Diversity and role of flower visitors in onion seed production

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Onion flowers attract a wide range of visitors, including pollinators. Many factors influence the abundance of floral visitors in onion, such as flower size, shape, colour, weather parameters and the availability of floral rewards. Quality seed production in onion (*Allium cepa* L.) is mainly driven by insect pollinators because of its protandrous nature and cross-pollination. The type of flower visitors, their numbers and the time of their visitation determine the pollination efficiency. Bees are the major pollinating agents in onions under natural conditions. However, using chemical pesticides against pests and diseases of onions during bloom decreases the diversity in and around crop fields. Anthropogenic factors like urbanization could have negative impacts on insect pollination services. Therefore, it is critical to adopt a sustainable approach to retain and conserve the existing insect pollinators and their diversity in the onion ecosystem. In this study, we review the research work done so far on the diversity and role of flower visitors and pollinators in onion seed production and the various factors affecting their survival and services in the onion ecosystem.

Keywords: Floral biology, foraging ecology, onion, pollinators, species diversity.

ONION, *Allium cepa* L. is one of the popular bulbous vegetables of Central Asia, belonging to the Liliaceae family[1]. It has been India's most important commercial vegetable and condiment crop for more than 5000 years. In onion bulb production, India is next to China, with 311.29 lakh tonnes of production and 16.26 MT/ha of productivity[2]. Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Rajasthan, Tamil Nadu and Haryana are the major onion-producing regions in India. Even though the production is high, the average productivity of onion in India is much less than the global average. The main reason for this is the non-availability of quality seed material. Annually, India requires 9400 tonnes of onion seeds to cover 11.73 lakh ha area under cultivation. Nearly 40% of the country's onion seed requirement is contributed by the organized sector, while the remaining requirement is met by the farmer's own seeds[3]. Quality seed material in onions is interrelated with pollination, which is attributed to the number and diversity of insect visitors. Therefore, it is necessary to conserve the insect visitors for good quantity and quality of onion seeds. Here, we review the research work done so far on the floral biology of onions, the diversity of flower visitors, the foraging ecology of pollinators and their role in onion seed production. We also discuss the effects of different factors on flower visitors in the onion ecosystem.

Floral biology of onion

Onion is a highly cross-pollinated crop due to its protandrous nature[4]. Self-pollination rarely occurs and the plant relies on insects for cross-pollination[5]. The umbelliferous inflorescence is visible at the top of the hollow green plant[4]. The umbel consists of a couple of white-coloured membranous sheaths that surround and protect the flowers. The middle of the umbel is slightly swollen. Each spathe bears an umbel, which contains 50–2000 flowers (normally 200–600) and the number of flower stalks produced per plant is also variable[4,6]. Each flower has six stamens, six perianth lobes, three carpels and one pistil. Each carpel contains two ovules. Flowering is normally signalled by the appearance of the scape (flower stalk). The flower opening in an umbel is highly irregular and lasts about two weeks. Strongly insolated parts of the umbel usually produce open florets first[1]. Thus, plants with many inflorescences can have open flowers for a month or more[7]. It may take 30 days or more for all stalks to flower[8].

Flower pollination may occur as late as six days after opening in onions. Majority of the pollen is shed within three days after flowering begins and is completed before the stigma becomes receptive (i.e. days four and five)[9]. Anther dehiscence occurs 3–4 days before the style reaches full length and the stigma becomes receptive[4]. Anthesis to the withering of petals and anthers takes about 10 days at 18°C and about 5 days at 30°C (ref. 1). Anthers of the three inner-whorl stamens open one by one and shed their pollen before the anthers of the outer whorls open[10]. The nectaries at the base of the stamens produce 30–60% of the total sugar nectar[10–12], which attracts insects for pollination[8]. The pollen from the flower that blooms at the end of the blooming period is less viable[13].

Diversity of flower visitors and pollinators in the onion crop ecosystem

Several flower visitors have been reported in onion flowers (Figure 1). Many factors influence the abundance of flower

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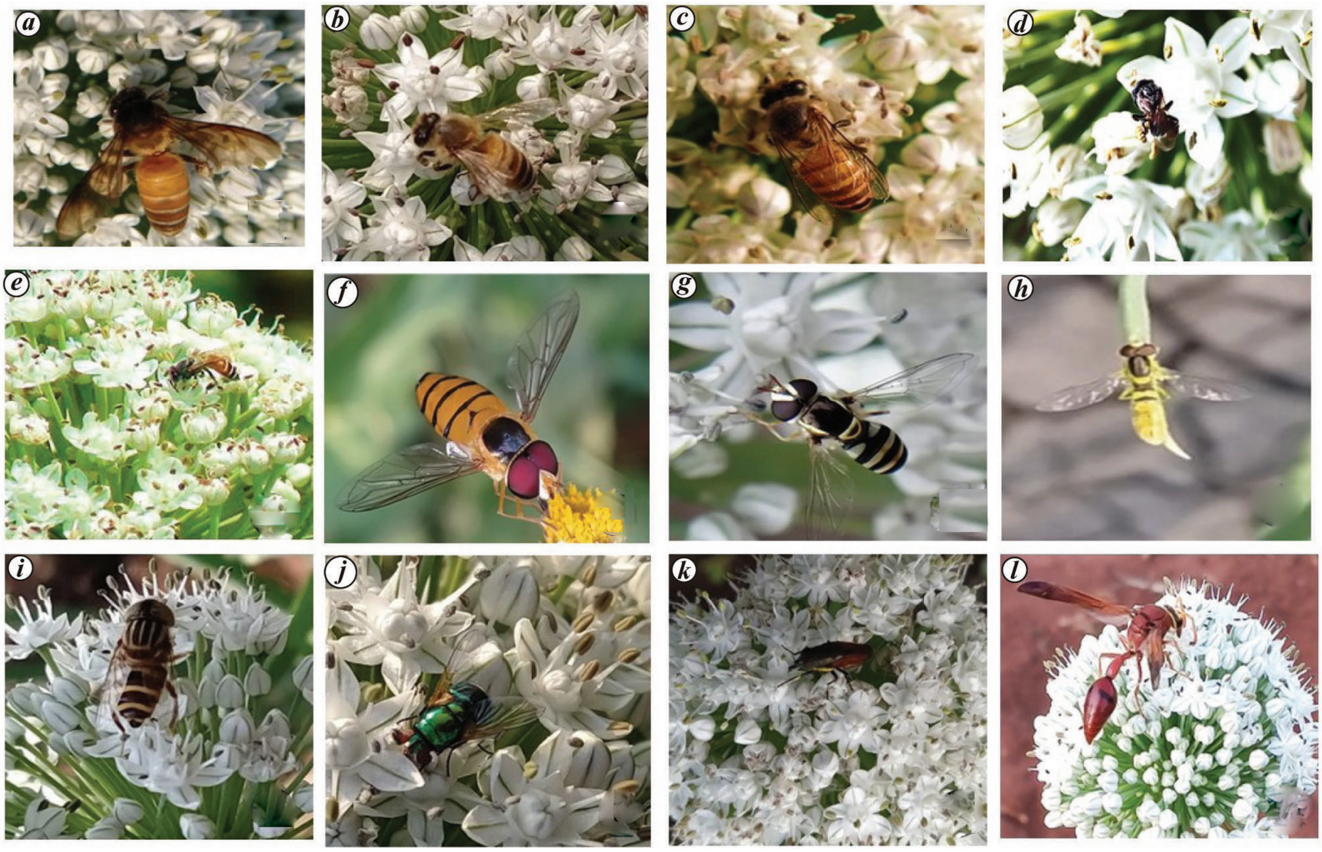

Figure 1. List of common flower visitors on onion blooms. ***a***, *Apis dorsata*; ***b***, *Apis mellifera*; ***c***, *Apis cerana indica*; ***d***, *Tetragonula* spp.; ***e***, *Apis florea*; ***f***, *Asarkina* spp.; ***g***, *Ischidion* spp.; ***h***, *Sphaerophoria* spp.; ***i***, *Eristalinus aeneus*; ***j***, *Lucilia serricata*; ***k***, *Stomorhina* sp.; ***l***, *Delta conoideum.*

visitors in onion, such as flower size, shape, colour, weather parameters and the availability of floral rewards. Pollen and nectar sources of onion blossoms attract insect visitors such as honey bees, syrphid flies, drone flies, halictid bees, butterflies, bumblebees, etc.[14]. Nearly 86.61% of flower visitors belong to the order Hymenoptera, followed by Diptera[15,16], Coleoptera and Lepidoptera (Tables 1–4). Though potassium content in the nectar deters the bees, different species of honey bees are among the major flower visitors in onion[16–22].

The visitation rate of Italian bee *Apis mellifera* has been reported as 5.48 bees/m^2/min (ref. 23) and 12 visits/min (ref. 19) in onion. Rock bee, *Apis dorsata* is the major visitor in mountainous areas of the Indian subcontinent[14,24]. Indian bee species *Apis cerana* and *Apis florea*, with visitation rates of 4.70 and 3.54 bees/m^2/min respectively, and *Trigona irridipennis*[25,26] are also important flower visitors in the onion ecosystem[23,27].

Syrphids like *Erisyrphus balteatus*, *Syrphus* sp.[18] and dipterans like *Calliphora vomitaria*, *Musca domestica*[22], *Amegilla calens*, *Lipotrichus collaris*[16], *Lipotrichus illustris*[18], *Lasioglossum malachusum*, *Lasioglossum pauxillum*[19] and horse flies[28] tend to visit onion flowers most frequently. The visitors were low in number during the initial flowering days and significantly increased during full bloom[23]. The flower visitation rate of *E. balteatus* has been recorded as 14 ± 4.61 flies/m^2/min (ref. 14). It is known that flower visitors have an ecological threshold level below which no activity occurs, which varies between and within species depending on the level of adaptation of a species to a particular habitat[29]. The flight activity of a pollinator may vary depending on the time of day and other weather factors like temperature, sunshine, wind velocity, rainfall and humidity[18,30].

From 6.00 am till 6.00 pm, onion flower visitors begin collecting floral rewards, with peak visitation from 10.00 am to 4.00 pm (refs 31, 32). The ideal temperature for optimum foraging activity is between 25°C and 30°C. An increase in temperature above the threshold and a decrease in relative humidity tend to have a negative impact on the foraging activity of flower visitors[14]. *A. mellifera* and syrphid flies have their peak foraging time in the morning (8.00–10.00 h) (ref. 24), whereas the peak foraging activity of *A. cerana*, *A. dorsata* and *A. florea* occurs between 10.00 and 14.00 h (ref. 14). The optimal conditions for bee flight and foraging are wind speed of less than 25 km/h, temperature of more than 21°C (70°F), humidity less than 75% and few or no clouds[33]. In particular,

Table 1. List of major hymenopteran flower visitors in onion

Scientific name	Family	Geographical location
Apis mellifera Linnaeus	Apidae	India (Karnataka, West Bengal and Maharashtra)[15,18,45], New Zealand[17], Pakistan[14,31], Cameroon[16], Egypt[18], Algeria[19]
Apis dorsata Fabricius	Apidae	India (Karnataka, West Bengal, Himachal Pradesh and Maharashtra)[15,23,24,35,44], Pakistan[14,31,34]
Apis cerana Fabricius	Apidae	India (Karnataka, West Bengal and Maharashtra)[23,34,65–67], Australia[68]
Apis florea Fabricius	Apidae	India (Karnataka, West Bengal, Himachal Pradesh and Maharashtra)[15,23,35,36,44], Pakistan[14,34], Australia[65]
Trigona iridipennis Smith	Apidae	India (Karnataka and Maharashtra)[23,35,36], Australia[65]
Amegilla calens (Lepeletier)	Apidae	Pakistan[14], Cameroon[16]
Xylocopa olivacea Fabricius	Apidae	Pakistan[14], Cameroon[16], India (West Bengal)[44]
Xylocopa inconstans Smith	Apidae	Pakistan[14], Cameroon[16]
Xylocopa nigrita (Fabricius)	Apidae	Pakistan[14], Cameroon[16]
Xylocopa fenestrae (Fabricius)	Apidae	India (Karnataka)[23,36]
Xylocopa pubescens Spinola	Apidae	Egypt[18]
Bombus spp.	Apidae	New Zealand[17], Algeria[19]
Lipotriches collaris (Vachal)	Halictidae	Pakistan[14], New Zealand[16], Cameroon[17]
Lipotriches azarensis (Cockerell)	Halictidae	Pakistan[14], New Zealand[16], Cameroon[17]
Lasioglossum atricrum (Vachal)	Halictidae	Pakistan[14], New Zealand[16], Cameroon[17]
Lasioglossum pauxillum (Schenck)	Halictidae	Algeria[19]
Sphecodes spp.	Halictidae	Algeria[19]
Lasioglossum saegeri Pauly	Halictidae	Pakistan[14], New Zealand[16], Cameroon[17]
Halictus farinosus Smith	Halictidae	Utah[19]
Belanogaster juncea (Fabricius)	Vespidae	Pakistan[14], Cameroon[16]
Vespula vulgaris Linnaeus	Vespidae	Pakistan[14], Cameroon[16]
Vespa cincta Fabricius	Vespidae	India (West Bengal)[44]
Eumenus spp.	Vespidae	India (Karnataka)[36]
Componatus flavimarginatus (Mayr)	Formicidae	Pakistan[14], Cameroon[16]
Componatus compressus (Fabricius)	Formicidae	India (Karnataka)[23,36]
Oecophylla smaragdina Fabricius	Formicidae	India (Karnataka)[23,36]
Megachile bituberulata Ritsema	Meghachilidae	Pakistan[14], Cameroon[16]
Chalicodoma rufipes (Fabricius)	Meghachilidae	Pakistan[14], Cameroon[16]
Osmia rufa (Linnaeus)	Meghachilidae	Wellebourne[30], USA (Utah)[41,42,69], England[43]
Ammophila spp.	Sphecidae	Pakistan[14], Cameroon[16]
Philanthus triangulum (Fabricius)	Sphecidae	Pakistan[14], Cameroon[16]

Table 2. List of major dipteran flower visitors in onion

Scientific name	Family	Geographical location
Erisyrphus balteatus (De Geer)	Syrphidae	Pakistan[14,34], Cameroon[16], India (West Bengal and Himachal Pradesh)[42,44]
Metasyrphus conferator (Wiedemann)	Syrphidae	India (Himachal Pradesh)[42]
Sphaerophoria scripta (Linnaeus)	Syrphidae	India (West Bengal)[44], Pakistan[14,34]
Eupodes corolla (Fabricius)	Syrphidae	Pakistan[14]
Mesembrius bengalensis (Wiedemann)	Syrphidae	Pakistan[14]
Eristalinus aeneus (Scopoli)	Syrphidae	Pakistan[14]
Chrysotoxum intermedium Meigen	Syrphidae	Pakistan[14], Cameroon[16]
Paragus borbonicus Macquart	Syrphidae	Pakistan[14], Cameroon[16], India (Karnataka)[23,36]
Eristalis spp.	Syrphidae	Wellebourne[30], India (Maharashtra)[35], USA (Utah)[41,42,69], England[43]
Musca domestica Linnaeus	Muscidae	India (Karnataka, West Bengal and Maharashtra)[15,23,35,36,44], Pakistan[14,34], Cameroon[16], Egypt[18], Australia[17], Israel[29], Washington[67]
Chrysomya chloropyga (Wiedemann)	Calliphoridae	Pakistan[14], Cameroon[16]
Calliphora spp.	Calliphoridae	Pakistan[14,34], Egypt[18], Wellebourne[30], USA (Utah)[41,42,69], England[43]
Lucilia spp.	Calliphoridae	New Zealand[15], Egypt[18], Wellebourne[30], USA (Utah)[41,42,69], England[43], Israel[67], The Netherlands[66], Australia[68]
Chrysomya bezziana (Villeneuve)	Calliphoridae	India (West Bengal)[44]
Sarcophaga sp.	Sarcophagidae	Pakistan[14,34], India (West Bengal)[44], Egypt[18]
Anthomyia punctipennis Wiedemann	Anthomyidae	Australia[17,68]
Anthomyia punctipennis Wiedemann	Anthomyidae	Australia[17,68]

A. dorsata requires a temperature of 16°C, relative humidity of 74%, light intensity of 600 lx and solar radiation of 10 mW/cm^2; *A. mellifera* requires 16°C, 75% relative humidity, 800 lx light intensity and 10 mW/cm^2 solar radiation; *A. cerana* needs 15.5°C, 76% relative humidity, 600 lx light intensity and 9 mW/cm^2 solar radiation, and *A. florea*

Table 3. List of major coleopteran flower visitors in onion

Scientific name	Family	Geographical location
Aulucophora faevicollis (Lucas)	Chrysomelidae	Pakistan[14], Cameroon[16]
Aulucophora abdomanalis (Fabricius)	Chrysomelidae	India (Karnataka)[23,36]
Monolepta signata (Oliver)	Chrysomelidae	India (Karnataka)[23,36]
Eurema spp.	Chrysomelidae	Pakistan[14], Cameroon[16]
Illeus cinctus Fabricius	Coccinellidae	India (Karnataka)[23,36]
Coccinella spp.	Coccinellidae	India (Karnataka)[15]
Coryna spp.	Meloidae	Pakistan[14], Cameroon[16]
Mylabris spp.	Meloidae	Pakistan[14], Cameroon[16]
Pachnoda interrupta (Olivier)	Cetonidae	Pakistan[14], Cameroon[16]
Chrysoperla cornea Stephens	Chrysopidae	Egypt[18], India (Karnataka)[23,36]
Anoplocnemis curvipes (Fabricius)	Pentatomidae	Cameroon[16]
Nezara spp.	Miridae	India (Karnataka)[15], Egypt[18]

Table 4. List of major lepidopteran flower visitors in onion

Scientific name	Family	Geographical location
Peiris spp. Schrank	Pieridae	India (Karnataka and Maharashtra)[15,35]
Venessa cardui (Linnaeus)	Pieridae	Pakistan[14], Cameroon[16]
Catopsilia florelia (Fabricius)	Peiridae	Pakistan[14], Cameroon[16]
Danaus chrysippus (Linnaeus)	Nymphalidae	India (Karnataka and Maharashtra)[15,35], Pakistan[14], Cameroon[16]
Danaus plexippus (Linnaeus)	Nymphalidae	India (Karnataka)[15]
Hypolimnas misippus (Linnaeus)	Nymphalidae	Pakistan[14], Cameroon[16]
Papilio demoleus Linnaeus	Papilionidae	India (Karnataka)[23]

needs 18.5°C temperature, 64% relative humidity, 1700 lx light intensity, and 20 mW/cm^2 solar radiation.

Foraging ecology of major pollinators visiting onion flowers

Foraging behaviour and population dynamics alone are not good indicators of any flower visitor as an effective pollinator. It is difficult to determine whether a flower visitor is an effective pollinator based solely on the above two factors. There are other factors that may play a role, including size and shape of the insect, whether it is thirsty for nectar or pollen, and whether it has the chance to come into contact with the stigmas of the flowers and deposit pollen on them. Considering these facts, *T. irridipennis*[6] and honey bees of genus *Apis*, viz. *A. dorsata*[23,24,34], *A. cerana indica*[35,36], *A. mellifera*[15,18] and *A. florea*[34,37], and syrphids[24] are reported to be effective pollinators in the onion ecosystem[20,24,32,37] because of their body size, morphology and short tongue[4,21]. Pollen gatherers in onion are very low or few and the majority are nectar gatherers. It is the small size of the anthers of the flowers which makes it tedious for pollen collection. The flowers get pollinated when the visitors dust-off the pollen smeared on the body while collecting nectar. For collecting nectar, they tend to visit the middle portion of the umbels rather than the top or bottom[38].

A. dorsata being the most efficient pollinator[21,24,37,39] has an average visitation rate of 5.24 bees/m^2/5 min (ref. 23), visiting an average of 3 umbels/min (ref. 35). A single bee tends to visit an average of 7.5 flower/umbel during a single visit[24] with a time of 2.9 ± 0.52 sec on every flower[36] and 17.83 sec on individual umbels[35]. Higher onion seed yield can be seen when *A. dorsata* is engaged in pollination services (340.7 g/100 umbels)[40]. *A. cerana indica* has an average visitation rate of 2.93 bees/m^2/5 min (ref. 23), with a single bee visiting 3.17 umbels/min (ref. 35) covering 5.42 flowers/umbel in a single visit[24] and spending 7.33 ± 2.41 sec/flower (ref. 36).

A single *A. mellifera* bee can visit an average of 21.64 flowers/min (ref. 21) with a minimum of 0.81 bees/m^2/min (refs 15, 23). The population density of *A. mellifera* in the field sometimes reaches up to 1.78/plant/min (44.67 bees/ 25 plants/min) (ref. 18). *A. florea* has an average visitation rate of 1.79 bees/m^2/min (ref. 23) with 18.83 sec spent per umbel[35] and 12.5 ± 0.40 sec stay time on each flower of an umbel[36]. *Tetragonula* spp. has an average stay time of 5.33 ± 0.73 sec/flower (ref. 36) with a maximum of 27.5 sec spent on individual umbels[35]. Syrphids are also efficient and major pollinators in the onion ecosystem, with a stay time of 8.8 sec/flower (ref. 24).

Honey-bee pollination studies in onion (excluding other flower visitors)

Many studies have been conducted on onions under caged conditions, allowing only single species of pollinators to check their efficiency in seed production. The honey bees and flies like *C. vomitaria*, *C. vicina*, *L. caesar*, *L. sericata* (Diptera: Calliphoridae), *M. domestica* (Diptera; Muscidae), *E. balteatus*, *E. aeneus* (Diptera: Syrphidae) and the solitary bee *Osmia rufa* (Hymenoptera: Megachilidae) proved to be the better pollinators under caged conditions[30,41–43] with a good seed set of more than 87.79% in *A. mellifera*-pollinated crops[16]. Even the seeds obtained from umbels pollinated by individual pollinators tend to have better germination, seedling emergence, survival and crossing rate[30]. For example, the umbels pollinated with only *A. mellifera* recorded 80.84% seeds/fruit (ref. 21), seed yield of 457.72 kg/ha, germination of 76%, and test weight of 3.23 g/100 seeds, which is significantly superior over flower visitor-excluded crops (seed yield of 5.91 kg/ha, germination of 14% and test weight of 2.67 g/100 seeds)[44].

Some studies reported that flies and honey bees are equivalent in their suitability as pollinators for caged onion[30]. Few studies suggested that calliphorid flies, *Eristalis* flies and *M. domestica* are more suitable than honey bees for pollinating onion in cages[42,43]. To support this, an experiment was conducted where *M. domestica* and *C. vicina* pollinated crops recorded 87.8% and 85.5% germination respectively, and it was observed that an increased supply of flies increased the yield[29].

Effect of pollinators on seed yield of onion

If onion blooms are not visited by insects, they will not generate excellent seeds. The scarcity of natural pollinators seriously hinders seed production, especially in India's mountainous regions[24]. Pollinators are crucial for onion seed production. Compared to bagged plants, open-pollinated plants show a 72–79% increase in seed setting[45]. According to some reports, open pollination results in a 61.8% seed setting rate compared to 1.5% for self-pollinated onion crops[40]. In open-pollinated plots, seed yield per bulb will be larger (5.74 g/flower) than in caged plots (1.29 g/flower)[25]. When compared to the yields of open fields with honeybee colonies, the number and weight of onion seeds per flower from the self-pollinated plant are low[46].

In comparison to self-pollinated plants, plots with induced bee pollination have higher seed set[47], maximum germination[24], and shoot and root length[32]. When onion blooms are pollinated by honey bees, the weight of 1000 seeds, germination capacity and energy are all high[48]. Bee pollination boosts seed output from 175% (ref. 49) to 1000% (ref. 45). It was found that honey-bee pollination resulted in a 10- to 11-fold increase in seed output[33]. Bees boost onion seed production by 8–10 times; therefore, seed production plots should include roughly two colonies per acre[50].

Effect of pesticide usage on pollinators visiting onion flowers

Although pesticides are often required to control pests attacking onions during the flowering stage, these have undesirable effects on the health and foraging visits of the pollinators (Table 5). Insecticides are known to repel or kill honey bees and lower crop yield[27]. Systemic insecticides, which are used for seed coating, translocate from the roots to the entire plant, including the flowers and may harm non-target pollinators. The susceptibility of the pollinators and other non-target organisms to the pesticides is mainly associated with the chemical structure of the pesticides rather than the body mass of the pollinators[51]. Pesticides like fipronil, imidacloprid, thiamethoxam, dimethoate, mancozeb, captan and azoxystrobin are some of the widely used chemicals in the onion ecosystem, which have been proven to be highly toxic to pollinators.

Fipronil is one of the important insecticides used to manage thrips of onion, to which majority of the pollinators show high susceptibility. Exposure to pollinators like *Mellipona scutellaris*, *A. mellifera* and *A. cerana indica* causes reduced flight velocity, lethargy[52,53], locomotion difficulty, olfactory and memory learning impairment[54], loss of ability to learn and memorize, and causes the paralysis of wings, legs and digestive system, hyperexcitation accompanied by the release of alarm pheromones and individual attacks[55], genetic instability, imbalance in reactive oxygen species[56] and antioxidants[57]. Up- and down-regulation in protein synthesis, which are associated with pathogen susceptibility, apoptosis, visual impairment, ischaemia and brain degeneration, have also been reported in *A. mellifera* exposed to fipronil[58]. Decreased secretory cell height and reduced reservoir volume of the mandibular glands, and decreased royal jelly secretion have also been observed in nurse bees[53].

Neonicotinoids like imidacloprid, thiacloprid, acetamaprid and thiamethoxam are reported to have harmful effects like impairment in brood development, cognitive and neurological impairment, reduced adult longevity, immunity suppression, abnormal foraging behaviour with delayed trips and a negative impact on the feeding and learning behaviour in honey bees, *Osmia lignaria* and *Bombus* species[59]. The reduced life expectancy of *Bombus impatiens*, decline in nest numbers of *Megachile rotundata* up to 50%, memory loss and decline in navigation skills are also reported[60]. Organophosphate compounds like dimethoate are reported to affect the olfactory and learning performances in *A. mellifera*[60].

Fungicides like amistar and azoxystrobin are known to affect the reproductive output of bumblebee colonies with reduced fecundity, the number of workers and sexuals, weight, and low foraging activity[61]. Fungicide captan used for seed treatment inhibits cell division and is acutely toxic to *O. lignaria* at field-relevant concentrations[62]. It can also enhance larval mortality and developmental deformities in honey bees[63,64].

Conclusion

The literature indicates that pollinators are essential for onion seed production. Cross-pollination occurs in majority

Table 5. Common pesticides used in onion and their effects on the pollinators

Insecticides	Effects on pollinators
Imidacloprid	• Abnormities or death during development[70], decreased foraging activity and negative effects on olfactory learned discrimination task[71], impaired olfactory learning and memory formation[72,73], adverse effect on foraging behaviour[74,75], cognition/neurological impairment[71], increased AChE activity[76] and decreased survival[73], increased susceptibility of the colony to microsporidia *Nosema*[77], increased incidence of colony collapse disorder[78,79] in *Apis mellifera*. • Reduction in feeding rate[80], reduction in mean daily locomotory activity[79], reduction in queen survival, worker movement, colony consumption and colony weight[81,82], decreased birth rates and increased death rates in the colony[83], impairment in pollen foraging efficiency[84] in bumble bees, *Bombus* spp. • Sub-lethal effects on larval development and longer developmental time for *Osmia lignaria*[85]. • Negatively affects the development of mushroom bodies in the brain[86,87] and impairs the walking behaviour of newly emerged adult workers for stingless bees (Hymenoptera: Apidae: Meliponinae)[88].
Thiacloprid	• Interference with navigation[89,90], immune suppression with *Nosema*[91] and additive interaction with black queen cell virus leading to increased larval mortality in *A. mellifera*[90].
Acetamiprid	• Impaired long-term retention of olfactory learning in *A. mellifera*[92].
Thiamethoxam	• Foraging difficulty[93], decreased colony performance and productivity, decelerated colony growth[90], behaviour and locomotive impairment[94], malpighian tubules show pronounced alterations for Africanized *A. mellifera*[95]. • Fewer total brood cells, higher offspring mortality, and male-biased offspring sex ratio for solitary bee *Osmia bicornis* (red mason bee)[90].
Clothianidin	• Decreased colony performance and productivity, decelerated colony growth[71], behaviour and locomotive impairment[90], cognition/neurological impairment[71] in *A. mellifera*. • Reduction in queen survival, worker movement, colony consumption and colony weight[81], reduced foraging activity, increased worker mortality, delayed weight gain and no new queens produced[96] in *Bombus* spp. • Fewer total brood cells, higher offspring mortality, and male-biased offspring sex ratio for solitary bee *O. bicornis* (red mason bee)[90].
Fipronil	• Reduced flight velocity, lethargy[38,53], motor and locomotion difficulty, olfactory and memory learning impairment[54], reduced learning and memory capacities leading to paralysis of wings, legs and digestive system, hyperexcitation accompanied by emission of alarm pheromone thus leading to individual attack[55], genetic instability, imbalance in reactive oxygen species[56] and antioxidants[57] in *A. mellifera* and *Apis cerana indica*. • Up- and down-regulation in protein synthesis which is related to pathogen susceptibility, apoptosis, ischaemia, visual impairment and brain degeneration in *A. mellifera*[60]. • Decreased secretory cell height of mandibular glands, reduced reservoir volume of mandibular glands and decreased royal jelly secretion in nurse bees of *A. mellifera*[53].
Dimethoate	• Affects the olfactory and learning performances in *A. mellifera*[61].
Captan	• Inhibits cell division and is acutely toxic to *O. lignaria* at field relevant concentrations[63] and can induce larval mortality and developmental malformations in honey bees[64,71].
Mancozeb, azoxystrobin	• Affect the reproductive output of bumble-bee colonies with reduced number of eggs laid, reduced number of workers and sexuals, reduced weight and low foraging activity[62].

of crops, including onion and insects play a key role in this process. Both pollinating and nectar-gathering insects are attracted to onion inflorescence. When the flowers are pollinated by insects, the quantity and quality of the seeds increase in value. Pollinators are attracted to flowers because of their colour, fragrance, form, pollen and nectar. However, they require a certain ecological threshold for normal functioning, below which no activity occurs. Indiscriminate use of pesticides affects the survival and services of pollinators. Studies on bee-friendly pesticides are needed in onion crop agroecosystems. Detailed studies are also required on this reveals the scope for conserving flower visitors in the onion crop ecosystem.

Conflict of interest: The authors declare that there is no conflict of interest.

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