehbaz
		<i>Sinapis pubescens</i> L.
	Cleomaceae	<i>Cleome amblyocarpa</i> Barratte § Murb.
	Convolvulaceae	<i>Convolvulus cantabrica</i> L.
	Lamiaceae	<i>Marrubium alysson</i> L
	Orobanchaceae	<i>Cistanche violacea</i> (Desf.) Hoffmanns. § Link
	Plantaginaceae	<i>Kickxia aegyptiaca</i> (L.) Nábělek
		<i>Plantago albicans</i> L.
	Poaceae	<i>Polypogon monspeliensis</i> (L.) Desf.
	Polygonaceae	<i>Rumex vesicarius</i> L.
	Resedaceae	<i>Reseda lutea</i> L
	Zygophyllaceae	<i>Zygophyllum creticum</i> (L.) Christenh. § Byng

without and with pollinators (Table 8). In open pollination, the fruit set rate was 55.55%, while in closed pollination, it remained at 22.22%. Also, during the harvest period, 24.08 kg of product per m² was obtained from open fields, while 1.38 kg of product was obtained from closed pollination. As a result, the effect of cross-pollination was calculated as 94.27% (Figures 8 and 9). To evaluate the qualitative effect of watermelon pollinators on production yield, the different yields of each treatment were accounted for, including the number of fruits formed and dropped, average weight, average size, and number of seeds/fruits harvested, and comparing them between watermelon production without and with pollinators (Figures 8 and 9).



Figure 8. Measurement: (a) Weight, (b) Size, (c) Number of seeds of the fruit harvested from each square (the left: cross-pollination; the right: self-pollination)

We took into account all the fruit regardless of size and calculated the percentage of fruit that did not meet and that met the commercial size standard, which for watermelon is between 4 and 5 kg in weight. We noted that without a pollinator, all watermelon fruits without cross-pollination

Table 8. Yields of free-range and caged quadrats during watermelon flowering in 2024

Parameters	Watermelon field	
	Square (1) Cross- pollination	Square (2) Self- pollination
Cultivated Area	1m ²	1m ²
Number of Flowers	72	72
Number of Fruit Sets	9	9
Total Harvest	5	2
Fruit Drops	4	7
Fruit Set Rate	55.55%	22.22%
Yield (R) Kg/m	24.08	1.38
Yield Increase %	94.27	

Table 9. Qualitative comparison of agricultural productivity of watermelon between cross- pollination and self- pollination

Production	Variable	Cross- pollination	Self- pollination	P- value	The increase (%)
Watermelon	Weight (kg)	4.82 ± 0.99	0.69 ± 0.03	< 0.001	85.68
	Length (cm)	34.63 ± 2.54	8.5 ± 0.35	< 0.001	75.45
	Width (cm)	62.81 ± 5.22	16.02 ± 0.67	< 0.001	74.49
	Seeds	478.75 ± 52 .5	162 ± 1.4	< 0.001	66.16
	Fruit / Plant	2.67	0.89		66.67
	In Commercial Size (C)%	100	0		100

were outside the commercial size range (Figures 8 and 9). It was found that the greatest effect of pollinators was on weight compared to other measurements, since the pollinators increased the weight by 85.68% (Figure 9, Table 9).

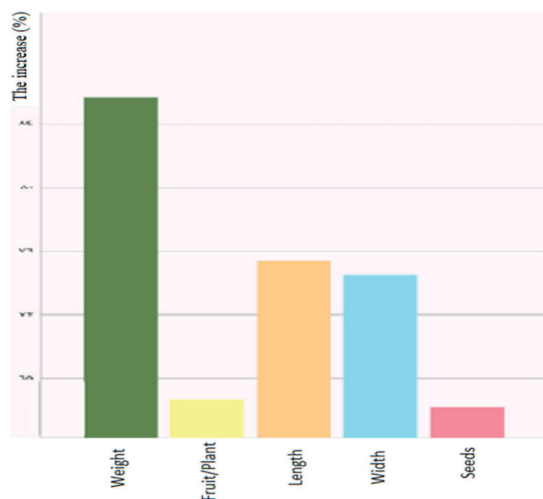


Figure 9. The effect of pollinators on watermelon agricultural productivity

DISCUSSION

Globally, research on watermelon pollinators and their influence on watermelon quality is scarce, especially in the leading watermelon-producing nations (China, Türkiye, and India). The majority of these studies have taken place in North America, while Africa, the watermelon's indigenous region, has seen a paucity of research on the subject (Arachchige et al. 2023). Only two studies on watermelon pollinators exist in North Africa. The initial study, carried out in Egypt's Kafr El-Sheikh Governorate, documented 11 species visiting summer-seeded watermelons (*Citrullus lanatus colothynthoides*), among them were Honeybees (*Apis mellifera*) and only one species of wild bee, *Andrena ovatula* K. (Taha and Bayoumi 2009). The second investigation took place in Algeria, particularly in the Tizi Ouzou region, where 11 species of bees were identified: six from the Apidae family, four from the Halictidae family, and one from the Megachilidae family. Honeybees (*Apis mellifera*) were the predominant species on watermelon flowers (*Citrullus lanatus*, Cucurbitaceae), succeeded by wild bees (*Lasioglossum pauxillum* and *Ceratina saundersi*) (Korichi et al. 2025).

This study is the inaugural complete assessment of pollinator efficacy, specifically wild bees, in watermelon cultivation throughout the Algerian Sahara. We identified five orders of insects that pollinate watermelon flowers: Hymenoptera (honeybees, wild bees, and wasps), Diptera, Lepidoptera, Coleoptera, and Hemiptera. This is corroborated by other

research (Arachchige et al. 2023). This diversity of pollinators is often attributed to the quantity of nectar in watermelon flowers (Hawker et al. 1983; Wolf et al. 1999). Our findings corroborate the research conducted by Arachchige et al. (2023), which recognized wild bees as significant visitors and designated the family Halictidae as the primary pollinator of watermelon. In contrast to the aforementioned study, which identified honey bees as the predominant floral visitors, constituting 73%–94% of all visitors, and noted that wild bees are comparably effective pollinators (Arachchige et al. 2023), our research in Algeria revealed that wild bees were the most prevalent, accounting for 62.62% of visitors, and demonstrated a 35.78% greater efficacy in pollination than honeybees. Our findings are corroborated by the research conducted by Karamaouna et al. (2024) and Leach and Kaplan (2022). The research conducted by Campbell et al. (2019) corroborated our findings that the bee species *Halictus* and *Lasioglossum* are the predominant pollinators of watermelon. Arachchige et al. (2023) corroborated our discovery with the genus *Hylaeus*. In our investigation, we documented the longest average duration of 3 minutes and 75 seconds spent on the watermelon blossom by the species *Lasioglossum pallens*. The study by Campbell et al. (2019) underscored the necessity of protecting *Lasioglossum* sp. due to its elevated frequency relative to other wild bee species on watermelon blossoms and its economic relevance. Our study of watermelon fields revealed that, in addition to the seven species of wild bees that were discovered, there were also other insects besides bees that act as effective pollinators, representing 22.77% of visits to watermelon blossoms in the area examined.

Our investigation of wild bees in watermelon fields in Biskra identified a temporal activity pattern tailored to arid circumstances. Foraging occurs predominantly in the early morning hours, enabling them to evade the perilous noon temperatures. Tetey-Enyo (2017) asserts that the elevated pollinator activity during the peak flowering period significantly boosts their efficacy as watermelon crop pollinators. The majority of visits were to male flowers, which contradicts findings from research on watermelon pollinators in the Tizi Ouzou region (Korichi et al. 2025). This disparity is ascribed to the volume of nectar produced, its sugar concentration, genetic influences (Prasifka 2018), or the higher prevalence of male flowers relative to female blooms, particularly evident in watermelons. In contrast to the aforementioned study, which limited all visits to nectar-seeding (Korichi et al. 2025), our observations revealed that wasps, butterflies, and hemipterans exclusively visit flowers for nectar, whereas beetles come solely for pollen. Flies, honeybees, and wild bees gather nectar and pollen.

Our findings unequivocally illustrate the role of these pollinators in enhancing watermelon output (94.27%) in southern Algeria and augmenting its quality (fruit shape and appearance). Marketing and quantitative metrics, such as fruit size and weight, fruit set rate, and seed count. This is corroborated by other research (Arachchige et al. 2023, Fekadie et al. 2023, Karamaouna et al. 2024, Leach and Kaplan 2022, Sawe et al. 2020, Taha and Bayoumi 2009, Toni et al. 2020, Walters 2005).

Wild pollinators possess considerable economic significance, as their absence (self-pollination) results in a marked decline in fruit yield, thus inflicting severe economic losses on farmers dependent on natural pollination (Gallai et al. 2009). In our investigation, fruit drop was the most significant component at 77.78%. This requires initiatives to preserve indigenous bees within agricultural systems (Leach and Kaplan 2022).

Our investigation on the influence of greenhouse edges and the flowering plants therein revealed increased interactions between pollinators and flowers in proximity to the experimental greenhouse compared to within it. This reflects the increased diversity of floral sources at the periphery in contrast to the singular crop (watermelon) cultivated within the greenhouse. Our findings indicated a beneficial impact of field edges and associated flowering plants on watermelon productivity indirectly through the attraction of wild pollinating bees. This was confirmed by the studies of Campbell et al. (2019) and Karamaouna et al. (2024), particularly regarding the smaller wild bees *Lasioglossum* and *Halictus*, which were more abundant at the edges. However, the research conducted by Karamaouna et al. (2024) examined the impact of cultivating flowering plants along the periphery of a watermelon field, revealing that fields with flowering borders exhibited increased productivity. Consequently, recognizing these efficient wild pollinators in agricultural crop production is a crucial strategy for conserving biodiversity in desert agricultural systems.

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Author's Contributions

Authors declare that each author's contribution is equal.

Statement of Conflict of Interest

The authors have declared no conflict of interest.

ÖZET

Biskra (Cezayir) ilinin Laghrousse bölgesindeki deneme alanında, Karpuz (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) bitkisinin 2024 incelenen böcek grupları arasında Hemiptera ve Coleoptera ziyaretçi olarak; Hymenoptera, Diptera ve Lepidoptera ise karpuzun tozlayıcıları olarak kabul edilmektedir. İstatistiksel analiz, Hymenoptera'nın en bol bulunan grup olduğunu ve bu bitkinin ana tozlayıcıları olduğunu göstermiştir. Karpuz kendi kendine döllenebilen bir bitki olmasına rağmen, yedi yabancı arı türünün; *Halictus rubicundus* (Christ, 1791), *Lasioglossum pallens* (Brullé, 1832), *Lasioglossum sisymbrii* (Cockerell, 1895) (Hymenoptera: Halictidae), *Hylaeus hyalinatus* (Smith, 1842) (Hymenoptera: Colletidae), *Megachile rotundata* (Fabricius, 1787) (Hymenoptera: Megachilidae), *Epeolus cruciger* (Panzer, 1799) ve *Anthophora bimaculata* (Panzer, 1798) (Hymenoptera: Apidae) türlerinin en etkili tozlayıcılar olduğu bulunmuştur. Bu kültürde yabancı tozlaşma yoluyla polinatörlerin müdahalesi, karpuzun niceliksel verimini %94,27 oranında, niteliksel olarak da meyvelerin piyasa değerini %100 oranında artırarak, kendi kendine tozlaşma yoluyla gerçekleşen geitonogamiye kıyasla önemli bir iyileşme sağlamaktadır. Çalışmada ayrıca, seranın kenarlarında karpuzları tozlaştıran yabancı arı türlerini çeken beş yabancı çiçekli bitki türü de tespit edilmiştir. Bu türler; *Reseda lutea* L. (Resedaceae); *Convolvulus cantabrica* L. (Convolvulaceae); *Carduus nigrescens* Vill. (Asteraceae); *Sinapis pubescens* L. (Brassicaceae); ve *Torilis arvensis* (Huds.) Link. (Apiaceae)'dir.

Anahtar kelimeler: Polinatörler, kantitatif ve kalitatif ürün, kendi-döller bitki, ksenogami, geitonogami

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