Citation/Atıf: Abou-Shaara HF. Strategies to temporarily repel honey bees from pesticide-treated areas, U. Bee J. / U. Arı D. 2025; 25 (1): 158-170. DOI: 10.31467/uluaricilik.1609659

DERLEME /REVIEW

STRATEGIES TO TEMPORARILY REPEL HONEY BEES FROM PESTICIDE-TREATED AREAS

Pestisit Uygulanan Alanlardan Bal Arılarını Geçici Olarak Uzaklaştırma Stratejileri

Hossam F. ABOU-SHAARA

Department of Plant Protection, Faculty of Agriculture, Damanhour University, Damanhour, 22516, EGYPT, E-posta: hossam.farag@agr.dmu.edu.eg, ORCID No: 0000-0001-7208-6526

Received / Geliş: 30.12.2024 Accepted / Kabul: 04.02.2025 DOI: 10.31467/uluaricilik.1609659

ABSTRACT

The exposure of forager honey bees, *Apis mellifera*, to pesticides during the treatment period or shortly after can result in instant death or direct impairment of their behaviors. Beekeepers are often faced with limited choices when pesticides are applied near their colonies. One proposed method is the use of repellent materials shortly before pesticide spraying or synchronizing the application time. This article aims to highlight key trends that can be employed to temporarily repel honey bees and emphasizes areas where further studies are needed. The significance of this article lies in the destructive impact of pesticides on honey bees, which are crucial global plant pollinators. The decline of honey bee colonies due to pesticide exposure is a growing concern. The article specifically identifies five strategies that can be employed to repel honey bees: 1) plant-based materials, 2) chemicals, 3) simulation, 4) technology-based repellents, and 5) physical barriers. However, some strategies have been overlooked in previous studies, leading to noticeable gaps in knowledge that should be addressed in further research. The article also presents some perspectives on the beneficial utilization of these specified strategies, paving the way for more innovative methods to mitigate the negative effects of pesticides on honey bees.

Keywords: Pesticides, Honey bees, Stressors, Colonies, Repelling

ÖZ

Toplayıcı bal arılarının, *Apis mellifera*, tedavi süresince veya hemen sonrasında pestisitlere maruz kalması anında ölüme veya davranışlarının doğrudan bozulmasına neden olmaktadır. Arıcılar, kolonilerinin yakınına pestisit uygulandığında genellikle sınırlı seçeneklerle karşı karşıya kalmaktadır. Önerilen yöntemlerden biri, pestisit püskürtmeden hemen önce kovucu malzemelerin kullanılması veya uygulama zamanının senkronize edilmesidir. Bu makale, bal arılarını geçici olarak kovmak için kullanılabilecek temel eğilimleri işaret etmeyi ve daha fazla çalışmaya ihtiyaç duyulan alanları vurgulamak amacındadır. Bu makalenin önemi, küresel bitki polinatörleri olan bal arıları üzerindeki pestisitlerin yıkıcı etkisinde yatmaktadır. Bal arısı kolonilerinin pestisit maruziyeti nedeniyle azalması giderek artan bir endişe kaynağıdır. Makale, bal arılarını kovmak için kullanılabilecek beş eğilimi özel olarak tanımlamaktadır: 1) bitki bazlı malzemeler, 2) kimyasallar, 3) simülasyon, 4) teknoloji tabanlı kovucular ve 5) fiziksel bariyerler. Bunlarla birlikte, önceki çalışmalarda bazı eğilimler göz ardı edilmiş ve bu da daha ileri araştırmalarda ele alınması gereken dikkat çekici bilgi boşluklarına yol açmıştır. Makale ayrıca, bu belirtilen eğilimlerin faydalı kullanımıyla ilgili bazı bakış açıları sunarak, pestisitlerin bal arıları üzerindeki olumsuz etkilerini azaltmak için daha yenilikçi yöntemlerin önünü açmaktadır.

Anahtar Kelimeler: Pestisitler, Bal arıları, Stres faktörleri, Koloniler, Uzaklaştırma

DERLEME /REVIEW

GENİŞLETİLMİŞ ÖZET

Amaç: Bu makale, bal arılarını geçici olarak kovmak için kullanılabilecek temel eğilimleri işaret etmeyi ve daha fazla çalışmaya ihtiyaç duyulan alanları vurgulamak amacındadır. Bu makalenin önemi, küresel bitki polinatörleri olan bal arıları üzerindeki pestisitlerin yıkıcı etkisinde yatmaktadır.

Giriş:Toplayıcı bal arılarının, *Apis mellifera*, tedavi süresince veya hemen sonrasında pestisitlere maruz kalması anında ölüme veya davranışlarının doğrudan bozulmasına neden olmaktadır. Arıcılar, kolonilerinin yakınına pestisit uygulandığında genellikle sınırlı seçeneklerle karşı karşıya kalmaktadır. Önerilen yöntemlerden biri, pestisit püskürtmeden hemen önce kovucu malzemelerin kullanılması veya uygulama zamanının senkronize edilmesidir.. Bal arısı kolonilerinin pestisit maruziyeti nedeniyle azalması giderek artan bir endişe kaynağıdır. Makale, bal arılarını kovmak için kullanılabilecek beş eğilimi özel olarak tanımlamaktadır: 1) bitki bazlı malzemeler. Örneğin, citronella yağı bal arıları için en umut verici kovuculardan biridir. Sarımsak, maydanoz, limon otu, tütün, acı bakla ve asır bitkisi özleri gibi bazı özler bal arıları üzerinde kovucu etki göstermiştir ve sarımsak en güçlü kovucu etkiyi göstermiştir. 2) kimyasallar. Örneğin, bal arısı alarm feromonları, 2-heptanon ve izopentil asetat. Yağlı tohumlu kolza tarlalarına, tarla fasulyelerine ve ayçiçeği başlarına uygulandığında, toplayıcılarda kovucu etki yaratmıştır. 3) simülasyon. Örneğin, bal arıları belirli böceklerin bulunduğu çiçekleri ziyaret etmekten kaçınırlar. Polen böceği *Meligethes aeneus*, Arjantin karıncaları veya *Plecia nearctica*'nın bulunduğu çiçekler. Bu kovuculuk eğiliminde, bu tür böceklere benzeyen yapay nesnelerin kullanılması, bal arılarının belirli çiçeklerde yiyecek aramasını görsel olarak bozabilir ve önleyebilir. 4) teknoloji tabanlı kovucular. Örneğin, insan duyma aralığının üzerinde frekanslara sahip ultrasonik dalgalar yayan ultrasonik cihazların kullanımı. Bu frekanslar böcekleri kovmak için yeterlidir. Başka bir yaklaşım, bal arılarının karanlığa maruz kaldıklarında anormal yiyecek arama davranışı sergilemeleri nedeniyle ışığa ve 5) fiziksel bariyerlere dayanmaktadır. Örneğin, ince ağ veya file gibi bariyerler kurmak, bal arılarının belirli yerlere erişmesini önleyebilir. Dışlama çitleri, bal arılarını kovmak için öldürücü olmayan ve fiziksel olarak göze çarpmayan bir yol sağlar.

Tartışma ve sonuç: Bu makale, bal arılarının pestisit uygulanmış alanlara erişimini sınırlandırmayı amaçlayan beş strateji sunmaktadır. Ancak, literatürde bal arılarının gerçekçi saha koşulları altında çeşitli pestisit türleriyle işlenmiş alanlardan başarılı bir şekilde uzaklaştırıldığını belgeleyen kapsamlı bir veriye rastlanmamıştır. Özellikle pestisitlerin bal arısı kolonileri için önemli bir tehlike oluşturmaya devam ettiği göz önünde bulundurulduğunda, bal arıları için kovucu kullanımının bu yönüyle ilgili belirgin bilgi boşlukları bulunmaktadır.

Bununla birlikte önceki çalışmalarda bazı eğilimler göz ardı edilmiş ve bu da daha ileri araştırmalarda ele alınması gereken dikkat çekici bilgi boşluklarına yol açmıştır. Makale ayrıca, bu belirtilen eğilimlerin faydalı kullanımıyla ilgili bazı perspektifler sunarak, pestisitlerin bal arıları üzerindeki olumsuz etkilerini azaltmak için daha yenilikçi yöntemlerin önünü açmaktadır. Pestisit uygulaması sırasında arı kolonilerini korumak için fiziksel bariyerlerin kullanılması en pratik yaklaşım gibi görünmektedir. Genel olarak, uygulama sırasında bal arıları ile pestisitler arasındaki etkileşimi azaltmak için yöntemler mevcuttur, ancak bunlar ticari ölçekte etkili bir şekilde uygulanmamaktadır.

INTRODUCTION

The honey bee, *Apis mellifera*, assumes a pivotal role in agriculture and plant pollination, contributing significantly to the global economy with annual earnings amounting to billions of US dollars (Morse and Calderone 2000, Paudel et al., 2015; Sillman et al., 2021). Estimates suggest that honey bees play a role in pollinating around 35% of global crop production (Aizen et al. 2009, Klein et al., 2007), with their pollination services enhancing crop quality, leading to amplified yields and improved fruit set (Abou-Shaara 2014). The foraging behavior of honey bees facilitates the crucial transfer of pollen from male to female flower parts, a vital process for the propagation of numerous plant species, encompassing fruits, vegetables, and wildflowers (Abou-Shaara 2014, Bänsch et al. 2021, Halder et al. 2019, Kendall et al. 2021, Rader et al. 2024). This mutualistic relationship between honey bees and agriculture underscores the indispensable role these insects play in sustaining food production

(Etxegarai-Legarreta and Sanchez-Famoso 2022, Patel et al. 2021).

The decline in honey bee populations, as evidenced by prior studies like Hristov et al. (2021) and Panziera et al. (2022), poses a significant threat to global food security and biodiversity. This decline can lead to diminished crop yields, compromised crop quality, and reduced genetic diversity, underscoring the importance of maintaining robust honey bee populations and implementing conservation strategies to uphold agricultural productivity and preserve plant species diversity (Halvorson et al., 2021). Concerns regarding the impact of pesticides on honey bees have escalated due to their potential adverse effects on bee health and colony viability (Abati et al. 2021, Johnson et al. 2010). Recent research has illuminated the harmful repercussions of pesticide exposure on honey bees. For instance, neonicotinoids, a prevalent class of insecticides, have been associated with hindered colony growth, compromised bee health, heightened vulnerability to pathogens, and negative effects on foraging behaviour (Dirilgen et al. 2023, Li et al. 2023, Woodcock et al. 2017). Numerous studies have delved into the immediate effects of pesticide exposure on honey bees, revealing the detrimental outcomes they experience (Johnson et al. 2010, Koch and Weisser 1997, Okubo et al. 2021). These investigations underscore the concerning impact of pesticides on honey bees and emphasize the urgency of adopting sustainable practices to mitigate risks to honey bee colonies.

Safeguarding honey bee colonies from the deleterious effects of pesticides is imperative for their survival and the continuity of pollination services. Various strategies have been proposed to mitigate the risks posed by pesticides to honey bees (Zhang et al. 2023). Integrated pest management approaches, involving pest level monitoring, alternative pest control methods, and reduced pesticide application during active bee foraging periods, offer a viable solution (Lundin et al. 2021, Pecenka et al. 2023). Additionally, modern pest control technologies like gene editing and silencing can aid in diminishing reliance on chemical pesticides (Gossen and McDonald 2020). Encouraging diverse floral resources and establishing pollinator-friendly habitats can furnish bees with alternative foraging options, thereby reducing exposure to pesticide-contaminated crops (Obregon et al. 2021, Zhang et al. 2023). When employed collectively, these methods can shield honey bee colonies from the adverse impacts of pesticides, ensuring their well-being and preserving the invaluable pollination services they provide.

Deterring honey bees from pesticide-treated areas can mitigate their exposure to harmful chemicals and diminish health risks. Various methods, encompassing natural plant extracts and synthetic compounds, have been explored to achieve this objective (Deshpande and Naik 2016, Malerbo-Souza and Nogueira-Couto 2004, Sidhu and Wilson Rankin 2016). This review article aims to underscore the significance of protecting honey bees by repelling them from pesticide-treated regions, focusing on strategies that merit exclusive scrutiny to enhance awareness and furnish updates on this critical subject.

Plant-based materials

Plant extracts and essential oils have been used to control *Varroa destructor* mites and other bee pathogens, in addition to improving honey bee health (Abou-Shaara 2017, Abou-Shaara et al. 2017, Abou-Shaara et al. 2023, Bava et al. 2023, Garrido et al. 2024, Jack and Ellis 2021). Using repellent materials as additives to pesticides is not a novel idea, but it has been commercially used for a long time. For example, QCymbush, a commercial formulation, has been found to repel honey bees for about 2 days after treatment, but the repellency is due to the added ingredients and not the insecticide cypermethrin itself (Delabie et al. 1985). Similarly, plant-derived materials have long been suggested as repellents to honey bees in pesticide-treated areas (e.g., Atkins et al. 1975, Jones 1952, Woodrow et al. 1965). This topic has been covered in detail in a chapter by Deshpande and Naik (2016). As quick snippets, citronella oil is one of the most promising repellents to honey bees (Kumar et al. 1986). Some extracts, such as garlic, parsley, citronella, tobacco, rue, and century plant extracts have shown repellent effects on honey bees, with garlic exhibiting the strongest repellent action lasting for 2.5 hours in the yellow passion-fruit crop and 6 hours in confined beef cattle feeders (Nicodemo and Nogueira Couto 2004).

The leaf extract and essential oil of *Ocimum sanctum* have demonstrated repellent activity against honey bees under semi-field conditions, with the essential oil showing the highest efficacy (Gill et al. 2002). Certain materials have shown repellent effects on the dwarf bees *Apis florea*, such as the essential oil of *Terminalia chebula* (Naik et al. 2010), as well as linalool and α-terpeniol, which are components of the essential oil derived from the flower of *Swertia densifolia* (Naik et al. 2015). Additionally, additives like ethylene glycol and glycerol have been found to enhance repellence against honey bees (Mishra and Sihag 2010), but further testing with other plant-based materials or pesticides is necessary. Consistent with that, the repellency of citronellal to honey bees from basil (*Ocimum sellowii*) crops has been increased when diluted in water and glycerine compared to water alone (Malerbo-Souza and Nogueira-Couto 2004).

It is worth noting that the ingestion of plant extracts, such as those from *Matricaria chamomilla*, *Origanum majorana*, *Punica granatum*, and *Echinodorus grandiflorus*, can have harmful effects on honey bees, leading to a reduction in their survival (Potrich et al. 2020). Therefore, when utilizing repellency strategies, it is crucial to select materials that are highly repellent to honey bees without causing subsequent harm to them. Furthermore, considering the target insect group is important when using plant-based products. For instance, certain plant-based insecticides like oil-free neem seed extract containing azadirachtin as the main active ingredient have shown no deterrent effects on honey bees (Naumann et al. 1994), indicating no negative impact on bee foraging. However, their toxicity to honey bees still remains a concern. Nicotine-based insecticides can also pose problems for honey bees, as even the highest nicotine concentrations did not completely repel them (Köhler et al. 2012). Similarly, some repellent oils, including eucalyptus, neem, citronella, garlic extract, and rotenone, have been found to have toxic effects on honey bees (Xavier et al. 2015). Therefore, it is essential to search for repellent materials that are safe for honey bees, even in cases of occasional ignition or topical exposure. Additionally, this highlights the importance of conducting selectivity tests when using plant-based pesticides to ensure minimal impact on honey bees, which are a non-target group (Cunha Pereira et al. 2020, Da Silva et al. 2020).

Repellent chemicals

There are certain compounds that can be extracted from honey bees or other insects, or artificially synthesized, which have deterrent effects. An example of this is the honey bee alarm pheromones, 2-heptanone and isopentyl acetate. When applied to oil-seed rape plots, field beans, and sunflower heads, they caused a repellent action to foragers (Free et al. 1985). 2-heptanone, which is secreted from honey bee mandibles, can cause temporary local anesthesia when honey bees bite their enemies (Papachristoforou et al. 2012) and has gained much attention as a repellent. It has shown a 2.5-hour repellent action in the yellow passion-fruit crop (Nicodemo and Nogueira Couto 2004). This chemical has also been found to be repellent to *A. florea* (Naik et al. 2002). However, when used as additives to insecticides in an agricultural setting, 2-heptanone has not shown significant repellent effects on honey bees (Rieth et al. 1986). The repellency of n.octyl.acetate and 2-heptanone to honey bees from basil crops has been increased when diluted in water and glycerine compared to water alone (Malerbo-Souza and Nogueira-Couto 2004). This indicates that the repellence of 2-heptanone is case-dependent, affected by crop type, application method, and additives.

Other compounds containing nitrogen, short side-chain substituted phenyl acetates, and/or tolyl compounds have shown promise as honey bee repellents (Atkins et al. 1975). Compounds such as diethyl-meta-toluamide, 2-ethyl-1,3-hexanediol, dimethyl phthalate, benzaldehyde, and menthol have caused a significant reduction in the number of bees around treated areas (Collins et al. 1996). Additionally, ketones, aldehydes, and phenols have exhibited approximately 80% repellency to honey bees under semi-field conditions, particularly p-ethoxyacetophenone, m-bromoacetophenone, 3,4,5-trimethoxyacetophenone, phenylacetaldehyde, 4-nitrobenzaldehyde, p-bromophenol, and p-cresol (Mishra and Sihag 2009).

Some pollinators exhibit a rejection behavior towards revisiting flowers that have been previously visited by conspecifics or heterospecifics, particularly when the nectar has been depleted. This behavior has been well-documented in honey bees (e.g., Giurfa 1993). Similar repellence has also been observed in various species of bumble bees from the genus *Bombus* spp., which utilize repellent forage-marking scents on flowers of *Symphytum officinale* to temporarily deter subsequent foragers for about 20 minutes (Stout et al. 1998). Chemicals from other insects can induce such rejection behavior in pollinators. For example, Argentine ants (*Linepithema humile*) employ chemical marking using iridomyrmecin from their pygidial glands, which affects certain bee species but not honey bees

(*A. mellifera*) (Wilson Rankin et al. 2020). However, honey bees tend to avoid flowers occupied by Argentine ants or treated with their pheromone (Sidhu and Wilson Rankin 2016). The possibility of developing effective repellent chemicals based on compounds extracted from insects deserves more attention, as it appears to have been overlooked in previous studies.

Simulation

In certain instances, honey bees exhibit avoidance behavior towards flowers already inhabited by specific insects. For instance, flowers hosting the pollen beetle *Meligethes aeneus* (Kirk et al. 1995), Argentine ants *Linepithema humile* (Sidhu and Wilson Rankin 2016), or the lovebug *Plecia nearctica* (Abou-Shaara et al. 2022) are examples of such cases. This phenomenon of repulsion can be leveraged through the use of artificial objects mimicking these insects, visually interfering with and deterring honey bee foraging activities on particular flowers. For instance, the implementation of artificial black spots on flower petals, resembling pollen beetles, demonstrated a dissuasive impact on honey bee foragers, effectively deterring them without necessitating landing on these flowers (Kirk et al. 1995). Despite the promising implications of such experimental paradigms, research in this domain remains relatively scarce. This strategy may be most applicable to limited areas such as small plots or gardens.

An alternative approach involves the simulation of certain bird vocalizations. Observations have indicated that bee-eaters, such as *Merops* spp., known predators of honey bees, can disrupt honey bee foraging patterns (Goras et al. 2023), with their vocalizations potentially impeding flying activities from bee colonies (Bota et al. 2022). Devices emitting simulated bee-eater vocalizations could prove effective in deterring bees from entering pesticide-treated zones. Nevertheless, empirical field data on the efficacy of this method remains scarce and warrants further investigation. Subsequent studies should be undertaken to evaluate the practicality of these devices, encompassing their deployment within apiaries or in proximity to treated areas.

Technology-based repellents

Various technologies exist that can effectively repel insects within designated areas. One such technology involves the utilization of ultrasonic devices that emit ultrasonic waves at frequencies beyond the human auditory threshold. These frequencies have demonstrated the capacity to repel insects (Kaila et al. 2015, Yturralde and Hofstetter 2012). An ultrasonic system underwent testing against varroa mites within colonies, yielding results that showcased its efficacy in combating varroa mites while leaving honey bees unaffected (Barry et al. 2018). Despite these promising outcomes, this particular avenue of research remains relatively unexplored, warranting further investigations into honey bee responses under diverse experimental settings. Noteworthy attributes of this technology include its cost-effectiveness, minimal environmental residue, and ease of application.

An alternative strategy revolves around light manipulation, spurred by observations of honey bees displaying aberrant foraging behavior during solar eclipses. Instances of interrupted foraging trips have been documented during partial solar eclipses (Hains and Gamper 2017). Total solar eclipses, inducing complete darkness, have been shown to impede flying activities (Galen et al. 2019), albeit not entirely halting them (Waiker et al. 2019), and reducing the diversity of bee species visiting floral resources (Sinu et al. 2024). These findings suggest that diminished sunlight prompts the cessation of foraging endeavors, prompting bees to return to their hives. Therefore, strategies that manipulate light within pesticide-treated zones can effectively dissuade honey bees from frequenting these areas. For instance, employing dark covers over treated regions until the conclusion of the spraying period or immediately prior to its commencement. Research highlights that particular wavelengths of LED lights, like ultraviolet, can deter honey bees by disrupting their visual perception (Kevan et al. 2001). Indeed, artificial lighting can adversely affect insect activities (Juddin et al. 2023). By deploying LED lights around apiaries in conjunction with other deterrent measures, it becomes feasible to establish visual barriers that discourage bees from departing their hives. Furthermore, outfitting unmanned aerial vehicles (UAVs) or drones with sound or light-emitting apparatuses could facilitate the development of dynamic and mobile deterrent systems, thereby presenting a worthwhile avenue for exploration under field conditions.

Physical barriers

The implementation of barriers, such as fine mesh or netting, has been shown to effectively deter honey bees from accessing specific sites (Sonter et al. 2024). Exclusion fencing offers a non-lethal physical method for repelling honey bees. Notably, greenhouses exemplify environments where exclusion fencing can be particularly beneficial, even though honey bees might not represent the most suitable pollinators for greenhouse crops (Nicodemo et al. 2018, Kiatoko et al. 2023). During pesticide applications, greenhouses can be sealed off to prevent incidental honey bee entry.

Similarly, beekeepers have the option to shield their colonies or apiaries with mesh or netting prior to pesticide treatments, allowing for adequate preparation time. This protective measure can be upheld for up to two days, ensuring adequate ventilation while securing food and water supplies for the colonies. Despite considerations regarding cost-effectiveness and labor, there is currently a dearth of empirical data regarding the merits and drawbacks of this approach.

On small farms, temporary covers can be placed over plants without disrupting pesticide application procedures. These covers can be installed before or shortly after spraying, particularly following evening treatments. In larger expanses, tall mesh barriers can be temporarily erected around farms. Leveraging technology, these barriers can be engineered for easy installation and removal through remote control functionalities.

DISCUSSION

Although repellents to deter honey bees from pesticide-treated areas have been suggested and studied for a long time, their impact is not significantly evident. One piece of evidence is the persistent and considerable impact of pesticides on honey bees, causing numerous direct and indirect effects on them. Even during the dominance of research studies on honey bees focusing on colony collapse disorder (CCD), the contribution of pesticide hazards to this issue has been suggested (Frazier et al. 2008, Frazier et al. 2011, Gross 2008). However, no studies have comprehensively discussed the effectiveness of repellents to protect honey bees from pesticide-treated areas in the context of CCD occurrence. Pesticide manufacturers, bee researchers, and other related organizations have not given adequate attention to this research area, and the absence of clear reasons for this oversight is notable. Perhaps the development of suitable repellent materials for field application is progressing slower than the development of pesticides. Specifically, such repellents should be able to restrict honey bee access to certain areas for at least 72 hours after application, rather than just a few minutes. Likewise, the limited longevity of repellents, particularly volatile substances, to maintain their effectiveness for an extended period after application in the field has been recognized as one of the challenges associated with their utilization (Zhang et al. 2023).

Without a doubt, the direct effects of pesticides on honey bee colonies when they are exposed to pesticides during application and in the few days following application are more harmful than the pesticide residues subsequently available in the environment (e.g. Johnson et al. 2010, Okubo et al. 2021, Tosi and Nieh 2019, Yao et al. 2018). Therefore, it is essential to develop effective formulations using plant extracts, synthetic chemicals, insect extracts, or their mixtures for practical application, while considering their repellent duration to be as long as 72 hours. In addition to using repellent materials to keep bees away from specific areas, attractants can be applied to untreated areas to draw honey bees towards them. For example, the attraction of honey bees towards untreated yards for a few days can be achieved by using attractants such as liquid paraffin as an additive to the leaf extract of *Swertia densifolia* (Naik et al. 2007). Research should investigate appropriate concentrations, carriers, and application methods to optimize the repellent effects while minimizing any negative impacts on the environment or non-target organisms. When considering application, it is crucial to apply these materials before pesticide application or develop slow-release devices that can be fixed around treated areas, instead of mixing them with pesticides. The latter approach is not ideal for protecting the bees, as they can still come into contact with pesticides and transfer the toxins to their colonies, thereby negatively affecting them.

The use of technology-based repellents, simulation approaches, and physical barriers shows great promise for repelling bees from certain areas for a relatively extended period, but further studies are still required to validate their effectiveness. These strategies require the involvement of technology companies to develop appropriate methods, as highlighted in the article. Applying pesticides during periods when honey bees are less active, such as early morning or late evening, allows for ample time to apply repellent methods that facilitate the bees' return to their hives before the application, thus avoiding immediate exposure. Careful studies and evaluations are necessary to determine effective methods to repel honey bees while preserving their vital role as pollinators and minimizing any impact on non-target organisms (Figure 1). Additionally, careful planning and coordination with beekeepers are essential to ensure the safety and well-being of the colonies during the implementation of any repellent method.

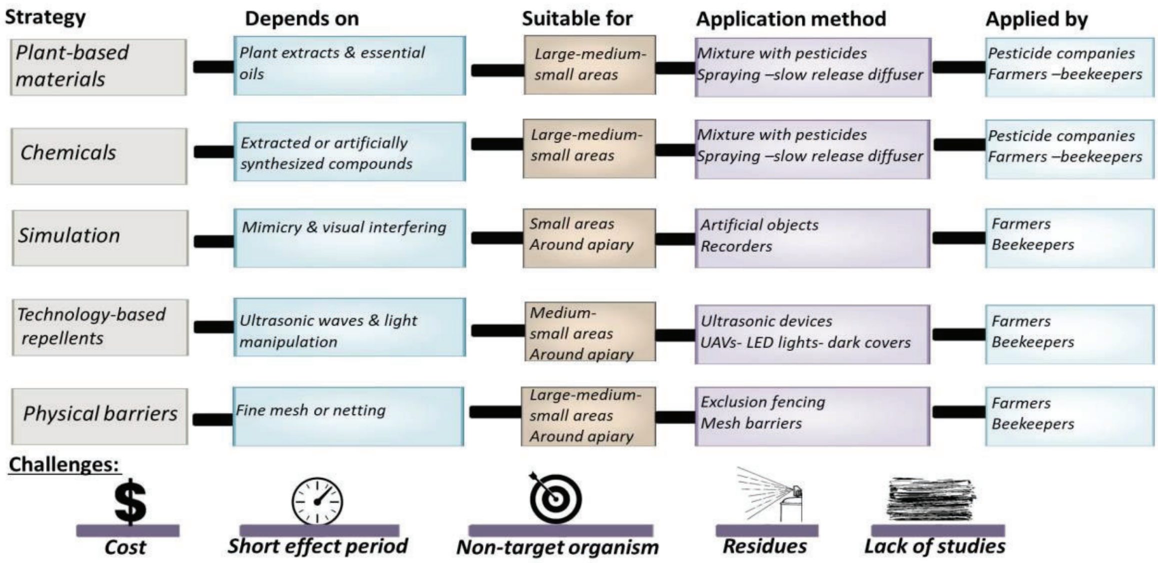

Figure 1. A summary of the strategies presented in the article and key points related to their application.

Conclusion: This article presents five strategies aimed at limiting the access of honey bees to pesticide-treated areas. However, no comprehensive data documenting successful repelling of honey bees from areas treated with various types of pesticides under realistic field conditions have been found in the literature. There are noticeable knowledge gaps in this aspect of using repellents for honey bees, particularly considering that pesticides continue to pose a significant hazard to honey bee colonies. The use of physical barriers to safeguard bee colonies during pesticide application appears to be the most practical approach. In general, methods to mitigate the interaction between honey bees and pesticides during application are available, but they are not effectively implemented on a commercial scale.

Author contribution: The author designed, wrote, and revised the manuscript.

Conflict of Interest: No conflict of interests to be reported.

Ethical issue: Not applicable because this article is a review on honey bees.

Source of Finance: Not applicable.

REFERENCES

Abati R, Sampaio AR, Maciel RMA, Colombo FC, Libardoni G, Battisti L, Lozano ER, Ghisi NC, Costa-maia FM, Potrich M.. Bees and pesticides: The research impact and scientometrics relations. Environmental Science and Pollution Research. 2021;28:32282-32298. https://doi.org/10.1007/s11356-021-14224-7.

Abou-Shaara HF. The foraging behaviour of honey bees, *Apis mellifera*: a review. Veterinarni Medicina. 2014;59:1-10.

Abou-Shaara HF. Using safe materials to control *Varroa* mites with studying grooming behavior of honey bees and morphology of *Varroa* over winter. Annals of Agricultural Sciences. 2017;62:205-210.

https://doi.org/10.1016/j.aoas.2017.12.002.

Abou-Shaara HF, Amiri E, Parys KA. Tracking the effects of climate change on the distribution of *Plecia nearctica* (Diptera, Bibionidae) in the USA using MaxEnt and GIS. Diversity. 2022;14:690. https://doi.org/10.3390/d14080690.

Abou-Shaara H, Jack C, Ellis JD. The impact of smoke and fogged/vaporized thyme oil on honey bee (*Apis mellifera*) survival and behavior in vitro. Journal of Apicultural Research. 2023;62:643-645. https://doi.org/10.1080/00218839.2022.2135809.

Abou-Shaara H, Staron M, Cermakova T. Impacts of oxalic acid, thymol, and potassium citrate as *Varroa* control materials on some parameters of honey bees. Turkish Journal of Veterinary & Animal Sciences. 2017;41:238-247. https://doi.org/10.3906/vet-1606-92.

Aizen MA, Garibaldi LA, Cunningham SA, Klein AM. How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. Annals of Botany. 2009;103:1579-1588. https://doi.org/10.1093/aob/mcp076.

Atkins EL, Macdonald RL, Mcgovern TP, Beroza M, Greywood-Hale EA. Repellent additives to reduce pesticide hazards to honeybees: laboratory testing. Journal of Apicultural Research. 1975; 14: 85-97. https://doi.org/10.1080/00218839.1975.11099808.

Bänsch S, Tscharntke T, Gabriel D, Westphal C. Crop pollination services: Complementary resource use by social vs solitary bees facing crops with contrasting flower supply. Journal of Applied Ecology. 2021;58:476-485. https://doi.org/10.1111/1365-2664.13777.

Barry BC, Verstraten L, Butler FT, Whelan PM, Wright WM. The use of airborne ultrasound for *Varroa destructor* mite control in beehives. In *2018* IEEE International Ultrasonics Symposium (IUS) pp. 1-9.

Bava R, Castagna F, Palma E, Marrelli M, Conforti F, Musolino V, Musella V. Essential oils for a sustainable control of honeybee varroosis. Veterinary Sciences. 2023;10:308. https://doi.org/10.3390/vetsci10050308.

Bota G, Traba J, Sarda-palomera F, Giralt D, Pérez-Granados C.Passive acoustic monitoring for estimating human-wildlife conflicts: The case of bee-eaters and apiculture. Ecological Indicators. 2022;142:109158. https://doi.org/10.1016/j.ecolind.2022.109158.

Collins AM, Rubink WL, Cuadriello Aguilar JI, Hellmich RL. Use of insect repellents for dispersing defending honey bees (Hymenoptera: Apidae). Journal of Economic Entomology. 1996;89(3):608-613. https://doi.org/10.1093/jee/89.3.608.

Cunha Pereira R, Faria Barbosa W, Pereira Lima MA, Vieira JOL, Carvalho Guedes RN, Rodrigues Da Silva BK, Lemes Fernandes F. Toxicity of botanical extracts and their main constituents on the bees *Partamona helleri* and *Apis mellifera*. Ecotoxicology. 2020;29:246-257. https://doi.org/10.1007/s10646-020-02167-7.

Da Silva IM, Zanuncio JC, Brügger BP, Soares MA, ZAnuncio AJV, Wilcken CF, Sediyama CS. Selectivity of the botanical compounds to the pollinators *Apis mellifera* and *Trigona hyalinata* (Hymenoptera: Apidae). Scientific Reports. 2020;10:4820. https://doi.org/10.1038/s41598-020-61469-2.

Delabie J, Bos C, Fonta C, Masson C. Toxic and repellent effects of cypermethrin on the honeybee: Laboratory, glasshouse and field experiments. Pesticide Science. 1985;16:409-415. https://doi.org/10.1002/ps.2780160417.

Deshpande PV, Naik DG. Repellents for honey bees. Mutualistic interactions between flowering plants and animals. 2016;148-173.

Dirilgen T, Herbertsson L, O'reilly AD, Mahon N, Stanley DA. Moving past neonicotinoids and honeybees: A systematic review of existing research on other insecticides and bees. Environmental Research. 2023:235:116612. https://doi.org/10.1016/j.envres.2023.116612.

Etxegarai-Legarreta O, Sanchez-Famoso V. The role of beekeeping in the generation of goods and services: The interrelation between environmental, socioeconomic, and sociocultural utilities. Agriculture. 2022;12:551. https://doi.org/10.3390/agriculture12040551.

Frazier J, Mullin C, Frazier M, Ashcraft S. Pesticides and their involvement in colony collapse disorder. American Bee Journal. 2011;151:779-781.

Frazier M, Mullin C, Frazier J, Ashcraft S. What have pesticides got to do with it? American Bee Journal. 2008;148:521-524.

Free JB, Pickett JA, Ferguson AW, Simpkins JR, Smith MC. Repelling foraging honeybees with alarm pheromones. Journal of Agricultural Science. 1985;105,:255-260.

Galen C, Miller Z, Lynn A, Axe M, Holden S, Storks L, Kephart J. Pollination on the dark side: Acoustic monitoring reveals impacts of a total solar eclipse on flight behavior and activity schedule of foraging bees. Annals of the Entomological Society of America. 2019.;12:20-26. https://doi.org/10.1093/aesa/say035

Garrido PM, Porrini MP, AlBeroni D, Baffoni L, Scott D, Mifsud D, Di Gioia D. Beneficial bacteria and plant extracts promote honey bee health and reduce nosema ceranae infection. Probiotics and Antimicrobial Proteins. 2024;16:259-274. https://doi.org/10.1007/s12602-022-10025-7

Gill K, Malik OP, Kalidhar SB, Mishra RC, Malik MS. Honey bee repellent activity of leaf extract and essential oil of *Ocimum sanctum* and isolation of a new compound. Journal of Medicinal and Aromatic Plant Sciences. 2002;24:951-956.

Giurfa M. The repellent scent-mark of the honeybee *Apis mellifera tigustica* and its role as communication cue during foraging. Insectes Sociaux. 1993;40:59-67. https://doi.org/10.1007/BF01338832

Goras G, Tananaki C, Liolios V, Kanelis D, Tofaris C, Giannouris E, Thrasyvoulou A. The conflict between avian predators and domestic honey bees: a case study of European bee-eater (*Merops apiaster* L.) preying on the honey bee (*Apis mellifera* L.) in Cyprus. Journal of Apicultural Research. 2023;62:1115-1122. https://doi.org/10.1080/00218839.2022.2069642

Gossen BD, Mcdonald MR. New technologies could enhance natural biological control and disease management and reduce reliance on synthetic pesticides. Canadian Journal of Plant Pathology. 2020;42:30-40. https://doi.org/10.1080/07060661.2019.1697370

Gross M. Pesticides linked to bee deaths. Current Biology. 2008;18, R684.

Hains BC, Gamper H. Disruption in honey bee (*Apis mellifera*) foraging flight activity during a partial solar eclipse shown by individual flight path tracking. Bulletin of Insectology. 2017;70:315-320.

Halder S, Ghosh S, Khan R, Khan AA, Perween T, Hasan MA. Role of pollination in fruit crops: A review. Pharma Innovation Journal. 2019;8,:695-702.

Halvorson K, Baumung R, Leroy G, Chen C, Boettcher P. Protection of honeybees and other pollinators: one global study. Apidologie. 2021;52:535-547. https://doi.org/10.1007/s13592-021-00841-1.

Hristov P, Shumkova R, Palova N, Neov B. Honey bee colony losses: Why are honey bees disappearing? Sociobiology. 2021; 68:e5851-e5851.

Jack CJ, Ellis JD. Integrated pest management control of *Varroa destructor* (Acari: Varroidae), the most damaging pest of (*Apis mellifera* L.(Hymenoptera: Apidae)) colonies. Journal of Insect Science.

2021;21:6. https://doi.org/10.1093/jisesa/ieab058

Johnson, R. M., Ellis, M. D., Mullin, C. A., & Frazier, M. 2010. Pesticides and honey bee toxicity–USA. Apidologie, 41, 312-331. https://doi.org/10.1051/apido/2010018

Jones, G. G. 1952. The responses of the honey-bee to repellent chemicals. Journal of Experimental Biology, 29, 372-386. https://doi.org/10.1038/s41598-017-15066-5

Juddin, A. S. S., Ngah, N., Umar, R., Asante, K., & Abdullahi, M. G. 2023. A review influence of light on insect activity and behavior: sustainable lighting and light pollution. J Sustainabil Sci Manag 18: 231-247.

Kaila, K., Bodkepranali, S., & Namdev, K. K. 2015. Development performance and evaluation of ultrasonic pest and insect repelling system. International Journal of Engineering Research and General Science, 3,19-25.

Kendall, L. K., Evans, L. J., Gee, M., Smith, T. J., Gagic, V., Lobaton, J. D. & Rader, R. 2021. The effect of protective covers on pollinator health and pollination service delivery. Agriculture, Ecosystems & Environment, 319, 107556. https://doi.org/10.1016/j.agee.2021.107556.

Kevan, P. G., Chittka, L., & Dyer, A. G. 2001. Limits to the salience of ultraviolet: lessons from colour vision in bees and birds. Journal of Experimental Biology, 204, 2571-2580. https://doi.org/10.1242/jeb.204.14.2571

Kiatoko, N., Pozo, M. I., Van Oystaeyen, A., Musonye, M., KIka, J., Wäckers, F. & Jaramillo, J. 2023. African endemic stingless bees as an efficient alternative pollinator to honey bees in greenhouse cucumber (*Cucumis sativus* L). Journal of Apicultural Research, 62, 1017-1029. https://doi.org/10.1080/00218839.2021.2013421.

Kirk, W. D., Ali, M., & Breadmore, K. N. 1995. The effects of pollen beetles on the foraging behaviour of honey bees. Journal of Apicultural Research, 34, 15-22.

Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. 2007. Importance of pollinators in changing landscapes for world crops. Proceedings of the royal society B: biological sciences, 274, 303-313.

Koch, H., & Weisser, P. 1997. Exposure of honey bees during pesticide application under field conditions. Apidologie, 28, 439-447. https://doi.org/10.1051/apido:19970610.

Köhler, A., Pirk, C. W., & Nicolson, S. W. 2012. Honeybees and nectar nicotine: deterrence and reduced survival versus potential health benefits. Journal of Insect Physiology, 58, 286-292. https://doi.org/10.1016/j.jinsphys.2011.12.002.

Kumar, J., Patyal, S. K., & Mishra, R. C. 1986. Evaluation of some essential oils as repellents to the Indian honeybee *Apis cerana indica* 1. Gustatory repellency and toxicity. Journal of Apicultural Research, 25, 256-261. https://doi.org/10.1080/00218839.1986.11100726.

Li, W., Lv, L., Wang, Y., & Zhu, Y. C. 2023. Mixture effects of thiamethoxam and seven pesticides with different modes of action on honey bees (*Aplis mellifera*). Scientific Reports, 13, 2679. https://doi.org/10.1038/s41598-023-29837-w.

Lundin, O., Rundlöf, M., Jonsson, M., Bommarco, R., & Williams, N. M. 2021. Integrated pest and pollinator management–expanding the concept. Frontiers in Ecology and the Environment, 19, 283-291.

Malerbo-souza, D. T., & Nogueira-Couto, R. H. 2004. Efficiency of n-octyl-acetate, 2-heptanone and citronellal in repelling bees from basil (*Ocimum sellowii*-Labiatae). Brazilian Archives of Biology and Technology, 47, 121-125.

Mishra, S., & Sihag, R. C. 2009. Efficacy of some chemicals as repellents against two honey bee species, *Apis mellifera* L. and *Apis* *florea* F. in semi-field trials. Journal of Apicultural Science, 53, 53-66.

Mishra S, Sihag RC. Efficacy of some chemicals and additives as bee repellents against two honeybee species, *Apis mellifera* L. and *Apis florea* F. in semi-field trials. Journal of Apicultural Science. 2010;54:21-34.

Morse RA, Calderone NW. The value of honey bees as pollinators of US crops in 2000. Bee culture. 2000;128:1-15.

Naik DG, Banhatti P, Chadawa SS, Thomas D. 2-Heptanone as a repellent for *Apis florea*. Journal of Apicultural Research. 2002;4: 59-61. https://doi.org/10.1080/00218839.2002.11101069.

Naik DG, Dandge C, Puntambekar H. *Swertia densifolia* leaf extract as a dose-dependant attractant or repellent for *Apis florea*. Journal of Apicultural Research. 2007;46:15-18. https://doi.org/10.1080/00218839.2007.11101361.

Naik DG, Puntambekar H, Anantpure P. Essential oil of *Terminalia chebula* fruits as a repellent for the Indian honeybee *Apis florea*. Chemistry & Biodiversity. 2010;7:1303-1310. https://doi.org/10.1002/cbdv.200900274.

Naik DG, Vaidya-Kannur H, Deshpande PV, Dandge CN, Reddy GV. Potential use of an essential oil from the flower of *Swertia densifolia* as a repellent for *Apis florea* (Hymenoptera: Apidae). Annals of the Entomological Society of America. 2015;108:18-25. https://doi.org/10.1093/aesa/sau005.

Naumann K, Currie RW, Isman MB. Evaluation of the repellent effects of a neem insecticide on foraging honey bees and other pollinators. The Canadian Entomologist. 1994;126:225-230.

Nicodemo D, Nogueira Couto RH. Use of repellents for honeybees (*Apis mellifera* L.) in vitro in the yellow passion-fruit (*Passiflora edulis* Deg) crop and in confined beef cattle feeders. Journal of Venomous Animals and Toxins including Tropical Diseases. 2004;10:77-85.

Nicodemo D, Malheiros EB, De Jong D, Couto RHN. Improved pollination efficiency and reduced honey bee colony decline in greenhouses by allowing access to the outside during part of the day. Sociobiology. 2018;65:714-721. https://doi.org/10.13102/sociobiology.v65i4.3455.

Obregon D, Guerrero OR, Stashenko E, Poveda K. Natural habitat partially mitigates negative pesticide effects on tropical pollinator communities. Global Ecology and Conservation. 202;28:e01668. https://doi.org/10.1016/j.gecco.2021.e01668.

Okubo S, Shoji A, Kimura K, Morimoto N, Yoshiyama M. Effectiveness of floral enhancement in reducing honeybee exposure to insecticides. Applied Entomology and Zoology. 2021;56:207-215. https://doi.org/10.1007/s13355-021-00727-9.

Panziera D, Requier F, Chantawannakul P, Pirk CW, Blacquière T. The diversity decline in wild and managed honey bee populations urges for an integrated conservation approach. Frontiers in Ecology and Evolution. 2022;10:767950. https://doi.org/10.3389/fevo.2022.767950.

Papachristoforou A, Kagiava A, Papaefthimiou C, Termentzi A, Fokialakis N, Skaltsounis AL, Theophilidis G. The bite of the honeybee: 2-heptanone secreted from honeybee mandibles during a bite acts as a local anaesthetic in insects and mammals. PLoS ONE. 2012;7:e47432. https://doi.org/10.1371/journal.pone.0047432.

Patel V, Pauli N, Biggs E, Barbour L, Boruff B. Why bees are critical for achieving sustainable development. Ambio. 2021;50:49-59.

Paudel YP, Mackereth R, Hanley R, Qin W. Honey bees (*Apis mellifera* L.) and pollination issues: Current status, impacts, and potential drivers of decline. Journal of Agricultural Science. 2015;7:93-109.

Pecenka JR, Ingwell LL, Krupke, CH, Kaplan I. Implementing IPM in crop management simultaneously improves the health of managed bees and enhances the diversity of wild pollinator communities. Scientific Reports. 2023;13:11033. https://doi.org/10.1038/s41598-023-38053-5.

Potrich M, Silva RTLD, Maciel RM, Costa-Maia FM, Lozano ER, Rossi RM, Dallacort S. Are plant extracts safe for honey bees (*Apis mellifera*)? Journal of Apicultural Research. 2020;59:844-851. https://doi.org/10.1080/00218839.2020.1735733.

Rader R, Schmidt L, Rocchetti M, Wright D, Bezerra Da Silva Santos K, Dingley A, Preradovic J, Jones J, Dawso, B, Devetter LW, Perović DJ, Davis AE. Future-proofing the pollination services to insect-pollinated crop production. Acta Horticulturae. 2024;388:17-36.

Rieth JP, Wilson WT, Levin MD. Repelling honeybees from insecticide-treated flowers with 2-heptanone. Journal of Apicultural Research. 1986;25:78-84. https://doi.org/10.1080/00218839.1986.11100697.

Sidhu CS, Wilson Rankin EE. Honey bees avoiding ant harassment at flowers using scent cues. Environmental Entomology. 2016;45:420-426. https://doi.org/10.1093/ee/nvv230.

Sillman J, Uusitalo V, Tapanen T, Salonen A, Soukka R, Kahiluoto H. Contribution of honeybees towards the net environmental benefits of food. Science of the Total Environment. 2021;756:143880. https://doi.org/10.1016/j.scitotenv.2020.143880.

Sinu PA, Jose A, Varma S. Impact of the annular solar eclipse on December 26, 2019 on the foraging visits of bees. Scientific Reports. 2024;14:17458 (2024). https://doi.org/10.1038/s41598-024-67708-0.

Sonter CA, Jones J, Dawson BM, Reid JN, Santos KC, Fuller S, Tighe M, Wilson C, Rader R. Protective covers impact honey bee colony performance and access to outside resources. Agriculture, Ecosystems & Environment. 2024;368:109028. https://doi.org/10.1016/j.agee.2021.107556.

Stout JC, Goulson D, Allen JA. Repellent scent-marking of flowers by a guild of foraging bumblebees (*Bombus* spp.). Behavioral Ecology and Sociobiology. 1998;43:317-326. https://doi.org/10.1007/s002650050497.

Tosi S, Nieh JC. Lethal and sublethal synergistic effects of a new systemic pesticide, flupyradifurone (Sivanto®), on honeybees. Proceedings of the Royal Society B. 2019;286:20190433. https://doi.org/10.1098/rspb.2019.0433.

Waiker P, Baral, S, Kennedy A, Bhatia S, Rueppell A, Le K, Rueppell O. Foraging and homing behavior of honey bees (*Apis mellifera*) during a total solar eclipse. The Science of Nature. 2019;106:1-10. https://doi.org/10.1007/s00114-018-1597-2.

Wilson Rankin EE, Cecala JM, Hernandez Pineda N, Lu, QY, Pelayo E, Choe DH. Differential feeding responses of several bee species to sugar sources containing iridomyrmecin, an Argentine ant trail pheromone component. Journal of Insect Behavior. 2020;33:83-90. https://doi.org/10.1007/s10905-020-09748-8.

Woodcock BA, Bullock JM, Shore RF, Heard MS, Pereira MG, Redhead J, Pywell RF. Country-specific effects of neonicotinoid pesticides on honey bees and wild bees. Science. 2017;356:1393-1395. https://doi.org/10.1126/science.aaa1190.

Woodrow AW, Green N, Tucker H, Schonhorst MH, Hamilton C. Evaluation of chemicals as honey bee attractants and repellents. Journal of Economic Entomology. 1965;58:1094-1102. https://doi.org/10.1093/jee/58.6.1094.

Xavier VM, Message D, Picanço MC, Chediak M, Júnior PAS, Ramos RS, Martins, JC. Acute toxicity and sublethal effects of botanical insecticides to honey bees. Journal of Insect Science. 2015;15:137. https://doi.org/10.1093/jisesa/iev110.

Yao J, Zhu YC, Adamczyk J. Responses of honey bees to lethal and sublethal doses of formulated clothianidin alone and mixtures. Journal of Economic Entomology. 2018;111:1517-1525. https://doi.org/10.1093/jee/toy140.

Yturralde KM, Hofstetter RW. Efficacy of commercially available ultrasonic pest repellent devices to affect behavior of bed bugs (Hemiptera: Cimicidae). Journal of Economic Entomology. 2012;105:2107-2114. https://doi.org/10.1603/ec12166

Zhang G, Olsson RL, Hopkins BK. Strategies and techniques to mitigate the negative impacts of pesticide exposure to honey bees. Environmental Pollution. 2023;318:120915. https://doi.org/10.1016/j.envpol.2022.120915.