Bees visiting the broad bean (*Vicia faba* L.) and the impact of border planting on their abundance and the yield improvement in Ismailia, Egypt

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Abstract. Incorporating flowering plants into cropping systems has the potential to actively enhance pollination and crops yields. This study evaluated whether the introduction of border planting affects bee visitation and yield of a broad bean (*Vicia faba* L.). Experiments were carried out in 2018 and 2019 in Ismailia, Egypt. Bee visitation and broad bean yields were compared between plots with and without border planting. Results showed that open flowers achieved higher yields than netted flowers. *Apis mellifera* L. was the dominant visitor, followed by four solitary bee species, *Chalicodoma siculum* (Rossi), *Colletes lacunatus* Dours, 1872, *Andrena ovatula* and *Xylocopa pubescens* (Kirby, 1802). The addition of border planting was associated with a significant increase in the abundance of all five bee visitors and the associated yields. Findings showed that flowering border plants adjacent to broad bean can actively enhance pollination services and yields of this commercially valuable crop, whilst helping to conserve vulnerable bee populations.

Keywords: Pollination, Border plants, Yield improvement, Broad bean-Bee visitation.

1. Introduction

The importance of insects' pollination in general and bees in particular is estimated with a great economic contribution in many countries (Kasina et al., 2009). Low and insufficient levels of insect visitation have been identified as a cause of yield instability in a variety of systems (Suso et al., 1996). Alternative agricultural practices are needed in order to conserve beneficial insects and support the sustainable production of pollinator-dependent crops in the future. New approach for increasing pollinator diversity and pollination efficiency in low- and middle-income countries was used by farming with Alternative Pollinators (FAP) using marketable habitat enhancement plants (MHEP) (Christmann et al., 2021). Retaining or introducing higher numbers of flowering plants is proving to be an effective strategy for restoring pollination services within agricultural systems (Albrecht et al., 2020). The incorporation of flowering strips has been shown to increase pollinators diversity and floral visitation in a wide variety of cropping systems such as apple (García & Minarro, 2014), blueberry (Blaauw & Isaacs, 2014), sweet pepper (Pereira et al., 2015), cucumber (Quinn et al., 2017), almond (Norfolk et al., 2016; Alomar et al., 2018) and melon (Azpiazu et al., 2020).

Pollination research tends to focus on large-scale agricultural systems within temperate regions (Steward et al., 2014). Less is known about how flowering vegetation affects pollination services in arid, smallholder farms across the Middle East and Northern Africa. Within Egypt, flowering minority crops have been linked with enhanced pollination and fruit set of almonds within traditional orchards (Norfolk et al., 2016). Although broad bean is able to self-fertilize, insect mediated cross-pollination can increase yield and bees are particularly effective pollinators (Riedel &Wort, 1960; Free, 1966; Kendall & Smith, 1975; Poulsen, 1975; Bond & Kirby, 1999; Bishnoi et al., 2012). Incorporating flowering plants into cropping systems has the potential to actively enhance pollination and crops yields. *Brassica napus* L. (Canola or oilseed rape) produces large amounts of nectar and pollen and is visited by a wide range of insects including honeybee, and many species of bumble and solitary bees (Bommarco et al., 2012; Stanley et al., 2013). *Phacelia tanacetifolia* (Phacelia) is a widely used food plant in the beekeeping and conservation of pollinators. 18 species of bees visiting *P. tanacetifolia* were recorded in Saudi Arabia, at the top with the highest recorded species, *A. mellifera* was the most common honey bee species (Owayss et al., 2020).

In this study, we want to know how the introduction of border plants can affect pollination services in a small farm in an arid region, Ismailia (Egypt) by increasing bee visits and improving the yield of broad bean. Two alternative flowering plants Phacelia (*Phacelia tanacetifolia*) and Canola (*Brassica napus* L.) were used as border plants to measure their influence on the abundance of bees and the yield of the plant.

2. Methods

2.1. Study area and experiment

Field experiments were conducted at Ismailia Governorate, Egypt. These experiments were carried out in the Experimental Research Farm, Faculty of Agriculture, Suez Canal University (30.26 N, 32.16 E) during winter of 2018 and 2019. The selected location was prepared for planting seeds in early winter of each year. The variety Giza 843 was cultivated based on recommendation from the Egyptian Ministry of Agriculture. Planting was performed in 25th October to 7th November in

2018 and 10th November in 2019. Blooming periods were started from January to March and yield parameters were measured in April/May "harvesting time of broad bean”.

In 2018, three plots cultivated with broad bean were prepared. Each plot area was approximately 30 m^2. There was a two meters separation area between the three cultivated plots. Five rows, each 6 m in length and 15 - 20 cm between rows, containing approximately 100 plants were chosen in each plot. In bee-exclusion experiment or effect on cross-pollination on bean yield, twenty broad bean plants were randomly selected and covered once the plants flowering started. Another 20 plants were not enclosed to allow bee visitation.

In 2019, two plants, Phacelia and Canola were selected for cultivation on the four borders surrounding two broad bean plots, the third plot was used as a control. The distance between the plots and the planted border was 20 cm and the number of border plants was also approximately 100 plants in each border (Fig. 1).

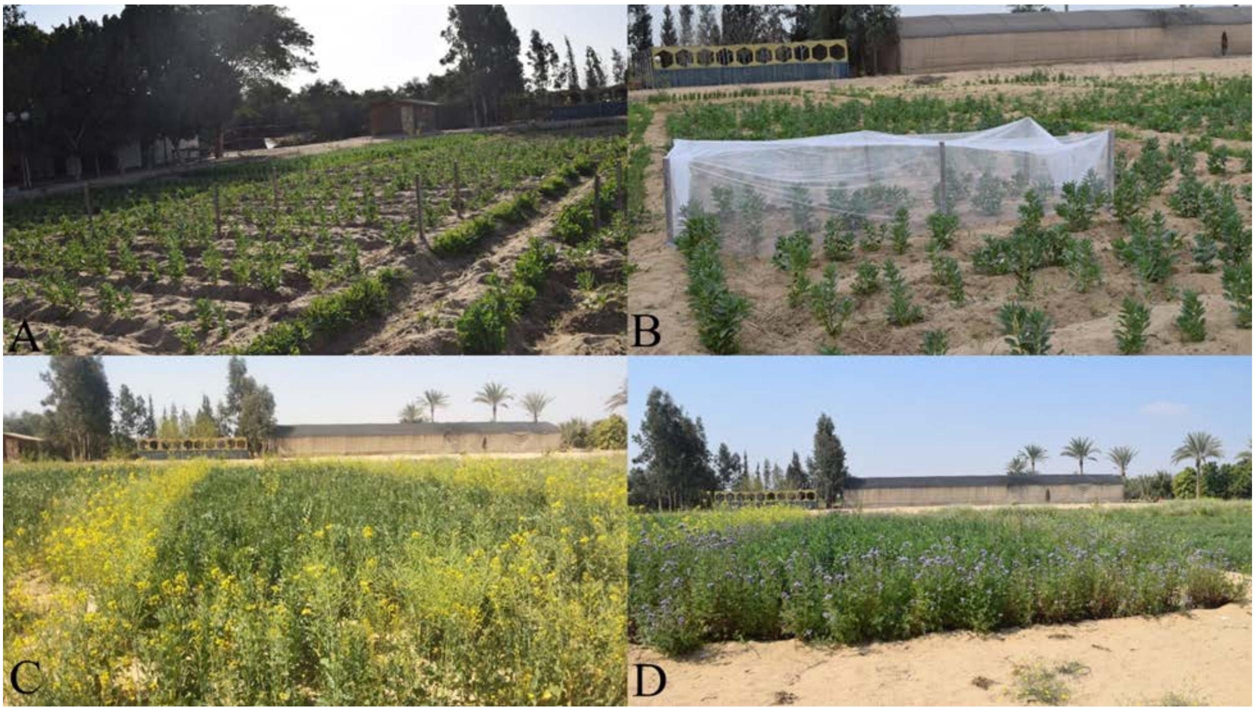

Figure 1. Experimental plot setting: A – Broad bean pollination without border, B – Bee-exclusion experiment, C – Broad bean with Canola, D – Broad bean with Phacelia

2.2. Counting and diversity of bees

Data of all bee species abundance, represented the mean of observed daily bee numbers during 4 or 6 weeks in three days of every week and during three times in the day (8 - 10 am, 10 am - 12 pm and 12 - 2 pm). To determine broad bean pollinating insects, observations were carried out in 2018 throughout the flowering period of broad bean (4 weeks), Twenty-five double net strikes were performed for collecting the bees during walking slowly, counted inside the net and released again. Double sweeping each plant individually were done immediately after each other. Unidentified specimens were killed in cyanide jars, pinned, and identified based on reference collection maintained at Department of Plant Protection, Faculty of Agriculture, Suez Canal University.

2.3. Behaviour observations

Bee pollinators were observed 6-11 times at the mid time of the day randomly. The behaviour was captured using a Nikon digital camera for the recording of total time spent on the flowers for gathering nectar and pollen trips in seconds. The camera was so close and fixed for 15 minutes during recording. Male and female of each species were differentiated in the field during the observations.

2.4. Impact on yield components

Twenty plants of each treatment were subjected to estimate the yield parameters (green and dry pod weight, pod length and number of green pods per plant).

2.5. Statistical analysis

All statistical analysis was performed using statistical software SPSS program version 22.0 (SPSS, 2013). Statistical significance was assigned as ($p \leq 0.05$). Means obtained from quantitative parameters were statistically analyzed using analysis of variance (ANOVA). Data were analyzed using Independent Samples t-test to compare means of yield of component in bee exclusion experiment.

3. Results

3.1. Daily abundance of bees on broad bean flowers.

Bee pollinators encountered on broad bean flowers were honeybee, *Apis mellifera* L., *Colletes lacunatus* Dours, 1872, *Chalicodoma siculum* Rossi, 1984, *Andrena ovatula* Kirby, 1802 and *Xylocopa pubescens* but due to the abundance records being limited, the authors decided to neglect the last one. The abundance of the bee species encountered on broad bean flowers was significantly different (Table 1). The most abundant specie was honeybee over all flowering weeks, compared to the other solitary bee species.

Table 1. Mean daily abundance of bee visitors on broad bean flowers.

Bee species	Week 1	Week 2	Week 3	Week 4
Apis mellifera	9.00 ± 3.16*	5.89±1.97	6.22±2.91	1.22±1.09
Chalicadoma siculum	0.67 ± 0.87	2.56±1.33	2.22±1.39	0.11±0.33
Colletes lacunatas	2.33 ± 1.73	1.67±1.87	3.11±2.37	0.22±0.44
Andrena ovatula	0.89 ±1.05	2.22±1.39	1.78±1.56	0.22±0.66
*Sig.***	0.00	0.00	0.00	0.00

* Mean ± standard deviation

** Sig. significance

3.2. Impact of bee visitation on broad bean crop yield components in open and self-pollination

The crop yield components were compared in open and closed pollination plants (Table 2). The netting experiments showed that all broad bean yield parameters were significantly higher ($p \leq 0.005$) in open flowers, green pod weight (15.80 g), dry pod weight (3.84 g), pod length (9.76 cm), and pod number (13.25) compared to self-pollination flowers.

Table 2. Comparison of mean yield parameters for open versus netted flowers.

	Crop yield components			
	Green pod weight (g)	Dry pod weight (g)	Pod length (cm)	Pod number
Closed pollination	0.32 ±0.98*	0.07 ± 0.23	0.38 ±1.16	0.10 ± 0.31
Open pollination	15.80 ± 1.94	3.84 ± 0.55	9.76 ± 2.27	13.25 ± 1.21
*Sig.***	0.002	0.006	0.001	0.000

* Mean ± standard deviation

** Sig. significance

3. 3. Behaviour observations

The behaviour of the five bee species studied was compared in Figure 2. The males of solitary bees were noticed for gathering nectar in three species; *C. siculum*, *C. lacunatus* and *X. pubescens*, while all females were noticed during their foraging on the flowers for gathering pollen and nectar.

Results showed the spent time, in seconds, of all bee pollinator species visiting the flowers for collecting nectar or pollen. The highest significant species in spending time on the flower was *A mellifera* workers with 77.33 seconds while the lowest were *A. ovatula and X. pubescens* with 46.67 seconds.

Other observed species, *C. siculum, C. lacunatus, A. ovatula and X. pubescens* males collect nectar, so they spend a short time on the flowers, The longest time spent on flowers was in *C. siculum* males (22.33 seconds), while males of *A. ovatula* didn't seen for gathering nectar or collecting pollen from broad bean flowers.

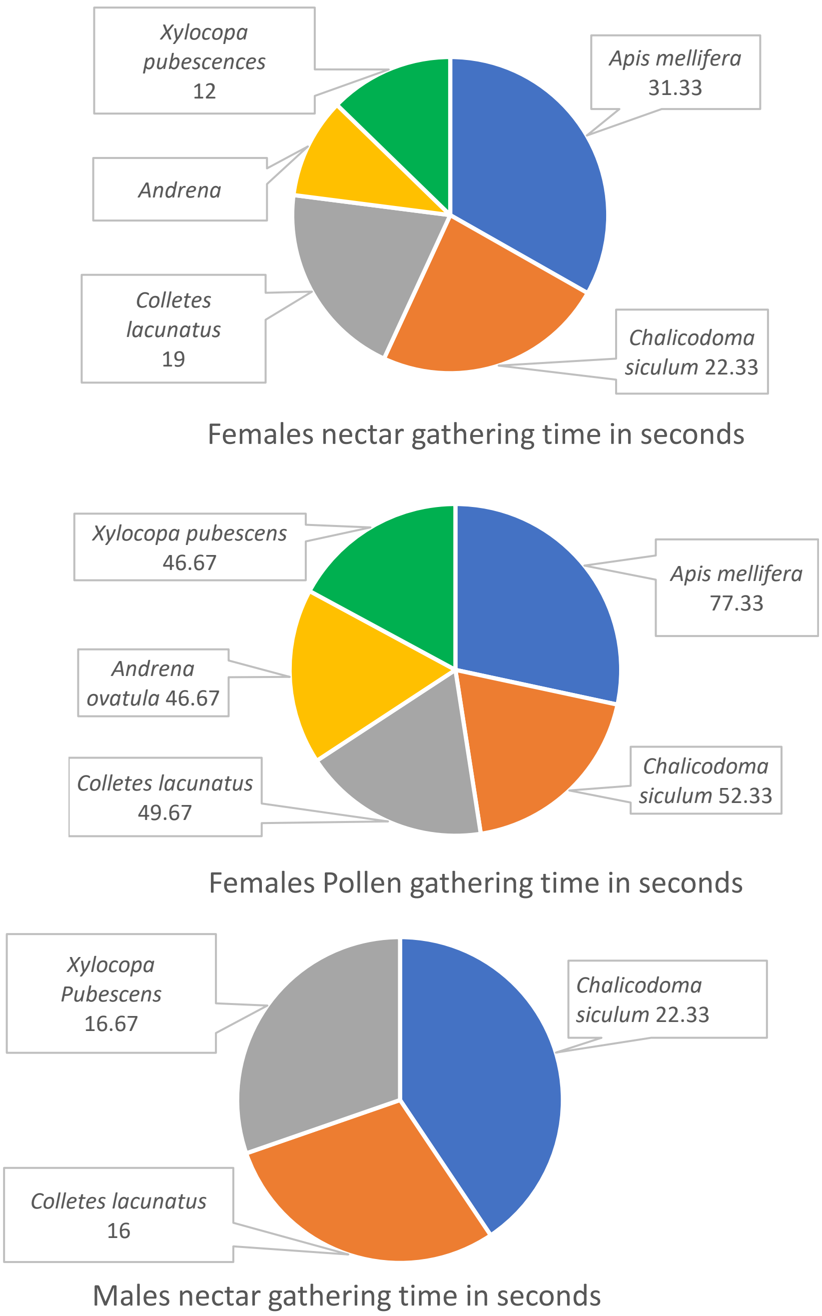

Figure 2. Foraging behaviour time of bee species spent on broad bean flowers

3.3. Impact of border plants on bee species diversity and abundance

The data collected revealed that bee species abundance was significantly higher on plots with border planting than the plot without (control). The mean abundance was 4.17 bees /day for the control plot, 6.15 bees /day for the plot bordered with Canola, and 6.11 bees /day for the plot bordered with Phacelia (Table 3 and Fig. 3).

Table 3. Comparison of mean bee species abundance for broad beans cultivated in the control plot, the plot bordered by Phacelia, and the plot bordered by Canola.

	Apis mellifera	***Andrena ovatula***	***Chalicodoma siculum***	***Colletes lacunatus***	***Xylocopa pubescence***
B.B.P.	6.11 ± 3.15*	1.80 ± 1.41	1.83 ± 1.37	2.32 ± 1.85	1.65 ± 1.40
B.B.C.	6.15 ± 3.9	2.00 ± 1.73	2.13 ± 1.43	2.59 ± 1.81	1.87 ± 1.44
B.B.	4.17 ± 3.41	1.19 ± 1.25	1.35 ± 1.38	1.76 ± 2.04	1.19 ± 1.03
Sig. **	0.011	0.072	0.015	0.013	0.023

Note: B.B.P. Broad bean bordered with Phacelia, B.B.C. Broad bean bordered with Canola, B.B. Broad bean only (control plot).
* mean ± standard deviation
** Sig. significance

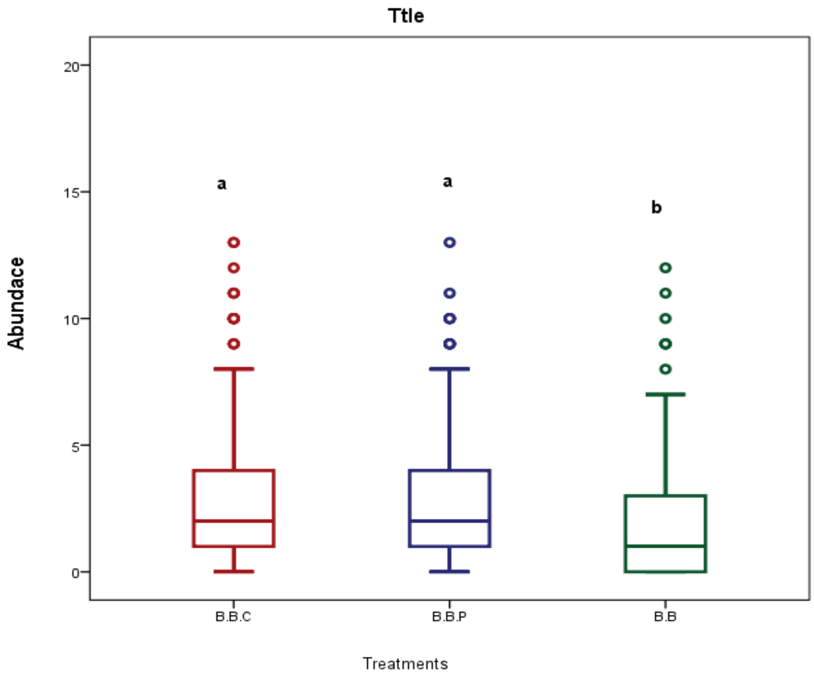

Figure 3. Box plots showing the impact of border plants on bee pollinator abundance. P<0.05; Test. Letters above bars represent significant differences based on *post-hoc* Pairwise, where treatments sharing a common letter are not significantly different from each other. Full treatment names are given in Table 4.

3.4. Impact of border plants on broad bean crop yield components

The plots with border planting recorded a higher total amount of yield parameters than the plot of broad bean only (Table 5). Concerning crop yield components, pod number was the only parameter significant among the three treatment plots ($P < 0.05$). The data revealed that the yield parameters were higher in the plot bordered with Canola compared to Phacelia.

Table 5. Comparison of mean yield parameters for broad beans cultivated in the control plot, the plot bordered by Phacelia, and the plot bordered by Canola.

	Crop yield components			
	Green pod weight (g)	Dry pod weight (g)	Pod length (cm)	Pod number
B.B.P.	19.31	5.59	12.56	13.70
B.B.C.	20.02	5.89	13.46	15.60
B.B.	15.62	3.84	11.54	10.55
Sig. **	0.00	0.00	0.071	0.00

Note: [a]B.B.P. Broad bean bordered with Phacelia, B.B.C. Broad bean bordered with Canola, B.B. Broad bean only (control plot).
** Sig. significance

4. Discussion and conclusion

The results of these experimental trials demonstrate that the yield components of broad bean are dependent on bee visitation and can be enhanced by the simple inclusion of flowering border plants.

The diversity of bee visiting broad bean in Egypt has been addressed in several studies (El-Berry et al., 1974; Ibrahim, 1979; Shebl & Farag, 2015) but little was known about their impact on the crop yield. Overall, few studies in the country evaluated the benefits of insect and bee pollination on crops (Shebl et. al., 2009; Kamel et al., 2015; Kamel et al., 2016; Osman & Shebl, 2020).

Data of bee pollinators abundance on broad bean flowers concluded that there were significant differences between bee species abundance encountered on the plant during the observation period. *A. mellifera* abundance was significantly higher than that of other bees because of the presence of apiaries around experimental farm. Due to the high contents of sugar concentration in the nectar and protein contents of the pollen, broad bean flowers are very attractive for different species of bees (Somerville, 1999). In this study, most of bee species visiting broad bean were long-tongued and large size bees which were found in all recorded species except for *Andrena ovatula* which is medium size and short tongued bees (Aouar-Sadli et al., 2008; Shebl & Farag, 2015; Sentil et al., 2022). The only exception with this was *C. lacunatus*, a large size bee but short tongued which we believe that broad bean is a great source of pollen for their brood. Other species of the same genus was also recorded previously in Egypt visiting broad bean such as *C. succinctus* (Linnaeus 1785) and *C. pumilus* Morice, 1904 (Ibrahim 1973; Ibrahim, 1979).

The importance of bees in broad bean and their impact on its production have been addressed in several works (Poulsen, 1975; Svendsen & Brødsgaard, 1997; Benachour et al., 2007; Aouar-Sadli et al., 2008; Benachour et al., 2022; Sentil et al., 2022) but nothing was known locally for Egypt which was figured out here. Our findings declared the great impact of bees on open and closed pollination plans. Insect pollination may give advantages other than increasing the yield of a crop. The green and dry seed weights, pod length and pod numbers were significantly higher in open pollination than in closed- pollination treatment. The open pollinated broad bean plants were accessible to bees produced more pods, seeds and seed quantity and quality were better than encaged plants (Benachour et al., 2007; Nayak et al., 2015; Balzan, 2017; Benachour et al., 2022; Sentil et al., 2022).

The pollinator richness, density and diversity are important for seed set of broad bean. These pollinators are positively affected by flower abundance and semi natural habitats cover (Hoehn et al., 2008; Corbet et al., 1991; Nayak et al., 2015; Norris et al., 2018). Using borders surrounding broad bean encourage and attract more bees. Our findings revealed that all observed bee species abundance was significantly higher on broad bean surrounded with phacelia and canola borders than broad bean without borders. It was proven that it works to increase bee visits to broad bean flowers more than control, which led to an increase in broad bean productivity (Owayss et al., 2020). Farming with Alternative Pollinators (FAP) was used border plants as a new approach for increasing pollinator diversity and pollination efficiency (Christmann et al., 2021).

The duration of bee visitations to flowers were significantly different in large and small size bees. The large size bees visited two or three flowers while small size bees visited one flower for a very long time. The amount of collected pollens was a consequence of species-specific anatomical characteristics, because larger bees had larger pollen-transporting surfaces such as the plumose ventral section of the abdomen and the dorsal part of the thorax or femur. It was clear that the bee body size appeared to impact flower visitations but other factors may also affect the bee activity. Body size was closely related to pollinating behaviour and each size class showed consistent patterns. Duration of a single flower visitation was significantly longer for small bees compared with very small and very large bees, Hoehn et al. (2008). Less frequent and more specialized pollinator species with long tongues improve pollination and cross-fertilization of broad bean, which is of great importance in plant breeding and seed production (Marzinzig et al., 2018).

Honey bee reached the nectar through bitten holes or by slipped their tongue between flower petals. To ensure pollination process bee should visit the front of the flowers to gather pollen (Corbet et al., 1991).

The increase in the number of bees visiting the broad bean was due to the stronger attraction of bee pollinators to phacelia and canola flowers in the treated plots which resulted an increasing in pod numbers and seed weighs. The pepper fruits produced in the intercropping were wider, longer, and heavier and developed more seeds than the fruits produced by single cropping (Pereira et al., 2015). Similar result was obtained on eggplants in Morocco but was not effective in broad bean (Sentil et al., 2022). The occurrence of beneficial insects was significantly greater on sunflower than on crop vegetation in control blocks (Jones & Gillett, 2005). The inclusion of *Calendula officinalis* in tomato fields was associated with increased abundance of bees (Balzan, 2017). Therefore, encourage farmers for using borders surrounding their bean crops could play a great role in increasing crop yields and their income. This also might play a potential role in protecting the beneficial pollinators and other beneficial insects as well. Eventually, this will improve the global pandemic of pollinator decline and in consequence pollination deficit which is a serious ecological problem in the recent decades. The findings inform the design of sustainable arid cropping systems that can simultaneously conserve pollinator biodiversity, whilst increasing the productivity of this valuable crop

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