BREEDING MASON BEES FOR THE POLLINATION OF FRUIT ORCHARDS IN CENTRAL EUROPE

MARTIN ŠLACHTA[1,*], ALENA VOTAVOVÁ[2], TOMÁŠ ERBAN[3], ONDŘEJ CUDLÍN[1], and PAVEL CUDLÍN[1]

[1] Department of Ecosystem Functional Analysis of the Landscape, Global Change Research Institute of the Czech Academy of Sciences, Lipová 1789/9, 370 05 České Budějovice, Czech Republic
[2] Research Institute for Fodder Crops, Ltd. Troubsko, Zahradní 400/1, 664 41 Troubsko, Czech Republic
[3] Crop Research Institute, Drnovská 507/73, 161 06 Praha 6 – Ruzyně, Czech Republic
* Corresponding author: slachta.m@czechglobe.cz

ABSTRACT

Solitary bees pollinate wild plants and crops. In the temperate zone, they mainly pollinate fruit trees. Most species nest in the soil, but mason bees nest in wooden cavities above ground. Their presence in orchards can be augmented by provision of artificial nesting sites. Two species of mason bees frequently use these artificial nesting opportunities in Central Europe. The red mason bee (*Osmia bicornis*) is the most common species in this region, which preferentially collects pollen from oak trees. The European orchard bee (*Osmia cornuta*) prefers pollen from fruit trees, but it is more thermophilic. Its spread to higher altitudes can be expected in response to climate change. A breeding technology based on detachable wooden nests is summarized in this paper based on a literature review and experimental experience in fruit orchards in Czechia.

Keywords: artificial nesting sites; climate change; fruit orchards; mason bees; pollination

Introduction

Insect pollination supports the production of many agricultural commodities and solitary bees contribute significantly to this pollination service (Garibaldi et al. 2013; Pardo and Borges 2020). Their role is important, especially in fruit production (Mallinger and Gratton 2015; Blitzer et al. 2016). In England, the share of solitary bees in apple tree pollination is estimated at 54–58% (depending on apple variety). For honeybees, this percentage is only at 23–28% and for bumblebees 13–38% (Garratt et al. 2016). Solitary bee communities are dominated by species nesting in the ground in nests up to several tens of centimeters deep (Mallinger and Gratton 2015; Blitzer et al. 2016; Garratt et al. 2016). Less frequent, aboveground nesting bees' nest in cavities in wood or other material. Mason bees (*Osmia* sp.) and leafcutter bees (*Megachile* sp.) nest generally in cavities made by wood boring beetles. The females collect pollen on well-developed hairs on her legs (ground-nesting bees) or ventral part of abdomen (aboveground nesting bees, Macek et al. 2010).

In the USA and Japan mason bees have been used for pollinating fruit trees since the middle of the last century (Bosch and Kemp 2002; Sedivy and Dorn 2014). Alfalfa leafcutting bee (*Megachile rotundata*) pollinates lucerne in the USA and in Canada. Fruit trees (almonds, apples, cherries) in the USA are pollinated by *O. lignaria, O. cornuta* (imported from Europe) and *O. cornifrons* (imported from Japan). In Japan, *O. cornifrons* pollinates most apple trees. It is also used to pollinate blueberries in commercial plantations in the USA. In the southern USA, *O. ribifloris* is bred for this purpose (Sampson et al. 2004; Mader et al. 2010; Sedivy and Dorn 2014). In Europe, the possibilities of using the red mason bee, *O. bicornis* (Linnaeus 1758) (syn. *rufa*), **RMB** and the European orchard bee, *Osmia cornuta* (Latreille 1805), **EOB** (Bosch and Kemp 2002; Krunic and Stanisavljevic 2006) for pollinating fruit trees has been investigated.

At the individual level, mason bees are more effective pollinators than the honeybee (*Apis meliffera*). They only need to visit a flower once for the effective pollination because they approach flowers from above and thus always come into contact with the flower's genitalia. In contrast, honeybee workers can collect nectar among the petals without coming into contact with pollen. Moreover, mason bees fly more often between individual trees and between rows of trees, which is important for cross-pollination, especially of apple and cherry trees. Mason bees can be easily bred, as they readily nest in large colonies and are willing to colonize artificial nests (Bosch and Kemp 2002; Sedivy and Dorn 2014). They are not aggressive and their stings are not as painful as those of honeybees or bumblebees are. They generally do not forage for food further than a few hundred meters from nests (Zurbuchen et al. 2010; Hofmann et al. 2020) and are thus better for targeting the pollination of a particular crop. The disadvantage is that they nest for only a few weeks each year.

The choice of the best species for fruit pollination has to take into consideration both its bionomy and habitat preferences. We review the bionomy of RMB and EOB. Their breeding in detachable wooden nests (Bosch and Kemp 2002; Krunic and Stanisavljevic 2006; Sedivy and Dorn 2014; Macivor 2017) was tested in fruit orchards

Šlachta, M., Votavová, A., Erban, T., Cudlín, O., Cudlín, P.: Breeding mason bees for the pollination of fruit orchards in Central Europe
European Journal of Environmental Sciences, Vol. 12, No. 1, pp. 16–20
https://doi.org/10.14712/23361964.2022.2

in Czechia (latitude 49–50° N) in 2018–2021. Resultant experience is summarized in the following text.

Bionomy of two species of mason bees

Both RMB and EOB are common species in Central Europe. EOB is more thermophilic and occurs mainly in lowlands in Czechia (Macek et al. 2010). Both species overwinter as adults in cocoons in their nests. In the spring, males hatch first and females a few days later. After copulation, the females establish nests in cavities in wood. Females build nests without the help of a male. They prefer holes with a diameter of 6–8 mm. They are not able to make holes in wood, so they generally use the tunnels bored by wood boring beetles or holes in wooden buildings, window frames, or walls and bricks. In cavities, they build linear nests consisting of a series of brood cells separated by partitions. The partitions are made of mud (mason bees) or pieces of leaves (leafcutter bees). One individual develops in each brood cell. The female supplies pollen mixed with nectar to each cell and lays an egg on it. The nectar is collected from a variety of sources and is combined with pollen while foraging for food. It lays an egg on the pollen mass and then closes the cell. If the weather is suitable and food is available, it takes about a day to build one cell. In order to confuse parasites the last cells are empty. There is usually 1–2 empty cells, each about 1 cm long. The nest is then closed with a massive stopper made of mud. Within one nest, females first lay female eggs, then only male eggs, which makes it easier for them to leave in spring. The female does not take care of the nests after sealing it and dies after a few weeks. The larvae turn into prepupa at the beginning of summer and remain in this stage until late summer, when they pupate. Adults hatch in October at the latest, but remain in the cocoon until spring. The cocoons of both species are different and can be distinguished. Female cocoons on average tend to be larger than male cocoons (Bosch and Kemp 2002; Krunic and Stanisavljevic 2006; Sedivy and Dorn 2014).

RMB is a polylectic species (i.e. it develops on pollen from various plant families), but usually collects pollen from oak or buttercups (Raw 1974; Persson et al. 2018; Šlachta et al. 2020). If oak is not available, it chooses blackberry (Raw 1974) or rapeseed (Holzschuh et al. 2013). It generally collects nectar from rapeseed, chestnut, maple, willow, fruit trees and *Rosaceae* plants (Jauker et al. 2012) as oak does not provide nectar. During foraging for pollen, the female first visits the sources of nectar, then sources of pollen (Raw 1974). Although it successfully develops on rapeseed pollen, this is not the preferred source of pollen (Holzschuh et al. 2013).

EOB is also a polylectic species, which focuses on collecting pollen from *Rosaceae* (Marquez et al. 1994) and is therefore being tested in southern Europe as an alternative pollinator of fruit trees (Sedivy and Dorn 2014). It also forages for pollen from *Brassicaceae* and develops successfully on pollen of *Sinapis arvensis*, for example. It mixes pollen from a variety of sources. Some females collect pollen from up to six plant families (Eckhardt et al. 2014). In addition to fruit trees, it also collects pollen from willows and oaks, depending on their availability around nests (Kratschmer et al. 2020).

Artificial nesting sites

Mason bees are willing to nest in reed stalks. Installing reed bundles stored in plastic pipes or covered shelters as protection against water is one way of increasing the range of nesting opportunities in orchards. Such nests are spontaneously inhabited by local populations or it is possible to buy cocoons with wintering adults in cocoons via online websites. The cocoons can then be stored directly in the nests to increase the chances of their being used. The disadvantage of reed stalks is the impossibility of regulating the number of parasites in the finished nests. There is also a high probability of attacks by insectivorous birds, which can be avoided by using wire mesh to prevent their access to nests.

A more suitable solution is to use detachable wooden nests. They consist of a set of wooden boards with grooves, which when placed together create a nesting cavity. These boards can be obtained from online suppliers or can be made by a carpenter. The boards must fit tightly together and not twist when wet so that parasites cannot enter the nests through the gaps. The cocoons can be removed from the nests at the end of the season and overwintered for use next year. This reduces the incidence of parasitism, as the parasites can be sifted out. The coccons can be kept in a small space, for example in a refrigerator, and the emergence of the bees can be delayed and synchronized with the flowering of the targeted crop. Parasitism is a major problem and cannot be completely eliminated, without the continuous control of the occurrence of parasites as they commonly occur in the wild and will always eventually find bee nests.

We experimentally verified that bees nest in cavities with diameters from 6 to 10 mm, but 8 mm is the most suitable. Although bees are able to nest in cavities with a square cross-section, a rounded cross-section is much more attractive, either circular or semi-circular (width 8 mm, length 8–10 mm). A board size of 15 cm (width) × 22 cm (length) proved to be suitable. Such long nesting cavities allow for the construction of up to 18 cells in a row, which saves bees the time spent establishing new nests. In longer cavities (over 15 cm) bees build relatively more cells with females than in shorter cavities (under 15 cm; Sedivy and Dorn 2014). The width of the cavity has a similar effect: there are more cells with females in wider cavities. With a cross-section of 8 mm, the female chambers make up about 30% of the total (Sedivy and Dorn 2014). The boards we used contained 8 nesting cavities of semicircular shape with a width and length of 8 mm and gaps between the cavities also with a width of 8 mm. One group of 7 nesting boards thus contained 48 nesting cavities. Although such a high density of nesting holes made it difficult for bees to find a particular nest, it was not a major problem as females eventually find their nest. However, for less intensive breeding, it is recommended that there are gaps of a few centimeter between the nesting cavities for easier orientation of the nesting females.

An important factor that influences the success of occupation is the choice of a suitable place for artificial nest sites. Mason bees prefer places with unshaded free access with an entrance oriented ideally to the southeast. They should be protected from the wind (usually from the northwest) and conspicuously located so that it is easy for bees to find them. It is advisable to use the wall of a building or another significant landmark (fence or edge of a group of trees) and place the nesting site in front of it. In orchards, fencing around the orchard can usually be used, i.e. a few meters from the nearest rows of trees, where they are thus better protected against pesticide sprays and well visible to bees. Visibility is further enhanced by painting the nest sites blue and locating the nests about a meter above the ground. In orchards where there is abundance of pollen and nectar, bees fly a maximum of 50–150 meters (Sedivy and Dorn 2014).

Some of the released bees do not nest in the nest in which they were released, and look for other nesting opportunities in the area. Therefore, in order to increase their abundance, there should be many nesting sites distributed throughout an orchard. An important part of their nests are the partitions between the brood cells and the plugs closing the nests. Mason bees build them from mud, which they collect near to the nests, for example from dirt roads. The mud must be moist. Providing this material close to the nest site, or digging up the turf and occasionally pouring water on the exposed soil, will save bees time spent finding suitable material and speed up the construction of nests.

Management of the artificial nests

At the end of the season, the artificial nests can be moved from the orchard to covered areas. It is best to wait until the end of June, as they should not be moved during the first few weeks after the nests are completed so that the larvae inside brood cells do not lose contact with the pollen reserves. In June, however, they are already large enough not to be at risk when moved in nests. The best time to open the nests and remove the cocoons is October, when they will have completed their development and the temperatures are favourable for drying the cocoons and artificial nests, which are mechanically cleaned and stored in a dry place until spring. It is also possible to chemically treat them against mould. However, it is advantageous to preserve the natural scent of the nests, because bees prefer such scented places for nesting. The smell is produced by the fatty acids contained in the cocoons. Due to the fact that the cocoons are relatively resistant to mechanical damage, they can be removed from the nests very quickly. A blunt tool with a diameter of 6 mm (screwdriver) can be used to push the contents of the nesting cavities along their entire length into a container. The mixture of cocoons, remnants of partitions and parasitized cells is then sieved through an 8 mm sieve. This separates the cocoons from impurities and parasites (parasites inside cocoons, however, escape attention). In addition, the cocoons can be cleaned of dirt using running water and then dried. However, this is not necessary.

Cocoons can be stored in large numbers during the winter in ventilated containers in which the air humidity is 65–90%. For example, paper boxes are suitable. Boxes with small holes for ventilation remain sufficiently moist for survival throughout winter. Storage is possible outdoors or in a refrigerator at a temperature of 2–4 °C. In spring, cocoons must be transferred to artificial nests at least one week in advance of the expected flowering of the fruit trees. Emergence from cocoons can be delayed by keeping them at 2–4 °C in a refrigerator. The second option is to transfer the cocoons to artificial nests at the end of February and let them hatch spontaneously. In the wild, EOB emerges from cocoons at the end of March and RMB in the second half of April. At temperatures around 20 °C, EOB emerges in a few days, especially if overwintered at a temperature higher than 4 °C, otherwise they do not emerge quickly and await more favourable temperature conditions. RMB behaves differently. It remains in the cocoons for two to three weeks, even under suitable temperature conditions. In a refrigerator (at a temperature of up to 4 °C), it is possible to keep them in cocoons until the summer.

In both species, the males hatch first and then after a few days the females. In good weather, they warm up and fly around the nest. At night, they return to their nests and look for suitable cavities. Females do not start nesting immediately as they need to acclimatize and start metabolic processes. They prefer to nest close to other nests and are attracted by the smell of cocoons. Thus, by inducing a small number of bees to nest one to two weeks before the transfer of the main population, as this will attract them to nest. A prerequisite is the availability of alternative food sources until the fruit trees bloom, e.g. willows. A large number of females will fly away to look for new nest sites, but by placing nests around an orchard, it is possible to keep them in the orchard.

Enemies

Cleptoparasites (nest parasites) are the most serious threat to mason bees in artificial nests. They feed on the food supplies of their hosts. A very common kleptoparasite is the Houdini fly (*Cacoxenus indagator*). This little fly with distinct red eyes penetrates into unfinished nests and lays eggs in the brood chambers and their larvae eat the pollen supplies. There can be up to about 20 larvae in one chamber. In this case, the bee larva has no chance of completing its development. In addition, young larvae are able to bite through the partition into the adjacent chamber if they do not have enough food. We usually see the adults near nests under construction, where they remain at the edge of nests until the bees leave the nests to forage for food at which time they enter the nests. Invasion of chambers by this fly is easily detected when the nests are opened in autumn as they contain conspicuous larval faeces in the form of long yellow fibers. Autumn sifting of cocoons gets rid of these larvae. Due to the small size of this fly, another preventive measure is to place adhesive tapes near the nests at the time of nesting. However, this method is not very effective.

Another kleptoparasite is the mite *Chaetodactylus osmiae*. It feeds on pollen in the nests and can multiply in the brood chambers so that they completely fill them. The life cycle, which consists of the development of the egg, two nymphal stages and the adult, can be completed up to ten times a year. Subsequently, some nymphs enter a resting stage called a hypopus, which are able to survive for several years without food. This resting stage takes two forms: mobile form, with four pairs of legs with claws to attach to adult bees, which transfer them to new nests, and an immobile form, without such legs. In contrast, they wait in the nests for new bees to repopulate them. Due to the small size of these resting stages, it is very difficult to get rid of them in artificial nests. They adhere to both boards and cocoons. In cases of severe parasitism, it is better to dispose the infested artificial nests. Otherwise, chemical protection (acaricides) can be applied, even directly to cocoons. *Monodontomerus obscurus* is a parasitoid whose larvae feed directly on bee larvae. Multiple larvae usually parasitize one bee, which eventually dies. This wasp uses its long ovipositor to lay eggs in its prey by penetrating the wall of nests in reed stalks, but finds it difficult penetrate the walls of artificial nests and rarely attack these nests. They search for their prey by smell. Wasp larvae eat the bee larva gradually and only kill it after it pupates and produces its cocoon in the host's cocoon. They can leave the nest in the same year if the temperature conditions are favourable or they overwinter in a cocoon. After leaving a cocoon, a small hole remains visible, as well as in the lid (and partitions), where they left the nest, or in the reed wall, through which they can bite directly. If wasp larvae overwinter in a cocoon, their presence can go unnoticed. In spring, however, it leaves nests in June, i.e. later than the mason bees. This makes it possible to get rid of them by removing non-hatched cocoons from the nests before June.

Another parasitoid of the mason bees is the *Anthrax anthrax*, which is a black fly, larger than the Houdini fly. The female flies into the entrance of nests and uses her abdomen to inject clay-coated eggs into the entrance. Mobile first instars called planidia hatch from these eggs and penetrate into the depths of the nest. There, they feed first on pollen and nectar and then on the larva of the bee, but they do not weaken it too much, so that it is able to form a cocoon and eventually pupate. Only then, they kill their host and produce their cocoon in its host's cocoon. The pupa has a crest of thorns on its head, which it uses to emerge from the bee's pupa and subsequently also from the nest, damaging all the chambers along the way and killing the bee larvae in them. This can significantly damage nests. An adult fly hatches from the pupa, and pupal exuvie can be found at or near the nests.

Also cuckoo wasps (*Chrysididae*) act as parasitoids of mason bees. However, they occur relatively rarely and do not pose a great threat to mason bees in artificial nests. The nests can also contain skin beetles (*Dermestidae*), whose larvae feed on residues of organic matter and do not pose a danger to bees. We have not noticed any problems with the ants either. Mason bee larvae can be infested with a fungal pathogen of the genus *Ascosphaera*, similar to honey bees. We did not have a problem with this pathogen in artificial nests, which must be thoroughly disinfected if this pathogen is detected. There is no other disease recorded for mason bees. During the wetter seasons (autumn, winter), organic residues in nests or wintered cocoons can be attacked by mould. In this case, it is advisable to treat artificial nests with an antifungal agent and dry them at a high temperature. Mould should not be present when the plates are stored disassembled, sufficiently dried and in a dry environment. To treat cocoons infested with mould, it is sufficient to dry them at high temperatures; the mould does not endanger bees inside cocoons.

Nests can be attacked by the beetle *Trichodes apiarius*. Adults feed on pollen and nectar and lay eggs on flowers or in artificial nests and their surroundings. On hatching their larvae enter bee nests and eat both pollen and bee brood. They eat the contents of one chamber after another until they destroy an entire nest. They remain in the nest and overwinter in the prepupal stage and pupate in spring. Adult larvae are strikingly pink and are up to 2 cm in size. Their cocoons cannot be overlooked during autumn sifting.

Insect-eating birds, such as great tit or spotted woodpeckers, pose a danger to nests, especially before and during winter. Not overwintering cocoons outside in artificial nests eliminates this danger. However, woodpeckers can use their beaks to significantly damage the relatively robust wooden boards of artificial nests during the nesting season. The only protection in this case is to prevent them from accessing the nests by enclosing them in wire mesh. However, this complicates the bees' access to nests as their wings rub against the mesh. Therefore, it is better to avoid this solution if possible and use it only in the case of need. Usually, nests are attacked by birds near forests or city parks, not in the open countryside and orchards.

Conclusions

RMB is less suitable for pollinating crops because it preferentially collects pollen from oaks. EOB prefers the pollen of *Rosaceae* and *Brassicaceae*, hence is more suited for pollination of fruit trees or rapeseed. EOB is more thermophilic than RMB but its spread to higher altitudes can be expected in Europe in response to climate change. The breeding technology, summarized in this paper, can be used to produce and introduce both species into fruit orchards for pollination purpose. Since EOB nests earlier than RMB, their combined breeding can be useful, since it increases the duration of the pollination service.

Acknowledgements

This work was supported by the Technology Agency of the Czech Republic (TA CR), project No. TH03030134.

REFERENCES

Blitzer EJ, Gibbs J, Park MG, Danforth BN (2016) Pollination services for apple are dependent on diverse wild bee communities. Agric Ecosyst Environ 221: 1–7.

Bosch J, Kemp WP (2002) Developing and establishing bee species as crop pollinators: the example of *Osmia* spp. (Hymenoptera: Megachilidae). Bull Entomol Res 92: 3–16.

Eckhardt M, Haider M, Dorn S, Müller A (2014) Pollen mixing in pollen generalist solitary bees: a possible strategy to complement or mitigate unfavourable pollen properties? J Anim Ecol 83: 588–597.

Garibaldi LA, Steffan-Dewenter I, Winfree R et al. (2013) Wild pollinators enhance fruit set of crops regardless of honey bee abundance. Science 339: 1608–1611.

Garratt MPD, Breeze TD, Boreux V et al. (2016) Apple pollination: demand depends on variety and supply depends on pollinator identity. PLoS ONE 11: e0153889.

Hofmann MM, Fleischmann A, Renner SS (2020) Foraging distances in six species of solitary bees with body lenghts of 6 to 15 mm, inferred from individual tagging, suggest 150 m-rule-of-thumb for flower strip distances. J Hymenopt Res 77: 105–117.

Holzschuh A, Dormann CF, Tscharntke T, Steffan-Dewenter I (2013) Mass-flowering crops enhance wild bee abundance. Oecologia 172: 477–484.

Jauker F, Franziska P, Wolters V, Diekötter T (2012) Early reproductive benefits of mass-flowering crops to the solitary bee *Osmia rufa* outbalance post-flowering disadvantages. Basic Appl Ecol 13: 268–276.

Kratschmer S, Petrovič B, Curto M, Meimberg H, Pachinger B (2020) Pollen availability for the Horned mason bee (*Osmia cornuta*) in regions of different land use and landscape structures. Ecol Entomol 45: 525–537.

Krunic M, Stanisavljevic L (2006) The Biology of European Orchard Bee *Osmia cornuta*. University of Belgrade, Belgrade.

Macek J, Straka J, Bogusch P, Dvořák L, Bezděčka P, Tyrner P (2010) Blanokřídlí České republiky I. Žahadloví. Academia, Praha.

Macivor JC (2017) Cavity-nest boxes for solitary bees: a century of design and research. Apidologie 48: 311–327.

Mader E, Spivak M, Evans E (2010) Managing Alternative Pollinators: A Handbook for Beekeepers, Growers, and Conservationists. SARE, NRAES. https://www.sare.org/resources/managing-alternative-pollinators/. Accessed 28 February 2022.

Mallinger RE, Gratton C (2015) Species richness of wild bees, but not the use of managed bees, increases fruit set of a pollinator-dependent crop. J Appl Ecol 52: 323–330.

Marquez J, Bosch J, Vicens N (1994) Pollens collected by wild and managed populations of the potential orchard pollinator *Osmia cornuta* Latr. (Hym. Megachilidae). J Appl Entomol 117: 353–359.

Pardo A, Borges PAV (2020) Worldwide importance of insect pollination in apple orchards: A review. Agric Ecosyst Environ 293. doi: 10.1016/j.agee.2020.106839.

Persson AS, Mazier F, Smith HG (2018) When beggars are choosers – How nesting of a solitary bee is affected by temporal dynamics of pollen plants in the landscape. Ecol Evol 8: 5777–5791.

Raw A (1974) Pollen preferences of three *Osmia* species (Hymenoptera). Oikos 25: 54–60.

Sampson BJ, Stringer SJ, Cane JH, Spiers JM (2004) Screenhouse evaluations of a mason bee *Osmia ribifloris* (Hymenoptera: Megachilidae) as a pollinator for blueberries in the Southeastern United States. Small Fruits Rev 3: 381–392.

Sedivy C, Dorn S (2014) Towards a sustainable management of bees of the subgenus *Osmia* (Megachilidae; *Osmia*) as fruit tree pollinators. Apidologie 45: 88–105.

Šlachta M, Erban T, Votavová A, Bešta T, Skalský M, Václavíková M, Halešová T, Edwards-Jonášová M, Včeláková R, Cudlín P (2020) Domestic Gardens Mitigate Risk of Exposure of Pollinators to Pesticides – An Urban-Rural Case Study Using a Red Mason Bee Species for Biomonitoring. Sustainability 12. doi: 10.3390/su12229427.

Zurbuchen A, Cheesman S, Klaiber J, Müller A, Hein S, Dorn S (2010) Long foraging distances impose high costs on offspring production in solitary bees. J Anim Ecol 79: 674–681.