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

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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.

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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 populationdeclines 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 thatattack 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 bitingand 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 aneffective 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, thesustainability 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 ascolony collapse (LUDICKE; NIEH, 2020). This collapse is characterized by the absence ofworker bees, which abandon the colony, leaving behind the queen and brood, whichcompromises 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 portionof these pesticide residues are carried by the wind, which can impact a wide range of insectsthat 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 productionand 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 thesechemicals 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 inBrazil, especially when we consider that there are around 3,000 species of bees in Brazil, ofwhich 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*odiversity.

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 veryimportant 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 focusesidentified. 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 adverseeffects associated with these insecticides widely used in agriculture. For example, the studiescarried 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 transmissionvia 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 ofthese 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

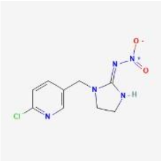
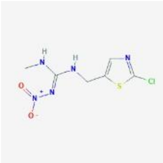
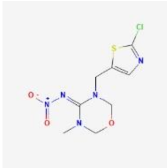
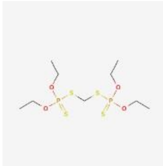
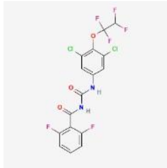
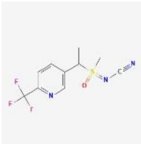
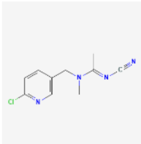
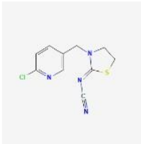
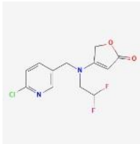
Xenoglossa pruinosa (Say, 1837) presents challenges, since responses may vary between species, making risk assessment difficult.

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 inbeekeeping, 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
	Apis mellifera	hyperexcitation (non-degradation of acetylcholine)	LU *et al.* (2024)
	Xenoglossa pruinosa	hyperactivity	RONDEAU; RAINE (2024)
	Trigona spinipes	interference in flightability	CUNHA PEREIRA *et al.* (2023)
	Apis mellifera, *Bombus* sp.; *Megachile*; *Melipona*; *Partamona*;	acute lethality	SHAHMOHAMADLOO; TISSIER; GUZMAN (2024)
	Apis mellifera	Genetic effects (detoxification processes)	DU *et al.* (2024)
Imidacloprid	*Tetragonisca angustula*; *Tetragonisca fiebrigi*; *Tetragonisca weyrauchi*	lethality	OLIVEIRA *et al.* (2023)

	Apis mellifera; *Apis florea*; *Xylocopa violacea*; *Xylocopa sarawakensis*	reduction in visits to flowers (decrease in foraging)	SALEEM *et al.* (2023)
	Apis mellifera;	Sexual stress (males)	MCAFEE *et al.* (2022)
	Apis mellifera	Sublethal effect (physiological)	DELKASH-ROUDSARI *etal.* (2022)
	Bombus terrestris	acute lethality	CABEZAS; FARINÓS (2022)
	Apis mellifera;	lethality	KAUR *et al.* (2020)
	Apis cerana cerana	Interference in climbing ability; decreased responsiveness to sucrose	GAO *et al.* (2020)
	Apis mellifera	lethality	SALEEM; HUANG; MILBRATH(2020)
	Apis mellifera, *Bombus* sp.; *Megachile*; *Osmia*;	acute lethality	SHAHMOHAMADLOO; TISSIER; GUZMAN (2024)
	Apis mellifera;*Apis florea*; *Xylocopa violacea*; *Xylocopa sarawakensis*	reduction in visits to flowers (decrease in foraging)	SALEEM *et al.* (2023)
Clothianidin	*Apis mellifera*	Genetic effects (detoxification processes)	DU *et al.* (2024)
	Apis mellifera	Genetic effects (detoxificationprocesses)	SON *et al.* (2023)
	Apis mellifera	oxidative stress; decrease immunity	ORČIĆ *et al.* (2022)
	Apis mellifera	hormetic effects	HARWOOD; PRAYUGO; DOLEZAL (2022)
	Bombus terrestris	acute lethality	CABEZAS; FARINÓS (2022)
Sulfoxaflor	*Apis mellifera*	Genetic effects (detoxification processes)	DU *et al.* (2024)
	Apis mellifera	sublethal effects (staggering, partial paralysis, contraction of the abdomen and spasms)	HELLER *et al.* (2022)
	Apis mellifera	Metabolic resistance	DU *et al.* (2024)
	Apis mellifera; *Apis florea*; *Xylocopa violacea*; *Xylocopa sarawakensis*	reduction in visits to flowers (decrease in foraging)	SALEEM *et al.* (2023)

	Apis mellifera, *Bombus*sp.; *Megachile*; *Scaptotrigona*; *Tetragonisca*	acute lethality	SHAHMOHAMADLOO; TISSIER; GUZMAN (2024)
	Apis mellifera	Genetic effects (detoxification processes)	DU *et al.* (2024)
Thiamethoxam	*Protopolybia exigua*	lethality	CRISPIM *et al.* (2023)
	Apis mellifera	Sexual stress (males)	MCAFEE *et al.* (2022)
	Apis mellifera	sublethal effects (staggering, partial paralysis, contraction of the abdomen and spasms)	HELLER *et al.* (2022)
	Apis mellifera;	letalidade	SALEEM; HUANG; MILBRATH (2020)
	Apis mellifera, *Bombus* sp.; *Megachile*; *Osmia*;	letalidade aguda	SHAHMOHAMADLOO; TISSIER; GUZMAN (2024)
	Apis mellifera	Metabolic resistance	DU *et al.* (2024)
Acetamiprid	*Apis mellifera*	sublethal effects (staggering, partial paralysis, contraction of the abdomen and spasms)	HELLER *et al.* (2022)
	Bombus impatiens	increase/decrease of males in the colony	CAMP *et al.* (2020)
	Bombus terrestris audax	moderate lethality	REID *et al.* (2020)
	Apis mellifera	moderate lethality	YANG *et al.* (2020)
Thiacloprid	*Bombus terrestris audax*	moderate lethality	REID *et al.* (2020)
	Apis mellifera	oxidative stress; decrease immunity	ORČIĆ et al.(2022)
	Apis mellifera;*Apis florea*; *Xylocopa violacea*; *Xylocopa sarawakensis*	reduction in visits to flowers (decrease in foraging)	SALEEM *et al.* (2023)
Ethion	*Apis mellifera*	sublethal effect (physiological)	DELKASH-ROUDSARI *etal.* (2022)
Hexaflumuron	*Apis mellifera*	sublethal effect (physiological)	DELKASH-ROUDSARI *etal.* (2022)
Flupyradifurone	*Apis mellifera*	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 isa growing recognition of the importance of investigating other native and wild species, suchas *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 ofreassessing 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 withbiological 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 impactson pollinators and ensure the resilience of agricultural systems in the long term.

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