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REVIEW ARTICLE

Pollinators of cucurbit crops: Diversity, efficiency and conservation challenges

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Abstract

Pollination is critical to crop productivity, with about 87 % of global food crops relying on pollinators. Cucurbits (Cucurbitaceae), including cucumber, pumpkin, melon, bitter gourd and squash, are highly dependent on insect pollination because of their monoecious or andromonoecious flowering systems. Effective fruit set and quality in these crops are linked to floral biology, stigma receptivity and synchronisation with pollinator activity. Pollination efficiency varies among cucurbit species and pollinators. In cucumber (*Cucumis sativus*), *Apis mellifera* accounted for 96.5 % of floral visits during the short rainy season and 64.3 % during the long rainy season, producing the highest fruit weight (1184.5 g) and seed number (472.8 seeds/fruit). In muskmelon (*Cucumis melo*), *Apis florea* and *Apis cerana* contributed to 93.3 % and 83.3 % fruit set, respectively, highlighting the role of native bees in successful fertilisation. In watermelon (*Citrullus lanatus*), at least six bee visits per pistillate flower are needed for full fruit development, with *Bombus impatiens* exhibiting greater pollen deposition efficiency than honey bees. Native squash bees (*Peponapis* and *Xenoglossa* spp.) are the most effective pollinators of pumpkin and squash due to early morning foraging and floral specialisation. Pollinator activity is influenced by temperature, humidity, pesticide use and habitat conditions. Declines in pollinator populations from habitat loss, agrochemicals and climate change pose serious risks to cucurbit yields. Conserving pollinator diversity and adopting pollinator-friendly farming practices are essential for sustaining productivity and ensuring the ecological resilience of cucurbit production systems.

Keywords: cucurbitaceae; floral biology; pollination biology; pollination efficiency; sustainable agriculture

Introduction

Pollination plays an important role in maintaining the natural eco balance and is the foundation of crop production, providing a link between the life cycle and agriculture. Consequently, pollination also has major economic importance, as it enhances both the quality and quantity of agricultural produce (1). About 87 % of global food crops are dependent upon animal pollination (2). Among insect-pollinated crops, fruits and vegetables remain the leading categories, each contributing approximately EUR 50 billion to global agricultural value, followed by oilseeds, nuts, spices and stimulants (3). Pollinator dependent crops supply up to 40 % of the world's essential dietary nutrients, underscoring their critical importance for global food security and nutritional quality (4). In addition, insect pollination is also essential for many aromatic and medicinal plants production such as cumin (*Cuminum cyminum* Linn), black cumin (*Nigella sativa* Linn), anise (*Pimpinella anisum* Linn), coriander (*Coriandrum sativum* Linn) and sunflower (*Helianthus* spp.) (1). Globally, pollination contributes more than US $ 800 billion annually in gross economic value, encompassing both food production and nutritional benefits (5).

Cucurbits belonging to the family Cucurbitaceae represent an economically and nutritionally important group of vegetable crops that includes cucumber (*Cucumis sativus* L.), pumpkin (*Cucurbita pepo* L.), melon (*Cucumis melo* L.), bitter gourd (*Momordica charantia* L.) and squash (*Cucurbita maxima* Duchesne). Worldwide, these crops are cultivated for their edible fruits, seeds and, in some cases, leaves and flowers, providing a rich source of vitamins, minerals and antioxidants (6). Their reproductive success and fruit quality depend largely on effective pollination, as most species are monoecious or andromonoecious, producing separate female and male flowers on the same plant, which require pollen transfer for fertilisation (7, 8).

In cucurbits, pollination is primarily arbitrated by insects, with honey bees (*Apis mellifera* Linn), squash bees (*Peponapis* and *Xenoglossa* spp.) and bumble bees (*Bombus* spp.) recognised as the most effective pollinators (9, 10). Effective pollination directly influences fruit set, size, shape and seed development, whereas inadequate pollination can lead to underdeveloped fruits, reduced yields and economic losses for growers (11). Pollination efficiency is influenced by factors such as floral phenology, nectar and pollen rewards, pollinator foraging behaviour and environmental conditions, including temperature, humidity and wind (12, 13).

Globally, there is growing concern over pollinator declines caused by habitat loss, climate change, pesticide exposure and disease pressure, which could significantly affect cucurbit production (14, 15). Since cucurbits rely heavily on biotic pollination for optimum yields, the conservation of pollinator diversity and the adoption of pollinator-friendly agricultural practices are critical. A deeper understanding of pollination biology in cucurbits supports integrated crop management and sustainable food production (16, 17). This review examines the diversity and role of pollinators in cucurbit yield, the factors affecting pollination efficiency and strategies to overcome related challenges. Furthermore, it emphasises the need for optimising floral resource management and habitat diversification to enhance pollinator services under changing agroecological conditions. Integrating pollination ecology with modern breeding and pest management approaches can ultimately improve crop resilience and productivity in cucurbit systems. Studies published between 2005 and 2025 were reviewed from databases including Google scholar, Science direct, Scopus and Web of science databases using keywords such as cucurbit pollination, bee diversity, pollination efficiency, and sustainable farming.

Floral biology of cucurbit crops

Floral phenology and structure

In most cucurbit species - a family of vining, flowering plants that includes economically important crops such as cucumber, pumpkin, melon, bitter gourd and watermelon - male (staminate) flowers appear several days to weeks before female (pistillate) flowers, a phenomenon known as protandry, which promotes cross-pollination and reduces the likelihood of self-fertilisation. Cucurbits are predominantly monoecious, bearing distinct male and female flowers on the same plant, although dioecious forms occur in some species. Female flowers are generally receptive for a single day, with stigma receptivity reaching its maximum during the morning hours, coinciding with peak pollinator foraging activity. The proportion of male to female flowers can vary throughout the growing season, with male flowers predominating during early flowering and female flowers increasing later in the season (9, 18, 19). In general, solitary staminate flowers are borne singly, or less commonly in clusters of two to three, on thin pedicels arising from the leaf axils. Clustered flowers may also be borne on thicker pedicels from axillary points (20, 21).

In muskmelon (*C. melo*), a warm-season fruit crop grown for its sweet, aromatic flesh, flowering begins about 37.10 ± 1.77 days after sowing in the post-monsoon season and 39.83 ± 1.93 days in summer, with 50 % flowering occurring at 55-60 days. The blooming period lasts around 43 days in post-monsoon and 42 days in summer, each showing two distinct peaks influenced by local climatic conditions. The corolla of staminate flowers comprises five yellow petals attached at the base, surrounded by a green calyx divided into five slender sepals. The androecium consists of fused filaments over five stamens, arranged into three groups of two pairs fused and one free, nearly occupying the corolla tube. The base of the corolla contains a rudimentary style encircled by nectaries. Pistillate flowers possess a similar perianth, but are slightly larger and borne at higher positions on the plant. The corolla is supported by a swollen ovary and contains a three-lobed stigma on a short style, surrounded by nectar (22).

In watermelon (*Citrullus lanatus* [Thunb.] Matsum. & Nakai), a widely cultivated fruit crop known for its large, fleshy berries, flowering begins approximately 40-50 days after planting, with male flowers appearing first and female flowers emerging 10-15 days later. Peak blooming occurs around 60–65 days for male flowers and 75-80 days for female flowers, aligning with peak pollinator activity in warm, humid conditions (23). In cucumber (*C. sativus*), flowers are unisexual and solitary, borne in the leaf axils. Female flowers possess a prominent inferior ovary at the base and five yellow, wrinkled petals fused at the base, while male flowers are more numerous, borne on long pedicels and contain three stamens with unequal filaments producing sticky pollen. Both flowers have five narrow sepals and nectar glands at the corolla base. The bright yellow corolla and abundant nectar attract pollinators, with maximum stigma receptivity and pollen viability occurring in the early morning hours (24). In pumpkin (*C. maxima*), male and female flowers exhibit distinct morphological characteristics. Female flowers possess a 3-5 cm ovoid ovary, while male flowers are long-stalked and pedicellate, appearing earlier (about 11-14 weeks after planting) than females, which develop approximately four weeks later. Typically, male flowers arise along the vine, whereas female flowers form near the main stem. Both are brightly colored, fragrant and nectar-rich, effectively attracting pollinators (25). In squash (*C. pepo*), the male and female flowers are separate, but both provide nectar for pollinators. Female flowers release around 90-120 µL of nectar and male flowers about 25-40 µL, along with roughly 16×10^3 pollen grains. Nectar forms near the base of the style in females and is drawn from pores beneath the anthers in males (26) (Table 1 and Fig. 1).

Floral anthesis and pollinator activity

Anthesis in cucurbits typically occurs in the early morning hours, generally between 05:00 and noon. During this period, nectar secretion, pollen viability and floral scent emission reach their peak, which attracts a high abundance of pollinators. This timing is critical as it directly influences pollination success, flower receptivity and overall pollination efficiency (27). In sponge gourd (*Luffa cylindrica [L.]* Roem.), flowers open early in the morning between 05:00 and 06:00 hr and close by 17:00-18:00 hr, showing a diurnal flowering pattern. Anther dehiscence begins about an hour before anthesis (around 04:00–06:00 hr) and completes by 08:00-10:00 hr (28). Muskmelon (*C. melo*), flowers open around 06:00 hr, with staminate flowers preceding hermaphroditic ones by about an hour; anther dehiscence follows approximately 15 min later (22, 29). Watermelon (*C. lanatus*) produces pistillate and staminate flowers that are solitary in the leaf axils. Anthesis occurs between 05:20 and 09:00 hr and flowers remain open until 12:00-14:30 hr, with duration influenced by current climatic conditions (19, 30).

Pollinator foraging peaks shortly after anthesis, when nectar and pollen are most abundant. Honey bees (*A. mellifera*) and native bee species are most active between 06:00 and 10:00 hr, coinciding with maximum stigma receptivity and pollen viability (31). Pollinator visits decline markedly by late morning as nectar secretion decreases and flowers begin to wilt, highlighting the importance of early-morning foraging for ideal fruit set and yield (32). In cucumber (*C. sativus*), *A. mellifera* activity peaks between 08:00-10:00 hr, while non-*Apis* species exhibit peak activity earlier, between 07:00-09:00 hr, depending on the season. In gourds, peak pollinator activity is observed frequently between 06:00–07:00 hr (33).

Table 1. Anthesis timing, stigma receptivity and flower longevity in cucurbit crops

Crop	Flower type	Time of anthesis	Stigma receptivity	Flower longevity	References
Cucumber	Monoecious	5:30-7:00 am	6:00-9:00 am	1 day	(20)
Pumpkin	Monoecious	5:30-7:00 am	6:00-10:00 am	1 day	(20)
Bottle gourd	Monoecious	5:30-7:00 am	6.00-9.00 am	1 day	(21)
Ridge gourd	Monoecious	5:30-7:00 am	6:00-9:00 am	1 night	(21)
Bitter gourd	Monoecious / Dioecious	5:30-7:00 am	5:30-10:30 am	1 night	(20)
Muskmelon	Monoecious / Andromonoecious	6-8 am	6:00-9:00 am	1 night	(20)
Snake gourd	Monoecious	6-8 am	6:00-10:00 pm	1 night	(20)

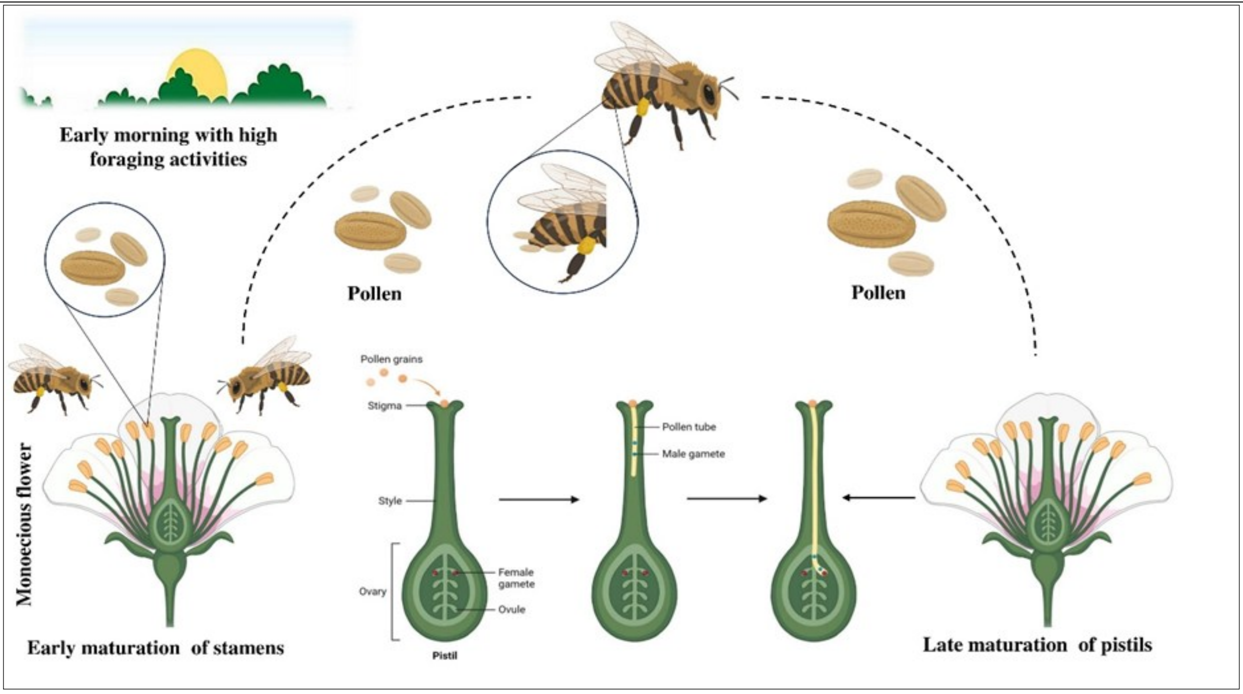

Fig. 1. Schematic representation of pollination dynamics in monoecious cucurbit flowers.

Diversity of pollinators in cucurbit crops

Major insect pollinators of cucurbit crops, reported as floral visitors, are summarized in Table 2.

Muskmelon (*Cucumis melo*)

Muskmelon is visited by a diverse assemblage of pollinators. In India, visual counts showed that *A. florea* and *A. cerana* were the most abundant, with equal overall abundance between *Apis* and non-*Apis* species. Among all visitors, *A. florea and A. cerana* contributed the most to fruit set (93.33 and 83.33 %, respectively), followed by *Tetragonula iridipennis* (26.67 %) and *Ceratina* spp. (16.67 %) (22).

Cucumber (*Cucumis sativus*)

In cucumber, pollination is predominantly carried out by *A. mellifera*, which accounted for 96.50 % and 64.29 % of floral visits during the short and long rainy seasons, respectively. The relative pollination efficiency of different insect species has been ranked as: *A. mellifera* > *Apis dorsata* Fab.> *Apis cerana* Fab.> *Xylocopa latipes* > *X. verticalis* (46). Bumblebees (*Bombus impatiens*) have been reported as the most effective pollinators than honey bees due to higher floral visitation rates, longer foraging times and greater pollen deposition in both watermelon and cucumber (30).

Watermelon (*Citrullus lanatus*)

Pistillate watermelon flowers generally require at least six bee visits for successful fruit set and yield (45). In triploid (seedless) varieties, which produce inviable pollen, interplanted diploid plants are necessary as pollen sources and insect-mediated pollen transfer is essential. Research indicates that bumblebees were more effective than *A. mellifera* in watermelon pollination, owing to higher pollen deposition rates, greater numbers of visits per flower and longer foraging durations (47).

Gourds

In bitter gourd (*M. charantia*) and ridge gourd (*Luffa acutangular* [L]), pollination is carried out by both Hymenoptera and Diptera, with *Bombus* spp. as the most copious pollinators in ridge gourd (35). In bitter gourd, major pollinators include *A. mellifera*, *Lasioglossum* spp., *Xylocopa* spp. and *Plebeia hildebrandti*, with Indian stingless bees (*T. iridipennis*) being particularly important (48, 49). In sponge gourd, key pollinators include *T. iridipennis*, *A. dorsata*, *A. cerana* and *A. mellifera*, with seasonal variation in dominance. In summer, honey bees comprise 57.69 % of visitors, dominated by *A. florea* (39 %), while in the rainy season, butterflies such as *Pelopidas mathias* (46.84 %) become more prevalent (40).

Influence of pollinators on crop yield in cucurbits

Pollinators play a critical part in determining fruit set, quality and yield in cucurbits, including pumpkin, cucumber, bitter gourd and melon. Among these, bees, particularly *A. mellifera* and native bee species-are the most effective, ensuring adequate pollen deposition and optimal seed set (1). Poor pollination often results in misshapen

Table 2. Major insect pollinators associated with cucurbit crops in different regions

Crop	List of pollinators	Country	Reference
Bottle gourd	Hawkmoths (*Hippotion celerio*, *Agrius convolvuli*), skipper butterfly (*Gorgyra johnstoni*) and honeybee (*Apis mellifera*)	Kenya	(34)
Bitter gourd	*A. mellifera*, *Lasioglossum* sp., *Xylocopa* sp. and *Plebiena hildebrandti*	Pakistan	(35)
	Halictus sp., *Megachile* sp. *and Apis dorsata*	India	(36)
Cucumber	*Aphis* sp., *A. mellifera*, *Lasioglossum fuscipenne*, *Heterotrigona itama*, *Musca domestica*, *Phaonia valida*, *Mylothris agathina*, *Acraea horta*, *Monomorium pharaonis*, *Gegenes niso* and Junonia terea	Nigeria	(37)
	A. mellifera and *Nannotrigona testaceicornis*	Brazil	(38)
	Bombus sp. and *A. mellifera*	Norway	(32)
Pumpkin	*A. mellifera*, *A. cerana*, *A. dorsata*, *A. florea*, *bumble bees (Bombus spp.)*, *Melipona quadrifasciata*, *Trigona spinipes*, *Xylocopa* spp., *Peponapis pruinosa*, *Xenoglossa* spp., *Agapostemon virescens*, *Augochlora pura*, *Dialictus* spp., *Halictus* sp., *Triepeolus remigatus*, *Melissodes bimaculatus*, *Pithitis smaragdula*	Germany	(39)
Musk melon	*Lasioglossum* spp. and *A. indica*	Norway	(32)
Ridge gourd	*Eristalinus* sp. and *Bombus* sp.	Pakistan	(35)
Sponge gourd	*A. indica*, *A. dorsata*, *A. florea* and *A. mellifera*	India	(40)
	A. mellifera	America	(21)
Squash	*Peponapis* spp. and *Xenoglossa* spp.	America	(41)
	Bombus terrestris, *B. impatiens* and *Eucera* spp.	Norway	(32)
Watermelon	*Lasioglossum* spp. and *A. mellifera*	Kenya	(42)
	Agapostemon splendens Lepeletier, *Campsomeris plumipes var. fossulana* Fabricius and *A. mellifera*	North central Florida	(43)
	A. mellifera, *Lasioglossum malachurum*, *Lasioglossum smaragdulus and Nomioides minutissimus*	Greece	(44)
	A. mellifera, *Nannotrigona perilampoides*, *Trigona corvina*, *Trigona fulviventris*, *Lasioglossum* spp.	Panama	(45)
Calbash gourd	*A. mellifera*	America	(7)

fruits, reduced yields and poor market quality (50). In cucumber, complete pollination produces uniform, well-shaped fruits with even maturity, while inadequate pollination leads to small, deformed fruits and reduced marketable yields (40). In a comparative study, hand pollination produced the highest fruit set (75.68 %), followed by pollination by honey bees (74.96 %) and open pollination (62.09 %). The proportion of healthy fruits was greatest under pollination by honey bees (92.22 %), compared to hand (85.85 %) and open pollination (79.64 %). Honey bee pollination also resulted in the highest average fruit weight (1184.5 g), fruit length (28.8 cm), seed number per fruit (472.8) and 1000 seed weight (29.14 g), confirming its efficiency in improving yield and quality in cucumber (51).

Factors and challenges affecting pollinator activity in cucurbit crops

Pollination in cucurbit crops is a critical determinant of fruit set, quality and yield, as these monoecious plants rely predominantly on insect-mediated transfer of pollen from male flowers to female flowers (52). The process is influenced by multiple interrelated factors, including the timing and duration of floral anthesis, which typically occurs in the early morning; the abundance and activity of pollinators such as *A. mellifera*, specialist squash bees (*Peponapis pruinosa*) and bumblebees; prevailing environmental conditions like temperature, humidity and wind; and crop management practices affecting floral biology and pollinator access. Adverse weather, imbalanced nutrient supply, excessive pesticide use, or habitat loss can disrupt pollinator behaviour and reduce pollination efficiency, leading to misshapen or underdeveloped fruits. Understanding these factors is essential for optimising pollination services and maximising cucurbit productivity (7, 8).

Temperature

Most bee species, including *A. mellifera and A. cerana indica*, exhibit peak foraging activity in cucurbits between 25-30 °C (50). Bees become sluggish and delay foraging, as their thoracic muscles require ~30-35 °C for sustained flight. Cool mornings after cloudy nights often delay activity onset (50). Very hot conditions increase desiccation risk and energy expenditure, causing a steep drop in activity by late morning or midday (53). Floral nectar secretion rates and sugar concentration in cucurbits are temperature-sensitive, with sunny, warm mornings producing greater nectar volumes and higher sugar content, thus enhancing visitation rates (54). Research indicates that both bumblebees (*Bombus* spp.) and Asian honeybees (*A. cerana*) were observed foraging actively on squash (*C. pepo*) flowers under ambient temperatures of 18-22 °C (26). This temperature range (18-22 °C) provided optimal foraging conditions for both bee species in the highland farms of Yunnan, China, where bumblebees and honeybees actively visited both male and female squash flowers to collect nectar and pollen.

Time of pollinator activity

Most cucurbit species (e.g., cucumber, pumpkin, bitter gourd) open their flowers early in the morning, with peak nectar production and pollen viability occurring soon after anthesis (54). Maximum bee visitation typically occurs between 06:00-10:00, coinciding with optimum temperature, moderate humidity and maximum nectar rewards. During this period, both nectar volume and sugar concentration are highest, making early visits more profitable for pollinators. For instance, the flowers are short-lived and the stigma remains receptive throughout the day, being most receptive in the early morning in cucumber. Flowers abort and drop from the vine if they are not pollinated during that time (50) (Table 3 and Fig. 2).

Native bee pollination

It was hypothetically said that pollination by native pollinators serves

Table 3. Major pollinators and their peak foraging activity periods in cucurbit crops

Crop	Pollinator	Peak activity time (hr)	References
Cucurbita pepo and *Cucurbita maxima*	*A. mellifera*, *A. dorsata* and *Bombus terrestris*	6-12 am	(55)
Watermelon	*A. cerana*, *A. florea* and *Melipona* sp.	8.30-10.30 am	(56)
	A. mellifera and *B. impatiens*	7-7.40 am	(30)
Cucumber	*A. cerana*	10 am-6 pm	(57)
	A. mellifera and *B. impatiens*	6-7 am	(30)
Bitter gourd	*A. dorsata*	5.30-6.30 am	(58)
Snake gourd	*A. dorsata*, *Vespa cincta* and *Trigona* spp.	6-8.30 am	(58)

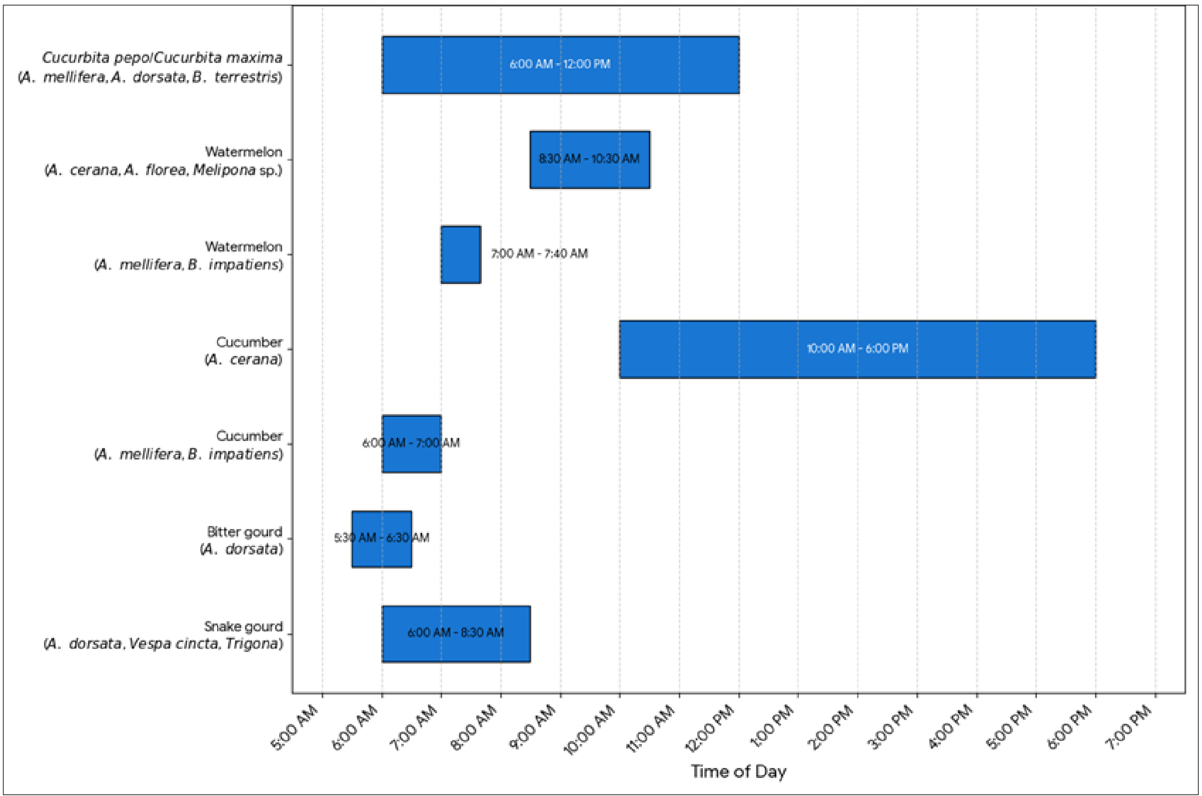

Fig. 2. Peak foraging activity periods of major pollinators in cucurbit crops.

as an efficient pollinator, as they belong to the particular region. Adaptation to that particular region by those pollinators makes the pollination activity easier. For instance, *A. dorsata*, *A. mellifera*, *A. indica*, *Halictus* sp., *Ceratina sexmaculata* Smith, *Vespa orientalis* Linnaeus, *Vespa auraria* Smith, *Megachile cephalotes* Smith, *Megachile bicolor* Fabricius (Family: Apidae), *Eumenes petiolata* Fabricius, *Eumenes dimidiatipennis* Sauss (Family: Eumenidae) and *Polistes hebraeus* Fabricius (Family: Vespidae) were recorded as native bee species in cucumber (59).

Among these, the pollination index of *Halictus* sp. was the highest (126537.60), followed by *C. sexmaculata* (121699.80) and *A. dorsata* (88678.20). Hence, it was recorded that *Halictus* sp. was the most effective pollinator, followed by *A. dorsata* and *C. sexmaculata* on *C. sativus* flowers under Hisar ecological conditions (Haryana) (59). Similar results were observed in *C. pepo*, where native pollinators like *Nomia* sp. and *A. dorsata* increased the overall fruit set percentage when compared to *Halictus* sp. (60). Bumblebee visitation significantly altered honeybee foraging behaviour on squash flowers. Honey bees avoided flowers occupied or recently visited by bumblebees and spent less time collecting resources where bumblebees were present. As a result, bumblebee abundance reduced honeybee activity on flowers. However, in habitats lacking bumblebees, honeybees increased their visitation - showing that bee interactions help maintain pollination resilience when one group declines (26).

Challenges faced and crop management practices to enhance pollination

The lack of pollination services is linked to a variety of challenges, including bad agricultural practices that have lowered the quantity of insect pollinators and jeopardised their foraging behaviour. The Intergovernmental Science Policy Platform for Biodiversity and Ecosystem Services (IPBES) conducted a global meta-analysis of their status and threats to pollinators and pollination, identifying intensive agriculture as a key issue. Farm management has a direct impact on the quantity and quality of pollinator feeding and nesting resources in agricultural fields (61) (Fig. 3).

Spraying insecticides during bloom can deter, harm, or kill pollinators. Avoiding application during peak foraging hours and using bee-safe formulations helps maintain activity (62). Companion planting of flowers like marigolds or sunflowers can support pollinator diversity and abundance, improving cucurbit pollination rates. Maintaining field margins, hedgerows and uncultivated patches provides habitat for wild pollinators, especially solitary bees (63). Sowing wild flowers along the crop edge has emerged as a potential management method because it allows alternative floral

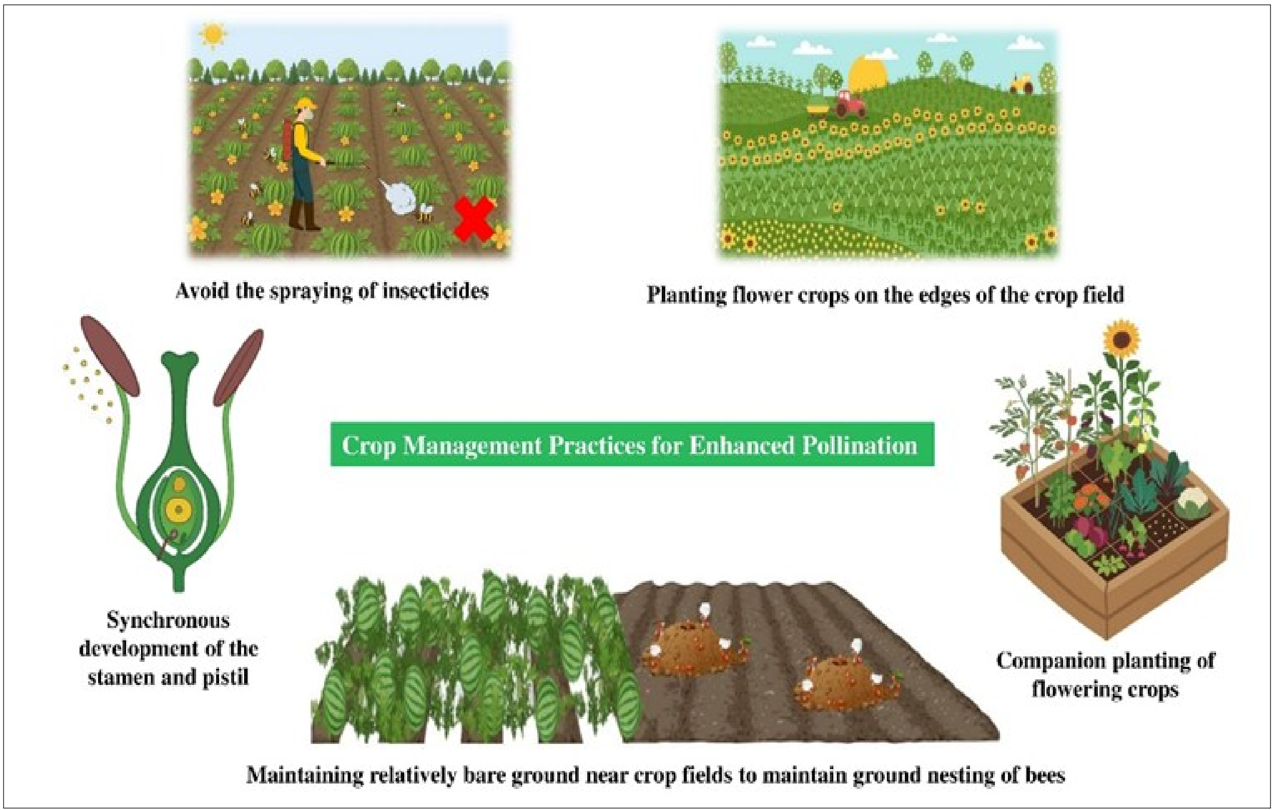

Fig. 3. Strategies for improving pollinator activity and crop pollination.

resources to be maintained for a longer period of time than multiple pollinating insects. Recent research has also shown that including flower patches can increase the abundance of pollinators, which can improve crop productivity in some orchards. For example, adding floral patches to pumpkins improved pollinator diversity, which increased seed set and sugar content (64). Many squash and pumpkin pollinators, including squash specialist bees like *Xenoglossa* spp., nest in the ground and require ideal nesting sites, which are often made up of rather bare, sun-exposed soil. Significant ground disturbance caused by methods such as tilling can affect bee emergence and abundance, while tillage does not always destroy existing nests (65, 66). Maintaining relatively bare ground in and near crop fields that is not subject to regular tillage can help to foster and sustain ground-nesting bee populations (67). Male and female flowers must blossom on the same day and in the same geographical area to pollinate squash and pumpkin. The ratio of male to female flowers is therefore a key determinant of pollination success. In some cultivars, skewed male-to-female flower ratios during the blooming period can occur. Planting various varieties in the same field can help to ensure that both sexes are present for pollination. While cross-pollination between varieties is not required for fruit set in squash and pumpkin, increasing the number of female flowers can enhance yields, provided there are sufficient male flowers to supply pollen (68). Female flower production can be stimulated through plant growth regulators application such as auxin and ethephon, or by pre-sowing treatments, such as soaking seeds in the garlic extract (68). However, excessively high female-to-male ratios can result in pollen limitation, reducing fruit set and yield (69). Thus, management practices should aim to maintain an adequate proportion of male flowers. Although bee attractants have been created to boost pollinator visitation, studies on comparable cucurbit crops such as watermelon and cucumber have indicated that these products do not significantly increase bee visitation rates or yields (70) (Fig. 1).

Conclusion

Pollination is an important aspect of cucurbit productivity, directly influencing fruit set, quality and economic returns. The heavy reliance of cucurbit crops on insect-mediated pollen transfer, particularly by bees, makes them highly susceptible to fluctuations in pollinator populations. Declines in pollinator abundance and diversity, driven by habitat loss, pesticide use, climate variability and emerging pests and pathogens, pose a tangible threat to global cucurbit production. The synthesis of existing evidence underscores the need for targeted conservation strategies, including habitat restoration, floral resource enhancement and pollinator-friendly pest management practices. Furthermore, identifying and promoting the most effective pollinator species for individual cucurbit crops is vital - for instance, *A. dorsata*, *A. florea* and *Halictus* spp. for cucumber (*C. sativus*); *A. cerana indica* and *Trigona* spp. for bitter gourd (*M. charantia*); *Xylocopa* spp. and *Amegilla* spp. for pumpkin (*C. moschata* and *C. maxima*); and *A. mellifera* and *A. dorsata* for bottle gourd (*Lagenaria siceraria*) and ridge gourd (*L. acutangula*). By integrating ecological insights into agronomic decision-making, growers can enhance pollinator activity, optimise yields and contribute to long-term agroecosystem sustainability. This review assures that safeguarding pollination services is not merely an ecological imperative but also a cornerstone for food security and the economic viability of cucurbit cultivation.

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Authors' contributions

MI collected literature, contributed to conceptualization and wrote the original draft. SMR was involved in conceptualization, literature collection and drafting and also reviewed and edited the manuscript. SA contributed to conceptualization, drafting and editing of the manuscript. SVR assisted in literature compilation and figure design. AJ contributed to figure design and layout development. JM participated in literature review and illustration design. BKS assisted in figure preparation and visualization. RAR contributed to the graphical presentation and refinement of figures. DDV assisted in literature organization and figure formatting. IA contributed to figure design and overall visual presentation. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflict of interests to declare.

Ethical issues: None

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