Research Article

Diversity and Effectiveness of Native Insect Pollinators in Carrot Seed Production

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Abstract | Carrot is one of the most consumed vegetable in Pakistan and ranked among top ten vegetables grown across the world. The present study was designed to evaluate the diversity and effectiveness of native insect pollinators in carrot seed production. An experiment was performed at the research farm of MNS University of Agriculture, Multan during vegetative season (October-April) in 2019-20. Seven syrphid fly and four bee species were found visiting the carrot flowers that comprised of 65% and 35% of total abundance respectively. Among Syrphidae, *Eristalinus aeneus* was the most abundant followed by *E. laetus* while *E. arvorum* was the least. In Apidae, *Apis dorsata* was the most abundant followed by *Lasioglossum* sp (Halictidae) while *Xylocopa* sp. was the least abundant bee species. The foraging behavior in terms of visitation rate proved *A. dorsata* and *Lasioglossum* sp. as the most efficient pollinators followed by *E. laetus*. Open pollination resulted in higher seed weight per umbel (4 times), total seeds per umbel (4 times), umbel diameter (1.5 times) and umbel weight (3 times) than caged (no insect visit) treatment. Conserving these native efficient pollinators by providing floral and nesting resources may enhance carrot seed production in Punjab, Pakistan.

Received | February 16, 2021; **Accepted** | February 07, 2022; **Published** | March 30, 2022

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Citation | Ali, M., M.A. Ahmad, A. Sajjad and S. Saeed. 2022. Diversity and effectiveness of native insect pollinators in carrot seed production. *Pakistan Journal of Agricultural Research*, 35(1): 197-202.

DOI | https://dx.doi.org/10.17582/journal.pjar/2022/35.1.197.202

Keywords | Honey bees, Cage pollination, Open pollination, Syrphid flies, Visitation rate

Introduction

Carrot is an economically important vegetable grown and consumed in Pakistan (Ahmad *et al.*, 2012). It is ranked among the top 10 vegetables grown in the world (Dawid *et al.*, 2015). The total production area of carrot in Pakistan is 28.9 thousand hectare with annual carrot production is 577.42 thousand tons (FAO, 2018). According to an estimate, Punjab province contributes about 65% of total area under carrot cultivation in Pakistan (Mahmood *et al.*, 2017). Carrot is rich in phytonutrients, phenolics and dietary fibers essential for human health (Surbhi *et al.*, 2018).

Pollination is an important ecosystem service which is contributing 35% to global food production. Among pollinators, insects particularly bees are playing key role in the pollination and seed setting of various crops (Klein *et al.*, 2007). According to an estimate, the contribution of pollinators in agriculture economy of Pakistan is around US $ 1.59 billion (Irshad

and Stephen, 2013). There is a difference among the crops in terms of pollination needs and requirement of insect pollinators (Morse and Calderone, 2000).

Carrot is highly cross pollinated crop since anthers become mature and shed pollen grains before the stigma of the flower is receptive, hence, its self-pollination is very difficult (Abrol, 2006). Its flowers mainly depend upon insect pollination to produce seed (Gaffney *et al*., 2011). Some previous studies from India and Pakistan have reported honey bees (*Apis florea*) and syrphid flies as the abundant pollinators visiting carrot flowers (Ahmad and Aslam, 2002; Abrol, 1997; Sinha and Chkrabarti, 1992). Studies elsewhere have also reported managed honey bee (*A. mellifera*) and alfalfa leaf cutting bee (*Megachile rotundata*) as the most efficient pollinator of carrot based on abundance and reproductive success of the crop (Gaffney *et al*., 2019; Tepedino, 1983). Moreover, caged plants of carrot with *Calliphora vicina* set 10-fold higher seed as compared to the cages with complete exclusion of insect pollinators (Howlett, 2012).

Since the diversity of pollinators visiting carrot flowers and their role in carrot seed production is poorly understood, therefore, current study is planned to report the diversity and abundance of native pollinators, their foraging behavior (in terms of stay time and visitation rate) and their contribution to the carrot seed production.

Materials and Methods

Study site

The study was conducted at the research farm of MNS University of Agriculture, Multan, Pakistan during the vegetative season (October-April) in 2019-20. The experimental crop carrot (*Daucus carota* L.) was grown on an area of 0.25 acre.

Abundance and diversity of pollinators visiting carrot flowers

The abundance and diversity of insect pollinators was observed during the flowering stage of crop (from last week of March to first week of May) at three days intervals. Data was recorded by observing 25 plants (60 sec for each plant) at three time periods (8 h, 12 h and 16 h) during a single day observation. The collected specimens were identified by the lowest taxonomic level possible with the help of bee and syrphid fly identification keys (Vockeroth, 1969; Michener, 2000).

Foraging behavior of Insect Pollinators

Foraging behavior of abundant insect pollinators was observed by recording stay time, visitation rate and nectar/pollen foraging habit. Stay time was observed as the time spent by an individual pollinator/umbel whereas visitation rate was taken as the number of umbels visited per minute and number of umbullets visited per umbel. Foraging habit in terms of nectar/pollen was recorded through careful visual observations of insect pollinators visiting carrot flowers. Fortnightly observations were taken at all the three time periods throughout the full flowering period of the carrot (Ali *et al*., 2011).

Effect of different treatments of pollination on carrot reproductive success

Two treatments of pollination *i.e.,* open pollination (free insect visits) and caged (no insect visit) were compared for their effects on the reproductive success parameters of carrot crop *i.e*., umbel diameter (cm), umbel weight (gm), seed weight per umbel (gm) and total seeds per umbel. One hundred umbels each for open pollination and caged treatment (excluded all the available pollinators with the help of muslin cloth bags) were maintained for comparison.

Data analysis

The data of stay time and visitation rate were analyzed with the help of analysis of variance (ANOVA) and means were compared by Tukey test at P= 0.05. For evaluating the difference in reproductive success parameters (umbel diameter, umbel weight, seed weight per umbel and total seeds per umbel) between open and caged pollination, Paired sample T-test was used. All the statistical analysis was done by using statistical software XLSTAT (XLSTAT, 2012).

Results and Discussion

Pollinator community of carrot included four bee and seven syrphid fly species belonging to two insect orders and three families. Overall, syrphids and bees comprised of 65% and 35% of total abundance, respectively. Among syrphidae, *E. aeneus* was the most abundant followed by *E. laetus* while *E. arvorum* was the least abundant. In Apidae, *A. dorsata* was the most abundant followed by *Lasioglossum* sp (Halictidae) while *Xylocopa* sp. was least abundant bee species. The average visitation frequency was also highest for *E. aeneus* followed by *E. laetus* and *A. dorsata*. All the syrphid and bee species foraged for both nectar and

Table 1: *Insect species visiting Daucus carota along with their abundance, visitation frequency and foraging behavior in flowers.*

Order	Family	Genus/Species	Total abundance	Visitation frequency (Individuals/umbel/minute)	Foraging task (N/P)*
Diptera	Syrphidae	*Eristalinus aeneus*	173	0.26	N/P
		Eristalinus laetus	97	0.14	N/P
		Ischiodon scutellaris	56	0.08	N/P
		Episyrphus balteatus	19	0.03	N/P
		Eupeodes corollae	18	0.03	N
		Sphaerophoria bengalensis	15	0.02	N
		Eristalinus arvorum	08	0.01	N
Hymenoptera	Apidae	*Apis dorsata*	74	0.11	N/P
		A. florea	51	0.08	N/P
		Xylocopa sp.	12	0.02	N/P
	Halictidae	*Lasioglossum* sp.	63	0.09	N/P

**N/P= Nectar/Pollen*

Table 2: *Foraging behaviour of abundant insect pollinators based on stay time and visitation rates.*

Pollinator Species	Stay time/umbel (N=50)	Number of umbullets visited/umbel (N=50)	Number of umbels visited/ minute (N=50)
Eristalinus aeneus	153.19 ± 20.28 b	21.42 ± 1.62 b	1.10 ± 0.07 c
Eristalinus laetus	70.24 ± 19.58 cd	7.58 ± 0.35 d	2.00 ± 0.20 b
Ischiodon scutellaris	109.75 ± 13.09 bc	14.53 ± 0.59 c	1.21 ± 0.12 c
Apis dorsata	43.40 ± 32.47 d	2.10 ± 0.29 f	3.00 ± 0.37 a
Apis florea	271.63 ± 14.46 a	25.84 ± 1.24 a	1.05 ± 0.05 c
Lasioglossum sp.	26.59 ± 4.67 d	4.89 ± 0.26 e	3.68 ± 0.52 a

Means with the same letters in a single column are statistically similar as per Tukey test at 5% level (± S.E.)

pollen except the three syrphid fly species (*Eupeodes corollae, Sphaerophoria bengalensis, E. arvorum*) that foraged for nectar alone (Table 1).

In terms of stay time, *A. florea* spent highest time per umbel (271.63 ± 14.46 sec) and also visited maximum number of umbullets per umbel (25.84 ± 1.24) followed by *E. aeneus* (153.19 ± 20.28 sec/umbel and 21.42 ± 1.62 umbullets per umbel) and *Ishciodon scutellaris* (109.75 ± 13.09 sec per umbel and 14.53 ± 0.59). The lowest stay time per umbel (26.59 ± 4.67 sec) was recorded for *Lasioglossum* sp. while lowest number of umbullets visited per umbel was recorded for *A. dorsata* (2.10 ± 0.29). Contrarily, visitation rate was highest for *A. dorsata* and *Lasioglossum* sp. followed by *E. laetus* (Table 2).

Paired sample t-test revealed significant difference between open pollination and caged treatments in terms of seed weight per umbel ($p<0.0001$), total seeds per umbel ($p<0.0001$), umbel weight ($p<0.0001$) and umbel diameter ($p<0.0001$). Open pollination resulted in higher seed weight per umbel (4 times), total seeds per umbel (4 times), umbel diameter (1.5 times) and umbel weight (3 times) as compared to the caged (no insect visit) treatment (Table 3).

In our study, syrphid flies were comparatively more abundant than the bee species although *A. dorsata* was the third most abundant insect pollinator visiting carrot flowers (Saeed *et al.*, 2008). Moreover, *A. dorsata* has been reported as the most abundant and efficient pollinators from onion (Saeed and masood, 2008) and other crops from Southern Punjab (Zameer *et al.*, 2017; Saeed *et al.*, 2012; Ali *et al.*, 2011). Studies elsewhere have also reported syrphid flies and honey bees as the abundant insect pollinators of carrot flowers (Abrol, 1997; Sinha and Chkrabarti, 1992). Contrarily, some other studies have reported low abundance of honey bees on carrot flowers due to low availability of foraging resources *i.e.* nectar and pollen (Topitzhofer *et al.*, 2019; Tepedino, 1983). Moreover, it is also

Table 3: *Comparison of reproductive success parameters of carrot in open and caged pollination treatments.*

T-test results	Seed weight/umbel (gm)		Total seeds/umbel		Umbel diameter (cm)		Umbel weight (gm)	
	open	caged	open	caged	open	caged	open	caged
Means ± S.E.	2.282 ± 0.20	0.54 ± 0.07	458.02 ± 41.77	118.50 ± 13.82	5.16 ± 0.15	3.15 ± 0.12	4.35 ± 0.30	1.40 ± 0.11
t (Observed value)	8.848		8.281		10.662		9.825	
|t| (Critical value)	1.982		1.982		1.982		1.982	
DF	108		108		108		108	
p-value (Two-tailed)	< 0.0001		< 0.0001		< 0.0001		< 0.0001	

N= number of samples required

recommended that carrot crop should not be located near other competing crop that divert the attention of honeybees (Free, 1970).

In present study, stay time per umbel was highest for *A. florea* and also visited maximum number of umbullets per umbel followed by *E. aeneus*. This foraging behaviour of visiting multiple flowers per plant may not be good for self-incompatible species due to geitonogamous pollination and leads to lower seed set (Ruane *et al*., 2014; Mitchell *et al*., 2004; De Jong *et al*., 1992). Contrarily, *A. dorsata* visited the lowest no. of umbullets per umbel and its visitation rate was also highest among the pollinator species. Visitation rate is an important parameter for assessing the effectiveness of insect pollinators (Zameer *et al*., 2017; Sahli and Conner, 2007; Canto-Aguilar and Parra-Tabla, 2000). Previously, *A. dorsata* has been reported as the best pollinator in terms of visitation rate from different pollinator dependent crops in Southern Punjab (Ali *et al*., 2014; Saeed *et al*., 2012; Ali *et al*., 2011).

Open pollination (free insect visits) resulted in 1.5 to 4 times improved reproductive success parameters of carrot as compared to the caged (no insect visit) treatment. A previous study from the same region also reported an increase of 616% in seed set per umbel of open pollinated onion than the caged treatment due to the visitation of honey bees and syrphid flies (Saeed and Masood, 2008). The combined pollination effectiveness of honey bees and syrphid flies for enhancing reproductive success has also been reported for canola (Ali *et al*., 2011) and bitter gourd (Saeed *et al*., 2012). Moreover, caged pollination of blow fly (*Calliphora vicina*) in carrot enhanced seed set ten times higher than the cages without insect pollinators (Ahmad and Aslam, 2002).

Conclusions and Recommendations

In conclusion, conserving these native insect pollinators (syrphid flies and bees) may enhance seed production of carrot and yield of other pollinator dependent crops on sustainable basis. Conservation efforts can be made by providing foraging and nesting resources for the available insect pollinators (Klein *et al*., 2003).

Acknowledgments

This research was financed by Agriculture Linkage Program (ALP) of Pakistan Agriculture Research Council (PARC) under project "Conservation of native bees through ecosystem approach for enhanced crop pollination"

Novelty Statement

Best of our knowledge no previous work has been done on carrot seed production by insect pollinator in same region. Moreover diversity of native insect pollinators of carrot has been described first time in South Punjab Pakistan.

Author's Contribution

Mudssar Ali, Asif Sajjad and Shafqat Saeed: Conceived the idea, designed the experiments and Contributed reagents/ materials/ analysis tools.
Mudssar Ali and Muhammad Awais Ahmad: Performed the experiments and Wrote the paper.
Mudssar Ali and Asif Sajjad: Analyzed the data.
All the authors commented on previous versions of the manuscript.

Conflict of Interest

There is no conflict of interests regarding the publication of this article.

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