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***Review Article** (Open Access)*

# POLLINATION EFFICACY OF WILD MASON BEES (*OSMIA CORNIFRONS*) VERSUS MANAGED HONEYBEES (*APIS MELLIFERA*) ON FRUIT SET AND SEED COUNT IN HIGH-DENSITY APPLE ORCHARDS

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## ABSTRACT
World food production is affected by pollination deficits, particularly considering apple pollination, which has traditionally been relied upon almost entirely upon commercialized managed honeybees. But when large numbers of honeybee colonies are present, there are side-effects associated with the strong behavior of the honeybees that can contribute to other wild bee declines and orchards that become vulnerable during the period when other crops in the landscape have lots of flowers to attract the honeybees. This review attempts to describe and evaluate the efficacy of different solitary mason bee species (both domesticated and from the wild) relative to the efficacy of domesticated honeybees at the microenvironment level in contemporary high-density apple orchards. This review draws together data from literature to discuss the mechanical, spatial and ecological properties that affect fruit and seed set. These findings suggest mechanical and behavioral benefits to mason bees. Estrogen forced mason bees to forage actively at flowers; pollen was dragged and considerable contact made between stigmas and pollen; nectar-seeking honeybees bearing pollen on their bodies tend to drag at flowers, and pack wet pollen away for transport; masks are non-aggressive and do not sustain enough damage to be repairable. Mason bees forage actively for pollen and "top-work" the flowers; they make considerable contact between the stigmas and the pollen; nectar-seeking honeybees which also forage at the flowers tend to "side work" and bring home wet pollen still viable; masks themselves don't sustain enough damage to be mended. In spatial aspects, mason bee flight often zig zags between rows, providing the greatest pollen transfer between cultivars when a trellis is used, achieved by often non-straight flying mason bee, against the almost linear flying honeybee. Also, mason bees have a short foraging range and will focus on pollinating this orchard while honeybees will be able to go to the other crop in the community if the apple is not in bloom. Perhaps more importantly, mason bees are very climate resistant and contribute to the pollination of apple flowers during the time of the year when temperatures are cooler than other plants bloom most extensively, and when their light, wind and rain exposure is lower. Today's intensive farming system based on managed honeybees is contrary to increasing yields and not dependable. Orchard managers need to adopt several pollinator portfolios, especially for solitary bee species and encourage their populations with habitat and supplemental nesting to achieve numbers of fruits that are consistently abundant and resilient to climate change.

***Keywords**: Apple trees, Pollination deficit, Mason bees, Honeybees, Foraging behavior, High-density orchards, Climate resilience, Crop yield*

## INTRODUCTION
Pollination deficit is a limiting factor for the productivity of crops worldwide and apple crops are particularly dependent on insect pollination for adequate size and quality (Garratt et al 2021; Olhnuud *et*

*al.,* 2022). Managed honeybees (Apis mellifera) have been almost exclusively used in the past in intensive culture due to their several advantages, the high demand for pollinators and the extensive training led by beekeepers and growers in orchards, particularly grapevine, tomato, and strawberry crops (Hünicken *et al.,* 2022). For this reason, orchard practices have biased strategies aimed at the best possible use of the honeybee and at the maximum visitations of more flowers and fruit development that can be achieved.

More recent research, however, has revealed that wild bees can be very effective pollinators of apple, and can substantially reduce the common pollen shortages while generally being at least as effective as honeybees in the UK (Eeraerts *et al.,* 2025) and around the world. Increasing densities of managed honeybee hives have the potential to reduce the abundance of wild bees, species richness and ultimately to decrease fruit counts (Angelella *et al.,* 2021) and is now viewed with increasing suspicion. Further, honeybees may negatively impact on the foraging activity and community structure of wild bees in apple orchards (Garibaldi *et al.,* 2021; Li *et al.,* 2025). However, the assimilation of unique wild bee assemblages enhances the general provision of pollination services (Wu *et al.,* 2021) and stabilizes crop yields (Hünicken *et al.,* 2021). Wild pollinators can provide apple pollination when honeybees are drawn to other nearby crops that mass flower (Osterman *et al.,* 2021).

While the importance of wild pollinators is increasingly recognized, little is known regarding the performance of both types of wild (e.g., Osmia cornifrons) and managed honeybees in a high density apple orchard in a highly specialized system. While meta-analysis studies have already investigated the overall effect of managed pollinator species on crop productivity (Hünicken *et al.,* 2022), there is a strong need for more empirical research examining the specific impact of these two groups of species on yield (fruit set and number of seeds) under conditions of high-density planting.

The purpose of this study was to evaluate and compare the pollination capability of the wild pollinator, O. cornifrons and the managed honeybee, A. mellifera in terms of fruit and seed set in high density apple production. The goal of this review was to provide background information on these species, describe some of their differences and unique roles, and translate that information into strategies to increase our understanding of these species and make informed decisions for effective and lasting management in apples without relying on any one managed species.

**Foraging Dynamics in HDAs**

Applications of modern high-density apple orchard systems (e.g. tall spindles) involve more continuous rows of trees. This architectural modification influences the microenvironment and translucent different physical barriers and way lines that impact differently Apis mellifera and Osmia cornifrons foraging behavior.

**Movement and handling of rows to maneuver.**

In high density trellised rows, the physical set-up can be viewed as a "highway" system for the foray of these insects, and each species starts the jungle at a location somewhere on the "highway" that will immediately influence the efficiency of cross-pollination among the species.

The honeybees (Apis mellifera) are systematic and very efficient foragers. They are strongly inclined to "fly the rows", or fly between plants, when kept in high density, but not inclined to fly over top of the canopy or through dense trellis. Pollinator rows have traditionally been placed among single-cultivar rows with the result that pollinator visits between different cultivars are normally rather restricted, which impacts cross-pollination effectiveness. Also, where higher numbers of hives occur – a higher concentration of honeybees can cause behavioral interference to alter normal foraging behaviors in the canopy (Li *et al.,* 2025).

The flight pattern of Mason Bees (Osmia spp.) is much less predictable, and more erratic, darting off in various directions. Their trajectory is not necessarily in a straight line, row to row, but they tend to zigzag between rows. They are an erratic form of canopy navigation – functionality of which gives them exceptional cross pollination ability (Roquer-Beni *et al.,* 2021). The fine-scale foraging maneuvers they perform result in more pollen transfer/flower visit, relative to the main cultivar, due to the constant entrance and exit of pollinizer rows. The systematic movement between rows by honeybees and the jumping movement between rows by wild and managed solitary bees seems to be complementary in space, enhancing the overall fruit-set (Estravis-Barcala *et al.,* 2021).

Foraging plants were found and foraging range of harvester was determined.
Each pollinator will have a narrow focus on a particular orchard block or a wider focus into the landscape.

Extensive A. mellifera Flight Range: Honeybees can forage far from their hives and are large-scale, landscape-level foragers. This large working radius indicates that the visitation rate of a certain orchard to the honeybees in it could be highly determined by the orchard-level landscape configuration in addition to the orchard-level field-level management (Eeraerts *et al.,* 2022). If a swarm locates an orchard, most of the foraging bees can "decide" not to forage in the orchard but to go to another, more productive, source of food (which could be as far as a mile or more away).

Mason bees are more widely distributed than O. cornifrons and are central place and short range foragers. They forage over a small area and move away from the nest, at most, 300m. These restrictions on space make them wholly dependent on the local context and availability of flowers to make foraging decisions and achieve reproductive success (Jaumejoan *et al.,* 2023). The closer proximity that Osmia cornifrons fly makes the supplemental populations used in an orchard block do a greater amount of work pollinating the orchard trees (Hyjazie & Forrest, 2024).

**The abortion of the flower opposite other flowers (constancy (fidelity) of the flower).**
In apple orchards, there is a mass outburst of flowers but some other flowers, including dandelions (Taraxacum officinale), are also found nearby and many other regional crops like oilseed rape/canola (Brassica napus).

Target selection – the honeybees' choice is done based on the Energetic-Honeybees-Optimization of the colony. In his pollination ecology lectures, Osterman always gave frequent examples to illustrate the fact that if there are other very rewarding crops in the vicinity with great mass-flowering such as oilseed rape, the oriental honeybees will be busy in these and leave the apple blossoms, thus keeping the main working force away from the orchard (Osterman *et al.,* 2021, Steele *et al.,* 2022). This behavioural susceptibility can cause a reduction in orchard visits and significant pollination shortages if it is the sole orchard visited by honeybees and experiencing pollination (Olhnuud *et al.,* 2022).

Mason bees thus offer a missed ecological sponge that mitigates the effects of these changes in honeybee populations, the Solitary Bee Insurance Effect. Although Osmia species are polylectic and may follow other types of pollen if orchard conditions vary or the nesting gradient (Lu *et al.,* 2021), central place foraging means that they cannot leave the orchard block to seek out other regional pollen sources. Changing the feeding target away from the orchard by providing an attractive co-crop of maculatively flowering species has proven effective; only wild and other locally flowered "other" managed bees will be present on the orchard to pollinate and ensure fruit set of apples (Eeraerts *et al.,* 2025; Osterman *et al.,* 2021).

**The behavioral mechanics, flight scales, and ecological functions of modern high-density managed honeybees (Apis mellifera) and mason bees (Osmia spp.) are compared below.**

| **Foraging Dimension** | **Honeybees (Apis mellifera)** | **Mason Bees (Osmia spp.)** |
| --- | --- | --- |
| **Canopy Navigation & Row Movement** | **Linear/Systematic:** Strong predisposition to fly straight **down the rows**. They actively avoid flying over the top of the canopy or passing through dense trellises *(Li et al., 2025)* | **Erratic/Zigzagging:** Multi-directional flight pattern. They frequently **crisscrossed between rows** rather than remaining in a single straight line. *(Roquer-Beni et al., 2021)* |

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|---|---|---|
| **Cross-Pollination Efficiency** | **Lower Efficiency:** Because high-density blocks separate cultivars by rows, linear down-row movement minimizes the interaction points between different cultivars, reducing effective cross-pollination. *(Li et al., 2025)* | **Exceptional Efficiency:** Continuous fine-scale maneuvers between main cultivar and pollinizer rows maximize inter-cultivar pollen transfer. Overstocks complement honeybee patterns to maximize the total fruit set. *(Estravis-Barcala et al., 2021)* |
| **Crowding & Density Effects** | **Behavioral Interference:** High hive densities create massive, localized populations that cause counterproductive competition and disrupt normal canopy foraging patterns. *(Li et al., 2025)* | **Spatial Complementarity:** They fill the spatial gaps left by honeybees, navigating tight canopy spaces without experiencing the same linear crowding dynamics. *(Estravis-Barcala et al., 2021)* |
| **Spatial Foraging Scale & Radius** | **Landscape level:** Expansive, large-scale foraging radius. Flight paths can extend miles away from the hive structure to exploit optimal regional resource. *(Eeraerts et al., 2022)* | **Orchard-block Level:** Central-place, short-range foragers. Their active flight radius is tightly constrained and rarely exceeds **300 m** from their nesting sites. *(Jaumejoan et al., 2023)* |
| **Orchard Dependency Factors** | **Landscape-Driven:** Local orchard visitation rates depend heavily on regional hive densities and large-scale landscape configurations rather than farm-level management. *(Eeraerts et al., 2022)* | **Locally Driven:** Foraging choices and reproductive success are entirely bound to immediate farm-level floral availability and local habitat context. *(Jaumejoan et al., 2023)* |
| **Target Tree Concentration** | **Volatile Allocation:** The bulk of the orchard's foraging workforce can rapidly pivot away from target trees if a superior resource patch is present in the broader landscape. *(Eeraerts et al., 2022)* | **Intensely Concentrated:** Providing local supplemental nesting structures within an orchard block focuses the pollinators' intensive efforts on the targeted trees. *(Hyjazie & Forrest, 2024)* |
| **Fidelity to Apple Bloom** | **Resource-Driven Alternation:** Low absolute constancy; foraging targets shift dynamically based on colony-wide energetic optimization algorithms. *(Osterman et al., 2021; Steele et al., 2022)* | **Spatially Constrained Constancy:** High operational constancy to the orchard block. Although polylectic by nature, they remain dedicated to local apple blossoms because of spatial limits. *(Lu et al., 2021)* |

| | | |
|---|---|---|
| **Response to Competing Flora** | **"The Honeybee Diversion":** Readily abandoning apple blossoms to seek out more rewarding mass-flowering regional co-crops (e.g., oilseed rape/canola), inducing orchard pollination deficits. *(Olhnuud et al., 2022; Osterman et al., 2021)* | **"The Solitary Bee Insurance Effect":** Provides an ecological buffer. Their short-range limits prevent them from escaping to distant co-crops, anchoring them to apple flowers. *(Eeraerts et al., 2025; Osterman et al., 2021)* |

**How pollen is transferred from flower to flower.**

The mechanism of pollination; how pollen is moved from flower to flower.

Copulation behaviors and morphology of bee species are discussed in terms of successful pollen transfer with the physical and morphological interactions of apple flowers and bees.

**Conduct real behaviors on the flower.**

A pollinator's foraging behavior at each flower is critical for the successful pollination of a flower.

Pollen collection by honeybees (Apis mellifera): Honeybees do not typically collect pollen—they typically collect nectar; this is a relatively rare occurrence. As they do so they will have learned to work around the peripheral nectarines of the apple blossom—known as working the side—exposing them to activities which they will be able to repeat with greater efficiency on their own. This allows them to draw nectar and to completely avoid pollination, thus limiting their pollination efficacy per visit.

Solitary wild bees, including mason bees (Osmia spp.), go out and actively search for pollen, on the other hand. The "top working", or "scrabbling" is a characteristic mode whereby they dive straight down into the middle of the flower. This is (is meant to ensure) physical contact to the flower reproductive structures. This is important because it is related to the pollination services provided to plants. Roquer-Beni *et al.,* (2021) demonstrated that wild bees' physical foraging activity vastly outcompeted honeybees' physical foraging activity in pollinating apples. Unlike domestic bees, wild bees do not side-work flowers and make much more positive contribution per visit to crop yields (Garratt *et al.,* 2021; Geeraerts *et al.,* 2025).

**Pollen Carrying Capacity**

Since the evolution of the pathways in each species that transports pollen, the quantity of pollen available for cross-pollination is radically altered.

Wet Pollen and Corbiculae (Honeybees): Honeybees are geared to carry large quantities of resources to a large colony. They also abmix pollen with nectar and saliva and pack it into pollen baskets, which are special structures with the hind legs of the pollen bearers (corbiculae). Once the pollen is mashed into this compact, juicy lump can be transported safely, but when the bees do forage after, the pollen is for the most part concealed and inaccessible for getting onto a stigma.

Mason Bees (Dry Pollen and Scopa): Mason Bees are a member of the Family Megachilidae and they have entirely different anatomic mechanisms. They gather their pollen dry and it is sparsely stored in the numerous hairs on the abdomen known as the scopa (Lu *et al.,* 2021). The pollen is not tightly compacted and lies loose at the base of the abdomen and is readily dislodged. The scopa acts like a dust mop as the mason bee hovers above the flower and dry pollen is brushed against the sticky stigma. These morphologic traits are important for the adequate pollination of the apple orchard in closely planted trees (Roquer-Beni *et al.,* 2021).

**Stigmatic Contact Rates**

Pollen-carrying apparatus and flower-handling behaviors are a direct determinant of actual pollen deposition per visit.

Figuring out the difference: In many flowers that are visited by a honeybee, any pollen loaded onto the legs by 'side-work' or by the carry-over effect of wet pollen on its legs will likely be lost so that the true percentage of flowers that actually end up with pollen is low. The in the collective world experiments and analyses of apple pollination research, there is an attempt to quantify that whilst the honeybee visitation per apple is quite high, the absolute number of successful pollen placements by wild bees is much higher and the pollen limitation is therefore alleviated far more effectively than by managed honeybees (Eeraerts *et al.,* 2025; Olhnuud *et al.,* 2022).

Very small stigmatic contact times have been observed among honeybees that visit the flowers and the low visitation frequency cannot be compensated. In fact, honeybee frequent foraging can paradoxically cause a decrease in the effectiveness of the Neonictot Worker bees due to the high density of honeybees and cause less successful pollen deposition into the orchard, ultimately to reduce the fruit set (Li *et al.,* 2025; Magrach *et al.,* 2025).

| **Pollination Mechanic** | **Honeybees (Apis mellifera)** | **Mason Bees (Osmia spp.)** |
|---|---|---|
| **Primary Foraging Goal** | Typically, nectar is harvested rather than pollen. | Actively seeks and collects pollen. |
| **Flower Handling Behaviour** | **"Side-working":** Reaches nectarines from the side, bypassing the flower's reproductive organs. | **"Top working" / "Scrabbling":** Dives straight into the centre of the blossom. |
| **Physical Stigmatic Contact** | Low contact rate: Completely avoids pollination structures during nectar extraction. | A high contact rate guarantees physical friction against the flower's reproductive organs. |
| **Anatomical Storage Structure** | **Corbiculae:** Specialized pollen baskets located on the hind legs of bees. | **Scopa:** Abundant and dense hairs located on the underside of the abdomen (Lu *et al.,* 2021). |
| **State of Carried Pollen** | **Wet:** Mixed with nectar and saliva and then tightly compressed into a dense pellet. | **Dry:** Collected dry and packed loosely into the abdominal hairs. |
| **Transfer Efficiency Mechanism** | Locked away for transport, mostly hidden and unavailable for brushing onto subsequent stigmas. | Scopa acts like a "dust mop," easily dislodging and dragging dry pollen across sticky stigmas. |
| **Per-Visit Deposition Rate** | A low percentage of visits resulted in profitable stigmatic contact and successful pollen deposition. | Vastly higher rates of successful pollen deposition per visit (Eeraerts *et al.,* 2025; Olhnuud *et al.,* 2022). |
| **Impact on Crop Yields** | High densities can cause interference, lowering successful deposition and fruit set (Li *et al.,* 2025; Magrach *et al.,* 2025). | Superior physical foraging behavior translates to highly positive contributions to crop yields (Eeraerts *et al.,* 2025; Garratt *et al.,* 2021; Roquer-Beni *et al.,* 2021). |

**Resilience and Foraging Thresholds in the Context of Climate Change**

The weather in April is more marginal, volatile and a time when apple blooms tend to occur. Weather conditions during and after flowering and competitiveness (to fly in suboptimal weather) are important factors that influence fruit set.

**Temperature Thresholds**

Thermal biology is one of the factors bees use in evaluating whether it is safe or not to leave the nest for foraging. Some species of these cannot work at the early spring temperatures.

Managed Honeybees: Relatively warm temperatures and in clear sunny weather, the honeybees get in the mood to forage on a colony-wide scale. They have a huge energetic cushion to play with in the form of a large colony and stocks of gathered nectar in the form of honey, which means that they can sit tight on cool or sodden spring mornings when it matters less.

Mason Bees (Osmia spp): Mason bees are unique in their adaptation to thermal conditions of their environment, that is, they can operate at ambient temperature and light intensities lower than those of most other bee species. Osmia spp. exhibit narrow timing for emergence, survival, and development that is like early spring climate (Scalici *et al.,* 2023). They will suit different climatic niches to those of the honeybees and can offer much climatic niche complementarity when included in the orchard. Mason bees also are much more active in the canopy than honeybees when it is too cold to fly, supplying continuous pollination services (Durrer *et al.,* 2025).

Note: Mason bees are excellent winter foragers but as pollinators managed in new and changing climates, the thermal sensitivity of the species as well as influences of extreme temperatures (Song *et al.,* 2023) are continuously monitored to ensure their survivability.

**Wind and Precipitation**

In high density orchards, spring weather with high winds and heavy cloud cover, coupled with light rain which lowers the insect flight potential, is often present.

Honeybee Flight suppression: Honeybee's do not like wind and rain. The rain, even if light and it's a windy day, will make A. mellifera stop all foraging. If apples are not under forced and a few days under HBB weather occur on the peak pollination day, serious fruit drop may occur.

Solitary bees—including Osmia—have a short and critical window of time that they must forage to provision their nests—typically a few weeks. I can't wait and wait for the weather. As a result, they are still out gathering food in light rain and high winds. One of the most important arguments for promoting using different species of insects including solitary and wild bees, is this natural stability of the environment, providing pollinator-dependent crops highly valued by growers, such as apple, a protection against adverse weather conditions in the spring (Hünicken *et al.,* 2021). Further, good habitat conditions locally for these species are known to strengthen the climate resilience of the overall pollination service these species provide (Durrer *et al.,* 2025).

Here is a table that detailed-grants a comparison between the climate resilience and foraging thresholds of the managed honeybee and mason bee, based only on the data provided in the information.

**Climate Resilience and Foraging Thresholds: Honeybees vs. Mason Bees**

| Environmental Factor | Managed Honeybees (Apis mellifera) | Mason Bees (Osmia spp.) |
|---|---|---|
| **Temperature Requirements** | Relatively warm temperatures are required to initiate colony-wide foraging. | They have adapted to function at much cooler temperatures, matching early spring climatic conditions (Scalici *et al.,* 2023). |

| | | |
|---|---|---|
| **Light Level Sensitivity** | They prefer clear, sunny weather to forage effectively. | They possess specific adaptations that allow them to fly at lower light levels. |
| **Wind and Precipitation** | Highly sensitive; foraging is completely suppressed during light rain and windy conditions. | Environmentally competitive; continues to forage through light rain and higher winds. |
| **Foraging Motivation & Urgency** | Low urgency; relies on a huge "energetic cushion" (stored honey/large colony) and can afford to sit out bad weather. | High urgency: face a limited, critical time window (a few weeks) to provision nests and cannot afford to wait out bad weather. |
| **Impact on Apple Yield** | Sole reliance on marginal peak bloom weather can lead to serious pollination deficits and fruit drop. | It significantly improves yield stability, protecting growers against poor spring weather (Hünicken *et al.,* 2021). |
| **Climatic Niche Role** | They leave pollination gaps during cool, sodden spring mornings when they remain in the hive. | Provides "climatic niche complementarity," moving in the canopy when honeybees are too cold to fly, ensuring uninterrupted service (Durrer *et al.,* 2025). |
| **Climate Change Vulnerability** | *Not specified in the provided text.* | Sensitivity to rapid climate change and thermal sensitivity (e.g., excessive heat) require continuous monitoring to ensure viability (Song *et al.,* 2023). |
| **Response to Habitat Enhancement** | *Not specified in the provided text.* | Improving local habitats directly reinforces the overall climatic resilience of the pollination services they provide (Durrer et al. 2025). |

## CONCLUSIONS

In this review the need to change pollinator paradigm to high density apple orchards is emphasized. The examined products reveal that managed honeybees (Apis mellifera) have been the traditional crop pollinator but are similarly undisturbed less efficient per-visit at source and highly susceptible to environmental and landscape alterations. Wild and managed solitary bees on the other hand, mason bees (Osmia cornifrons) and mason bee spp., are also good foragers on apple and have functional traits that make them effective pollinators.

**There are 3 main learning points.**

Mechanical and Behavioral Superiority: Mason bees top-work and carry free, dry pollen on their abdominal scopa, so that rates of stigmatic contact are high. Wet pollen is frequently carried by honeybees in their corbiculae, though usually the pollen is not deposited in the nest, as they are instead visiting flowers for nectar (Roquer-Beni *et al.,* 2021; Eeraerts *et al.,* 2025).

Spatial and Architectural Complementarity: In trellised orchards of high density, honeybees' linear flights reduce the chance for the pollination of alternate cultivars. This pollen exchange (by Mason bees) is dynamic between cultivars (inter-cultivar pollen exchange) with bees crossing rows. They are additionally characterized by limited foraging range which means that they focus their pollination efforts on the orchard targeted, while honeybees can be diverted by the huge amounts of flowers produced by other crops, such as oilseed rape (Osterman *et al.,* 2021).

Climatic resilience of honeybees due to marginal weather (cold, rainy, windy), mason bees forage in all weather conditions, low temperatures and light. This is required to insure yield during the short flowering time of apples in early spring (Durrer *et al.,* 2025; Hünicken *et al.,* 2021).

The field application of large number of managed honeybees is an obsolete, inefficient and in some aspects counterproductive practice, particularly if it affects fruit set due to competition and behaviour problems (Li *et al.,* 2025). As the spring weather becomes more unpredictable with climate change (Marshall *et al.,* 2023) and the farming landscape becomes more fragmented, orchard managers will need to become accustomed to and accepting of pollinator diversity. To exploit the "insurance effect" of solitary bees, growers can invest in enhancing local habitat and can provide supplemental localized nesting sites for cavity nesting bees and exposure to fewer pesticides. Concurrently and/or synergistically using Osmia species with intensive honeybee stocking will be important in sustainably producing high yield and resilient fruits for the future.

**List of Abbreviations**

- **A. mellifera:** *Apis mellifera* (European Honeybee)
- **B. napus:** *Brassica napus* (Oilseed rape / Canola)
- **DNA:** Deoxyribonucleic Acid (used in metabarcoding studies to track pollen diets)
- **IPM:** Integrated Pest Management
- **O. cornifrons:** *Osmia cornifrons* (Japanese Horn faced Bee / a species of Mason Bee)
- **O. excavata:** *Osmia excavata* (A species of Mason Bee)
- **O. lignaria:** *Osmia lignaria* (Blue Orchard Bee / a species of Mason Bee)
- **spp.:** Species pluralis (Multiple species within the specified genus, e.g., *Osmia spp.*)
- **T. officinale:** *Taraxacum officinale* (Common Dandelion)

**Declarations**

Ethics approval and consent to participate were obtained from all participants.
Not applicable. This is an article type Review manuscript which is a collective work based on previous works. The authors do not have any original study involving humans or animals for this article.

**Consent for publication**

Not applicable. This manuscript contains no personal information, images or video material.

**Data and Materials availability:**

The data that was used for this study did not reveal any new datasets. All information and conclusions are based on those of published, peer reviewed literature in the references section and were obtained from publicly available sources.

**Competing interests**

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**Authors' contributions**
The author(s) carried out literature review, underwent information consolidation, manuscript writing and prepared a comparative analysis. The author(s) declares that the work has been read and approved by all the authors.

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