


NEONICOTINOIDS VERSUS BEES: A BRIEF REVIEW ON THE EFFECTS ON THESE POLLINATORS AND THE NEED FOR REEVALUATION OF AGRICULTURAL PRACTICES

 <https://doi.org/10.56238/arev6n4-262>

Date of submission: 17/11/2024

Date of publication: 17/12/2024

William Cardoso Nunes¹, Malislene Lucas de Araujo², Diones Krinski³ and Miriam Hiroko Inoue⁴

ABSTRACT

Neonicotinoids, a class of widely used insecticides in agriculture, have been associated with significant negative impacts on pollinators, especially bees. This study conducts a systematic literature review to assess the effects of these compounds, with a focus on native and wild species. Exposure to neonicotinoids can cause direct mortality and sublethal effects in bees and other pollinators, impairing foraging behavior and colony health. Among the 42 reviewed articles, the European honeybee (*Apis mellifera*) was the most investigated species, with 17 mentions. However, the inclusion of native species, such as *Bombus terrestris* and *Melipona scutellaris*, is gaining prominence, highlighting the need to protect pollinator diversity to ensure agricultural sustainability and biodiversity. The study concludes that a reassessment of agricultural and regulatory practices is urgently needed to mitigate the effects of neonicotinoids on ecosystems.

Keywords: Ecological Risk Assessment (ERA). Sustainability. *Apis mellifera*. Non-*Apis* bees. Imidacloprid. Clothianidin.

¹ Master's student in Environment and Agricultural Production Systems Mato Grosso State University (UNEMAT) Tangará da Serra, Mato Grosso, Brazil

E-mail: william.cardoso@unemat.br

ORCID: <https://orcid.org/0000-0001-8753-0570>

² Master's student in Environment and Agricultural Production Systems Mato Grosso State University (UNEMAT) Tangará da Serra, Mato Grosso, Brazil

E-mail: malislene.araujo@unemat.br

ORCID: <https://orcid.org/0009-0004-4559-3732>

³ PhD in Zoology

Federal University of Paraná (UFPR) Curitiba, Paraná, Brazil

E-mail: diones.krinski@unemat.br

ORCID: <https://orcid.org/0000-0002-4719-5314>

⁴ PhD in Agronomy

State University of Maringá (UEM) Maringá, Paraná, Brazil

Mato Grosso State University, Brazil

E-mail: miriam@unemat.br

ORCID: <https://orcid.org/0000-0002-5332-5170>

INTRODUCTION

Neonicotinoids are a class of systemic insecticides widely used to control numerous pests and to treat agricultural seeds (WARE; WHITACRE, 2004). Due to their widespread use in recent years, neonicotinoid-based products have been associated with bee population declines in several countries (GOULSON, 2013; MEIKLE *et al.*, 2021). Because these compounds are highly systemic with long-term persistence, they are frequently applied to seeds of economically important crops, such as corn (*Zea mays*) and soybeans (*Glycine max*), during the sowing process (DOUGLAS; TOOKER, 2015). As they act as agonists of nicotinic acetylcholine receptors in the central nervous system of insects (MATSUDA *et al.*, 2001), blocking them and, consequently, preventing the passage of nerve impulses (TOMIZAWA; CASIDA, 2005), this mode of action allows the control mainly of insects that attack the roots and the collar, as well as those that feed on the aerial part of the plant. In addition, neonicotinoids can act by contact, making them suitable for controlling many biting and sucking insects. They are also used in seed treatments to protect against soil-dwelling insects; they are absorbed by the root system and are then distributed evenly, maintaining an effective concentration of active substance in young plants.

Recent studies have demonstrated the deleterious effects of these insecticides on the survival, behavior and health of honey bee colonies and other wild pollinators (RUNDLÖF *et al.*, 2015; TSVETKOV *et al.*, 2017). The toxicity associated with neonicotinoids represents a significant concern for the health of bee populations, since these chemical compounds have demonstrated the potential to be lethal or cause sublethal effects, even at extremely low concentrations (WOODCOCK, *et al.*, 2017; PEREIRA; DINIZ; RUVOLO- TAKASUSUKI, 2020).

Several scientific studies indicate that exposure to minimal amounts of neonicotinoids, such as 5 nanograms per bee, can result in the mortality of up to 50% of exposed individuals (TSVETKOV *et al.*, 2017). This finding is especially alarming considering that the application of these pesticides is a common practice in modern agriculture, where they are frequently used in seed treatment and crop protection.

As a result, contamination of the agricultural environment is becoming widespread, affecting not only honeybees (*Apis* spp.) but also other pollinators and beneficial organisms that play crucial roles in maintaining biodiversity and pollinating plants. The magnitude of this problem highlights the urgent need for a reassessment of current

agricultural practices and the regulation of neonicotinoid use in order to protect bee health and, consequently, the sustainability of agricultural ecosystems.

In addition to direct mortality, neonicotinoids also affect the behavior and health of bee colonies (MEDRZYCHI *et al.*, 2003). Exposure to these pesticides can interfere with the bees' ability to forage, navigate, and communicate, resulting in a phenomenon known as colony collapse (LUDICKE; NIEH, 2020). This collapse is characterized by the absence of worker bees, which abandon the colony, leaving behind the queen and brood, which compromises the survival of the colony and causes disorientation (FISCHER *et al.*, 2014).

Neonicotinoid contamination is not limited to honeybees, but also affects a variety of other pollinators, such as butterflies and beetles. Research indicates that a significant portion of these pesticide residues are carried by the wind, which can impact a wide range of insects that play essential roles in pollination and maintaining biodiversity (FERREIRA *et al.*, 2022).

This situation raises serious concerns about the health of agricultural ecosystems and biodiversity in general, since the loss of pollinators can compromise agricultural production and the stability of natural habitats. In the Brazilian context, the increased use of pesticides, including neonicotinoids, is closely associated with the expansion of monocultures, which are particularly susceptible to severe pesticides and therefore require intensive pesticide applications (IBAMA, 2020). Incidents of mass mortality of bees have been frequently recorded, which highlights the urgency of a more rigorous assessment of the impacts of these chemicals on pollinators (JACOB, 2019).

Despite growing concern for the health of bees and other pollinators, there is still a significant gap in research analyzing the specific effects of neonicotinoids on native bees in Brazil, especially when we consider that there are around 3,000 species of bees in Brazil, of which approximately 10% are stingless bees (SILVEIRA; MELO; ALMEIDA, 2002). These data alone make it imperative to conduct additional studies to better understand the extent and severity of the impacts of neonicotinoids on this bee diversity.

In summary, neonicotinoids pose a significant threat to bee populations and biodiversity in general. The combination of direct mortality, sublethal effects, and environmental contamination requires urgent attention and coordinated actions to mitigate the impacts of these pesticides and protect pollinators that are essential for agriculture and ecosystems (YANG *et al.*, 2020). Therefore, the present study aimed to evaluate, based on

a literature review, the impact of the use (or not) of neonicotinoids on bees, which play a very important ecosystem role through pollination.

THEORETICAL FRAMEWORK

The theoretical framework in a study comprises a critical and organized analysis of the literature relevant to the topic, providing a theoretical contextualization and defining the key concepts. It should comprehensively contain the theories, models and previous research, identifying gaps, contradictions and consensus in the literature that are important for the focus of the work being developed.

METHODOLOGY

The review was conducted through a bibliographic search in scientific databases Scopus and Google Scholar, with the aim of compiling and analyzing data on the effects of neonicotinoids on bees. A systematic methodology adapted by Galvão and Pereira (2014) was used to select the articles. The process was carried out in the following steps:

1. Research Question: The central question that guided this review was: What are the main impacts of neonicotinoids on bee populations, with a focus on biodiversity?
2. Literature Search: The search was conducted in scientific databases, including Scopus, and Google Scholar, covering the period from 2020 to 2024. The keywords used were: *Neonicotinoids*, *Bees*, *Toxicity*. The search included articles that discuss both the mechanisms of action of these pesticides and their impacts on biodiversity and agriculture.
3. Selection of Articles: The initial selection of articles was based on the analysis of titles and abstracts, taking into account the relevance to the central theme of the review, with some filters being selected to search within: Article title, Abstract, Keywords; Study area: Limited to Agricultural and Biological Sciences, thus limiting the number of articles to 42 according to the.
4. Document type: Limited to the article. Only studies that addressed the effects of neonicotinoids on bees and other pollinators were included, excluding articles that dealt with other types of pesticides or species not related to pollinators.
5. Data Extraction: The pre-selected articles were organized in a spreadsheet, categorized by search terms, database, year of publication, study location, and

authors. This organization allowed for quantitative and qualitative analysis of the articles, in addition to facilitating the visualization of the results in tables.

6. **Assessment of Methodological Quality:** Each article was fully analyzed to assess the methodology, objectives, results and conclusions. The evaluation focused on methodological quality, seeking to identify possible biases and the robustness of the reported findings.
7. **Data Synthesis (Meta-analysis):** The collected data were synthesized by grouping the studies into different thematic categories, according to the main research focus identified. This included the analysis of the impacts of neonicotinoids on bee mortality, sublethal and behavioral effects, and the implications for agricultural sustainability and biodiversity conservation.

This methodological approach allowed a comprehensive and critical analysis of the selected studies, contributing to a better understanding of the impacts of neonicotinoids on pollinators and the urgency of regulatory actions to protect biodiversity, especially bees.

RESULTS AND DISCUSSION

By reviewing the 42 scientific articles on the impact of neonicotinoids on several species of native bees in the regions analyzed, it was possible to identify a series of adverse effects associated with these insecticides widely used in agriculture. For example, the studies carried out by Pereira *et al.* (2024) that evaluated the direct toxicity of neonicotinoids such as imidacloprid, spinosad and malathion, and showed that such products resulted in interference in flight behavior; and also provide contamination of bees through transmission via trophallaxis, resulting in additional deaths within the colony. These impacts not only affect individual bees, but also compromise biodiversity and the overall health of ecosystems.

Studies conducted by several authors over the last two years have shown that neonicotinoids are harmful to the functioning of bee colonies, impairing their ability to pollinate and, consequently, reducing the productivity of plants that depend on these essential pollinators (SON *et al.*, 2023; BARTLETT *et al.*, 2024; PEREIRA *et al.*, 2024; RONDEAU; RAINE, 2024). Analysis of these studies indicates a growing concern about the need to mitigate the effects of neonicotinoid use to protect bees and, by extension, agricultural and natural biodiversity. Preserving bee populations is vital to maintaining ecological balance and ensuring the sustainability of agricultural systems.

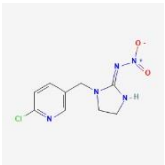
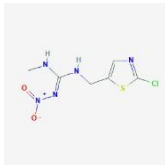
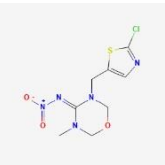
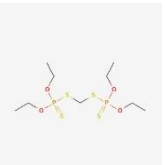
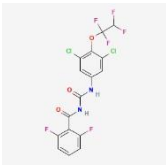
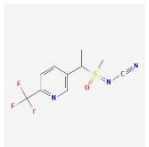
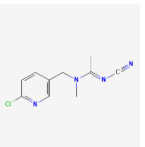
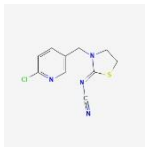
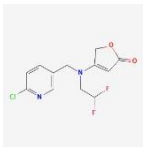
The evaluation of neonicotinoid toxicity in different bee species, such as *Apis mellifera* (Linnaeus, 1758), makes it possible to evaluate possible variations that impact the health of these pollinators (CABEZAS; FARINÓS, 2022; OLIVEIRA, *et al.*, 2023). Thus, neonicotinoids, widely used in agriculture, have been recognized for their high toxicity, which can cause lethal and sublethal effects in bees. The extrapolation of toxicity data obtained in *A. mellifera* to native Brazilian bees such as *Melipona scutellaris* (Latreille, 1811), *Trigona spinipes* (Fabricius, 1793), *Tetragonisca angustula* (Latreille, 1811), *Tetragonisca fiebrigi* (Schwarz, 1938), *Tetragonisca weyrauchi* (Schwarz, 1943) and *Xenoglossa pruinosa* (Say, 1837) presents challenges, since responses may vary between species, making risk assessment difficult.

The European honeybee (*A. mellifera*) was the most studied species, appearing in 17 of the reviewed articles. This is probably related to the fact that this bee is bred and used in beekeeping, which certainly facilitates research on this species. In addition, its economic importance as a pollinator makes it a focus of research on the impacts of neonicotinoids, with the aim of evaluating the damage to colony health and their effectiveness in pollination (SON *et al.*, 2023; LU *et al.*, 2024). Although *A. mellifera* continues to be the predominant focus of studies on the effects of neonicotinoids, studies relating to species such as the honeybee *Bombus terrestris* (Linnaeus, 1758) and *Melipona scutellaris* indicate a growing effort to explore the impacts of these insecticides on native and wild bees.

This trend towards valuing pollinator diversity is essential to ensure ecosystem resilience and the sustainability of agricultural production. *Bombus terrestris*, for example, plays a crucial role in the pollination of several crops and wild plants (KAWAKITA *et al.*, 2004; CAMERON *et al.*, 2007; WILLIAMS *et al.*, 2008;). In addition, native species of stingless bees from Brazil, such as *Melipona scutellaris*, *Trigona spinipes*, *Tetragonisca angustula*, *Tetragonisca fiebrigi*, *Tetragonisca weyrauchi* and *Xenoglossa pruinosa*, are equally important in the pollination of tropical plants and in honey production. These bees contribute significantly to the maintenance of biodiversity and agricultural productivity, being fundamental for the balance of ecosystems (ALEEM; HUANG; MILBRATH, 2020). The inclusion of these species in neonicotinoid research is essential, as pollinator diversity contributes significantly to the stability and productivity of agricultural ecosystems, in addition to offering ecosystem services necessary for food security and biodiversity (LUNDIN *et al.*, 2015; CABEZAS; FARINÓS, 2022; OLIVEIRA, *et al.*, 2023).

In light of the above, we note that the use of pesticides, particularly neonicotinoids, has been extensively studied in 42 articles, which analyzed 9 different molecules (Table 1). These pesticides have generated significant impacts on pollinators, such as bees and other insects that play crucial roles in maintaining ecosystems and agricultural production. Although pesticides are often used to control pests in agricultural practices, their adverse effects are not restricted to target species, but also affect beneficial plants essential for pollination (SHAHMOHAMADLOO; TISSIER; GUZMAN, 2024).

Table 1: Number of occurrences of the molecules cited in the 42 articles evaluated.

Insecticide molecules studied*				
Imidacloprid	Clothianidin	Thiamethoxam	Ethion	Hexaflumuron
				
Sulfoxaflor	Acetamiprid	Thiacloprid	Flupyradifurone	
				

* Molecular structures were taken from the Pubchem website.

Studies have shown that the application of these chemicals, especially on a large scale, contributes to the decline of pollinator populations, affecting their health, behavior, and reproductive capacity (FAIRBROTHER *et al.*, 2014; ZHOU *et al.*, 2024) (Table 2). Thus, Ecological Risk Assessment (ERA) is a critical tool used to measure pesticide toxicity, but it has been shown to be limited to the use of surrogate species, such as the western honeybee (*A. mellifera*), which may not significantly represent impacts on pollinator diversity in the field. This limitation raises questions about the effectiveness of current regulations and the need to reform assessment methods in order to better protect pollinators and, consequently, ensure food security and biodiversity (LEVIN *et al.*, 1989).

Table 2. Neonicotinoids effects on bees

Neonicotinoids	Species	Effects on bees	Reference
		hyperexcitation	
	<i>Apis mellifera</i>	(non-degradation of acetylcholine)	LU <i>et al.</i> (2024)
	<i>Xenoglossa pruinosa</i>	hyperactivity	RONDEAU; RAINE (2024)
	<i>Trigona spinipes</i>	interference in flight ability	CUNHA PEREIRA <i>et al.</i> (2023)
			SHAHMOHAM
	<i>Apis mellifera</i> , <i>Bombus</i> sp.; <i>Megachile</i> ;	acute lethality	ADLOO; TISSIER;
	<i>Melipona</i> ; <i>Partamona</i> ;		GUZMAN (2024)
		Genetic effects	
	<i>Apis mellifera</i>	(detoxification processes)	DU <i>et al.</i> (2024)
Imidacloprid	<i>Tetragonisca angustula</i> ; <i>Tetragonisca fiebrigi</i> ; <i>Tetragonisca weyrauchi</i>	lethality	OLIVEIRA <i>et al.</i> (2023)
	<i>Apis mellifera</i> ;	reduction in visits to flowers (decrease in foraging)	
	<i>Apis florea</i> ;		SALEEM <i>et al.</i> (2023)
	<i>Xylocopa violacea</i> ;		
	<i>Xylocopa sarawakensis</i>		
	<i>Apis mellifera</i> ;	Sexual stress (males)	MCAFEE <i>et al.</i> (2022)
	<i>Apis mellifera</i>	Sublethal effect (physiological)	DELKASH-ROUDSARI <i>etal.</i> (2022)
			CABEZAS;
	<i>Bombus terrestris</i>	acute lethality	FARINÓS (2022)
	<i>Apis mellifera</i> ;	lethality	KAUR <i>et al.</i> (2020)
	<i>Apis cerana cerana</i>	Interference in climbing ability;	GAO <i>et al.</i> (2020)

		decreased responsiveness to sucrose	
	<i>Apis mellifera</i>	lethality	SALEEM; HUANG; MILBRATH (2020)
			SHAHMOHAM
			ADLOO;
	<i>Apis mellifera</i> , <i>Bombus</i> sp.; <i>Megachile</i> ; <i>Osmia</i> ;	acute lethality	TISSIER; GUZMAN
			(2024)
	<i>Apis mellifera</i> ; <i>Apis florea</i> ; <i>Xylocopa violacea</i> ; <i>Xylocopa sarawakensis</i>	reduction in visits to flowers (decrease in foraging)	SALEEM <i>et al.</i> (2023)
Clothianidin	<i>Apis mellifera</i>	Genetic effects (detoxification processes)	DU <i>et al.</i> (2024)
	<i>Apis mellifera</i>	Genetic effects (detoxification processes)	SON <i>et al.</i> (2023)
	<i>Apis mellifera</i>	oxidative stress;	ORČIĆ <i>et al.</i>
		decrease immunity	(2022)
			HARWOOD;
	<i>Apis mellifera</i>	hormetic effects	PRAYUGO; DOLEZAL
			(2022)
			CABEZAS;
	<i>Bombus terrestris</i>	acute lethality	FARINÓS
			(2022)
		Genetic effects	
	<i>Apis mellifera</i>	(detoxification processes)	DU <i>et al.</i> (2024)
Sulfoxaflor		sublethal effects	
		(staggering, partial paralysis, contraction of the abdomen and spasms)	HELLER <i>et al.</i> (2022)
	<i>Apis mellifera</i>		

	<i>Apis mellifera</i>	Metabolic resistance	DU <i>et al.</i> (2024)
	<i>Apis mellifera</i> ;	reduction in visits to flowers (decrease in foraging)	
	<i>Apis florea</i> ;		SALEEM <i>et al.</i>
	<i>Xylocopa violacea</i> ;		(2023)
	<i>Xylocopa sarawakensis</i>		
	<i>Apis mellifera</i> , <i>Bombus</i> sp.; <i>Megachile</i> ; <i>Scaptotrigona</i> ; <i>Tetragonisca</i>	acute lethality	SHAHMOHAM ADLOO; TISSIER; GUZMAN (2024)
		Genetic effects	
	<i>Apis mellifera</i>	(detoxification	DU <i>et al.</i> (2024)
		processes)	
Thiamethoxam			CRISPIM <i>et al.</i>
	<i>Protopolybia exigua</i>	lethality	(2023)
	<i>Apis mellifera</i>	Sexual stress (males)	MCAFEE <i>et al.</i>
			(2022)
		sublethal effects	
	<i>Apis mellifera</i>	(staggering, partial paralysis, contraction of the abdomen and	HELLER <i>et al.</i> (2022)
		spasms)	
			SALEEM;
	<i>Apis mellifera</i> ;	letalidade	HUANG; MILBRATH
			(2020)
			SHAHMOHAM
	<i>Apis mellifera</i> , <i>Bombus</i> sp.; <i>Megachile</i> ; <i>Osmia</i> ;	letalidade aguda	ADLOO; TISSIER; GUZMAN
			(2024)
	<i>Apis mellifera</i>	Metabolic resistance	DU <i>et al.</i> (2024)
Acetamiprid		sublethal effects	
	<i>Apis mellifera</i>	(staggering, partial paralysis, contraction of the abdomen and	HELLER <i>et al.</i> (2022)
		spasms)	
	<i>Bombus impatiens</i>	increase/decrease of	CAMP <i>et al.</i>
		males in the colony	(2020)

	<i>Bombus terrestris audax</i>	moderate lethality	REID <i>et al.</i> (2020)
	<i>Apis mellifera</i>	moderate lethality	YANG <i>et al.</i> (2020)
Thiacloprid	<i>Bombus terrestris audax</i>	moderate lethality	REID <i>et al.</i> (2020)
	<i>Apis mellifera</i>	oxidative stress; decrease immunity	ORČIĆ <i>et al.</i> (2022)
	<i>Apis mellifera</i> ; <i>Apis florea</i> ; <i>Xylocopa violacea</i> ; <i>Xylocopa sarawakensis</i>	reduction in visits to flowers (decrease in foraging)	SALEEM <i>et al.</i> (2023)
Ethion	<i>Apis mellifera</i>	sublethal effect (physiological)	DELKASH-ROUDSARI <i>et al.</i> (2022)
Hexaflumuron	<i>Apis mellifera</i>	sublethal effect (physiological)	DELKASH-ROUDSARI <i>et al.</i> (2022)
Flupyradifurone	<i>Apis mellifera</i>	hormetic effects	HARWOOD; PRAYUGO; DOLEZAL (2022)

* based on articles used in this review.

Furthermore, pollination is a vital ecosystem service, with approximately one-third of human food production directly dependent on pollination by animals, especially bees. Therefore, preserving pollinator populations is essential not only for ecosystem health but also for agricultural sustainability, as indicated by studies linking pollinator declines to increased food insecurity and biodiversity loss (KAUR *et al.*, 2020).

FINAL CONSIDERATIONS

Thus, we conclude that, although the European honeybee (*A. mellifera*) has been the predominant focus in studies on the impacts of neonicotinoids, with 26 occurrences, there is a growing recognition of the importance of investigating other native and wild species, such as *B. terrestris* and *M. scutellaris*, mentioned in two articles each..

Pollinator diversity is essential for ecosystem resilience and agricultural sustainability, as neonicotinoids negatively affect not only target species but also

biodiversity in general. In addition, the text highlights the need to improve Ecological Risk Assessment (ERA) tools, which are currently based on surrogate species and do not adequately reflect impacts on pollinator diversity.

Given the evidence presented in the study of these 42 articles, we note the urgency of reassessing agricultural practices that rely on neonicotinoid-based products. Considering this, we highlight that a promising approach involves the use of biorational strategies, such as the integration of selective pesticides with organisms that can be used in conjunction with biological agents, such as natural predators, parasitoids, microorganisms, insecticidal plants, among others. These combinations have the potential to reduce dependence on neonicotinoids, promote ecological balance, and promote effective pest management. In addition, the transition to these types of sustainable practices could mitigate negative impacts on pollinators and ensure the resilience of agricultural systems in the long term.

REFERENCES

1. Ardestani, M. M. (2020). A brief overview on the application, potential exposure routes, and the effects of neonicotinoid insecticides on the honey bee pest *Varroa mite*. In **Proceedings of the Zoological Society** (pp. 118–126). New Delhi: Springer India.
2. Bargar, T. A., Hladik, M. L., & Daniels, J. C. (2020). Uptake and toxicity of clothianidin to monarch butterflies from milkweed consumption. **PeerJ*, 8*, e8669. <https://doi.org/10.7717/peerj.8669>
3. Bartlett, L. J., et al. (2024). Neonicotinoid exposure increases **Varroa destructor** (Mesostigmata: Varroidae) mite parasitism severity in honey bee colonies and is not mitigated by increased colony genetic diversity. **Journal of Insect Science*, 24*(3), 20. <https://doi.org/10.1093/jisesa/ieae021>
4. Baysal, M., & Atli-Eklioğlu, Ö. (2021). Comparison of the toxicity of pure compounds and commercial formulations of imidacloprid and acetamiprid on HT-29 cells: Single and mixture exposure. **Food and Chemical Toxicology*, 155*, 112430. <https://doi.org/10.1016/j.fct.2021.112430>
5. Cabezas, G., & Farinós, G. P. (2022). Sensitivity of buff-tailed bumblebee (**Bombus terrestris** L.) to insecticides with different mode of action. **Insects*, 13*(2), 184. <https://doi.org/10.3390/insects13020184>
6. Camp, A. A., et al. (2020). Effects of the neonicotinoid acetamiprid in syrup on **Bombus impatiens** (Hymenoptera: Apidae) microcolony development. **PloS One*, 15*(10), e0241111. <https://doi.org/10.1371/journal.pone.0241111>
7. Cecala, J. M., & Wilson Rankin, E. E. (2021). Pollinators and plant nurseries: How irrigation and pesticide treatment of native ornamental plants impact solitary bees. **Proceedings of the Royal Society B*, 288*(1955), 20211287. <https://doi.org/10.1098/rspb.2021.1287>
8. Crispim, P. D., et al. (2023). Lethal and sublethal dose of thiamethoxam and its effects on the behavior of a non-target social wasp. **Neotropical Entomology*, 52*(3), 422–430. <https://doi.org/10.1007/s13744-023-01045-5>
9. Cunha Pereira, R., et al. (2024). The stingless bee **Trigona spinipes** (Hymenoptera: Apidae) is at high risk from a range of insecticides via direct ingestion and trophallaxis. **Pest Management Science*, 80*(4), 2188–2198. <https://doi.org/10.1002/ps.7967>
10. De Montagu, C. T., & Goulson, D. (2020). Identifying agricultural pesticides that may pose a risk for birds. **PeerJ*, 8*, e9526. <https://doi.org/10.7717/peerj.9526>
11. Delkash-Roudsari, S., et al. (2022). Side effects of imidacloprid, ethion, and hexaflumuron on adult and larvae of honey bee **Apis mellifera** (Hymenoptera, Apidae). **Apidologie*, 53*(1), 17. <https://doi.org/10.1007/s13592-021-00880-6>
12. Douglas, M. R., & Tooker, J. F. (2015). Large-scale deployment of seed treatments has driven rapid increase in use of neonicotinoid insecticides and preemptive pest

- management in US field crops. *Environmental Science & Technology, 49*(8), 5088–5097. <https://doi.org/10.1021/es506141g>
13. Du, Y., et al. (2024). Biochemical and molecular characterization of neonicotinoids resistance in the tarnished plant bug, *Lygus lineolaris*. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 275*, 109765. <https://doi.org/10.1016/j.cbpc.2023.109765>
 14. Fairbrother, A., et al. (2014). Risks of neonicotinoid insecticides to honeybees. *Environmental Toxicology and Chemistry, 33*(4), 719–731. <https://doi.org/10.1002/etc.2527>
 15. Gao, J., et al. (2020). Physiological analysis and transcriptome analysis of Asian honey bee (*Apis cerana cerana*) in response to sublethal neonicotinoid imidacloprid. *Insects, 11*(11), 753. <https://doi.org/10.3390/insects11110753>
 16. Goulson, D., Thompson, J., & Croombs, A. (2018). Rapid rise in toxic load for bees revealed by analysis of pesticide use in Great Britain. *PeerJ, 6*, e5255. <https://doi.org/10.7717/peerj.5255>
 17. Guo, Y., et al. (2021). Bio-based clothianidin-loaded solid dispersion using composite carriers to improve efficacy and reduce environmental toxicity. *Pest Management Science, 77*(11), 5246–5254. <https://doi.org/10.1002/ps.6535>
 18. Harwood, G. P., Prayugo, V., & Dolezal, A. G. (2022). Butenolide insecticide flupyradifurone affects honey bee worker antiviral immunity and survival. *Frontiers in Insect Science, 2*, 907555. <https://doi.org/10.3389/finsc.2022.907555>
 19. Heller, S., et al. (2022). Toxicity of formulated systemic insecticides used in apple orchard pest management programs to the honey bee (*Apis mellifera* L.). *Environments, 9*(7), 90. <https://doi.org/10.3390/environments9070090>
 20. Huang, A., et al. (2021). The toxicity and toxicokinetics of imidacloprid and a bioactive metabolite to two aquatic arthropod species. *Aquatic Toxicology, 235*, 105837. <https://doi.org/10.1016/j.aquatox.2021.105837>
 21. IBAMA. (2020). Relatórios de comercialização de agrotóxicos. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. Disponível em: <http://www.ibama.gov.br/>(<http://www.ibama.gov.br/relatorios/quimicos-e-biologicos/relatoriosde-comercializacao-de-agrotoxicos#historicodecomercializacao>).
 22. Jacob, C. R. O. (2019). *Impacto de inseticidas neonicotinoides em abelhas africanizadas e nativas sem ferrão (Hymenoptera: Apoidea): toxicidade, alterações na atividade de locomoção e riqueza de espécies em pomares de citros*. [Tese de doutorado, Universidade de São Paulo].
 23. Kaur, S., et al. (2020). Impact of type and extent of sugars on the oral toxicity of imidacloprid on honeybees, *Apis mellifera* (Linn.). *Journal of Entomological Research, 44*(4), 595–599. <https://doi.org/10.5958/0974-8172.2020.00104.6>

23. KOMORI, Y. et al. Functional impact of subunit composition and compensation on *Drosophila melanogaster* nicotinic receptors—targets of neonicotinoids. *PLoS Genetics*, v. 19, n. 2, p. e1010522, 2023.
24. LIGONNIERE, S.; RAYMOND, V.; GOVEN, D. Use of double-stranded RNA targeting β 2 divergent nicotinic acetylcholine receptor subunit to control pea aphid *Acyrtosiphon pisum* at larval and adult stages. *Pest Management Science*, v. 80, n. 2, p. 896-904, 2024.
25. LIN, C. H. et al. Honey bees and neonicotinoid-treated corn seed: contamination, exposure, and effects. *Environmental Toxicology and Chemistry*, v. 40, n. 4, p. 1212-1221, 2021.
26. LU, W. et al. Nicotinic acetylcholine receptor modulator insecticides act on diverse receptor subtypes with distinct subunit compositions. *PLoS Genetics*, v. 18, n. 1, p. e1009920, 2022.
27. LU, X. et al. Rational design of triazinone derivatives with low bee toxicity based on the binding mechanism of neonicotinoids to *Apis mellifera*. *Journal of Agricultural and Food Chemistry*, v. 72, n. 23, 2024.
28. LUDICKE, J. C.; NIEH, J. C. Thiamethoxam impairs honeybee visual learning, alters decision times, and increases abnormal behaviors. *Ecotoxicology and Environmental Safety*, v. 193, p. 110367, 2020.
29. LUNDIN, O. et al. Neonicotinoid insecticides and their impacts on bees: a systematic review of research approaches and identification of knowledge gaps. *PLoS One*, v. 10, n. 8, p. e0136928, 2015.
30. MA, Y. et al. A facile one-pot route to fabricate clothianidin-loaded ZIF-8 nanoparticles with biocompatibility and long-term efficacy. *Pest Management Science*, v. 79, n. 7, p. 2603-2610, 2023.
31. MATSUDA, K. et al. Neonicotinoids: insecticides acting on insect nicotinic acetylcholine receptors. *Trends in Pharmacological Sciences*, v. 22, n. 11, p. 573-580, 2001.
32. MCAFEE, A. et al. Drone honey bees are disproportionately sensitive to abiotic stressors despite expressing high levels of stress response proteins. *Communications Biology*, v. 5, n. 1, p. 141, 2022.
33. MEDINA, A. M. B. Análise de resíduos de neonicotinóides no pólen forrageado e em tecidos das espécies de abelhas *Apis mellifera africanizada* e *Tetragonisca angustula* Latreille (1811). 2021. Tese (Doutorado em Química Analítica e Inorgânica) - Instituto de Química de São Carlos, University of São Paulo, São Carlos, 2021. doi:10.11606/T.75.2021.tde-30062021-154020. Acesso em: 2024-09-17.
34. MEDRZYCHI, P. et al. Effects of imidacloprid administered in sub-lethal doses on honey bee behaviour. Laboratory test. *Bulletin of Insectology*, v. 56, n. 1, p. 59-62, 2003.

35. MEIKLE, W. G. et al. Traces of a neonicotinoid pesticide stimulate different honey bee colony activities, but do not increase colony size or longevity. **Ecotoxicology and Environmental Safety**, v. 231, p. 113202, 2022.
36. MULVEY, J.; CRESSWELL, J. E. Time-dependent effects on bumble bees of dietary exposures to farmland insecticides (imidacloprid, thiamethoxam and fipronil). **Pest Management Science**, v. 76, n. 8, p. 2846-2853, 2020.
37. OLIVEIRA, A. A. et al. Correction to: Toxicity of imidacloprid for stingless bees of the genus **Tetragonisca** (Meliponini). **Apidologie**, v. 55, n. 1, p. 7, 2024.
38. ORČIĆ, S. M. et al. Acute toxicity of sublethal concentrations of thiacloprid and clothianidin to immune response and oxidative status of honey bees. **Apidologie**, v. 53, n. 4, p. 50, 2022.
39. PEREIRA, N. C.; DINIZ, T. O.; TAKASUSUKI, M. C. C. R. Sublethal effects of neonicotinoids in bees: a review. **Scientific Electronic Archives**, v. 13, n. 7, p. 142-152, 2020.
40. PEREIRA, R. C. et al. The stingless bee **Trigona spinipes** (Hymenoptera: Apidae) is at risk from a range of insecticides via direct ingestion and trophallactic exchanges. **Pest Management Science**, v. 80, n. 4, p. 2188-2198, 2024.
41. PROUTY, C. et al. Host plant species mediates impact of neonicotinoid exposure to monarch butterflies. **Insects**, v. 12, n. 11, p. 999, 2021.
42. REID, R. J. et al. Assessing the acute toxicity of insecticides to the buff-tailed bumblebee (**Bombus terrestris audax**). **Pesticide Biochemistry and Physiology**, v. 166, p. 104562, 2020.
43. RONDEAU, S.; RAINE, N. E. Single and combined exposure to 'bee safe' pesticides alter behaviour and offspring production in a ground-nesting solitary bee (**Xenoglossa pruinosa**). **Proceedings of the Royal Society B**, v. 291, n. 2019, p. 20232939, 2024.
44. ROSA-FONTANA, A. S. et al. Is the water supply a key factor in stingless bees' intoxication? **Journal of Insect Science**, v. 20, n. 6, p. 26, 2020.
45. ROTHMAN, J. A. et al. The direct and indirect effects of environmental toxicants on the health of bumblebees and their microbiomes. **Proceedings of the Royal Society B**, v. 287, n. 1937, p. 20200980, 2020.
46. RUNDLÖF, M. et al. Seed coating with a neonicotinoid insecticide negatively affects wild bees. **Nature**, v. 521, n. 7550, p. 77-80, 2015.
47. SALEEM, M. S. et al. Neonicotinoid pesticide applications affect pollinator abundance and visitation, leading to implications for sunflower production (**Helianthus annuus** L.). **Cogent Food & Agriculture**, v. 9, n. 1, p. 2258773, 2023.

48. SALEEM, M. S.; HUANG, Z. Y.; MILBRATH, M. O. Neonicotinoid pesticides are more toxic to honey bees at lower temperatures: implications for overwintering bees. **Frontiers in Ecology and Evolution**, v. 8, p. 556856, 2020.
49. SALEEM, M. S.; HUANG, Z. Y.; MILBRATH, M. O. Neonicotinoid pesticides are more toxic to honey bees at lower temperatures: implications for overwintering bees. **Frontiers in Ecology and Evolution**, v. 8, p. 556856, 2020.
50. SAMSON-ROBERT, O. et al. Planting of neonicotinoid-coated corn raises honey bee mortality and sets back colony development. **PeerJ**, v. 5, p. e3670, 2017.
51. SHAHMOHAMADLOO, R. S.; TISSIER, M. L.; GUZMAN, L. M. Risk assessments underestimate threat of pesticides to wild bees. **Conservation Letters**, v. 17, n. 4, p. e13022, 2024.
52. SILVEIRA, F. A.; MELO, G. A. R.; ALMEIDA, E. A. B. **Abelhas brasileiras: Sistemática e identificação**. 1ª ed. Belo Horizonte: Fundação Araucária, 253 p., 2002.
53. SOARES, J. B. C. **Toxicidade de inseticidas neonicotinoides sobre abelhas Apis mellifera L. (africanizadas)**. 2016. Dissertação (Mestrado em Ciência Animal) - Universidade Federal Rural do Semi-Árido, 2016.
54. SON, M. et al. Effects of clothianidin pesticide application on the strength of honey bee colonies and stress-related genes in the vicinity of rice fields in the Republic of Korea. **Diversity**, v. 15, n. 12, p. 1217, 2023.
55. TOMIZAWA, M.; CASIDA, J. E. Neonicotinoid insecticide toxicology: mechanisms of selective action. **Annual Review of Pharmacology and Toxicology**, v. 45, n. 1, p. 247-268, 2005.
56. TSVETKOV, N. et al. Chronic exposure to neonicotinoids reduces honey bee health near corn crops. **Science**, v. 356, n. 6345, p. 1395-1397, 2017.
57. WARE, G. W.; WHITACRE, D. M. Uma introdução aos inseticidas. **The pesticide book**, v. 6, 2004.
58. WERNECKE, A.; CASTLE, D. Effects of tank mixtures of plant protection products on honey bees and possible physiological interactions. **Journal of Cultivated Plants**, 2020.
59. WOOD, T. J.; GOULSON, D. The environmental risks of neonicotinoid pesticides: a review of the evidence post 2013. **Environmental Science and Pollution Research**, v. 24, p. 17285-17325, 2017.
60. WOODCOCK, B. A. et al. Country-specific effects of neonicotinoid pesticides on honey bees and wild bees. **Science**, v. 356, n. 6345, p. 1393-1395, 2017.

61. WU, C. et al. Effects of imidacloprid, a neonicotinoid insecticide, on the echolocation system of insectivorous bats. **Pesticide Biochemistry and Physiology**, v. 163, p. 94-101, 2020.
62. YANG, Y. et al. Acute and chronic toxicity of acetamiprid, carbaryl, cypermethrin and deltamethrin to **Apis mellifera** larvae reared in vitro. **Pest Management Science**, v. 76, n. 3, p. 978-985, 2020.
63. ZHANG, X. et al. Design, synthesis, and synergistic activity of eight-membered oxabridge neonicotinoid analogues. **Journal of Agricultural and Food Chemistry**, v. 69, n. 10, p. 3005-3014, 2021.
64. ZHOU, C. et al. Computational modeling-oriented substructure splicing application in the identification of thiazolidine derivatives as potential low honeybee toxic neonicotinoids. **Journal of Agricultural and Food Chemistry**, 2024.