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The relevance of evaluating the potential adverse effects of biopesticides on bees

A pertinência da avaliação dos efeitos adversos potenciais dos biopesticidas sobre as abelhas

La relevancia de evaluar los efectos adversos potenciales de los biopesticidas en las abejas

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Abstract

The use of biological products in Brazilian agriculture, such as “biological control agents” (Law No. 15,070/2024), also known as biological pesticides or biopesticides, is on the rise. Although they are used indiscriminately, little is known about their possible risks to nontarget organisms. Thus, this study aimed to collect and analyze data that included biopesticides production, including growth regulators and microbiologicals, specific manufacturers, the adverse effects of currently registered biopesticides on bees and the relevance of assessing potential adverse effects on bees. We also comment on the relevance of such studies in the context of conserving wild bee populations. Studies have already reported the risks biopesticides pose to pollinators and ecosystems, calling for the 1) evaluation and expansion of legal standards that establish and regulate the risk assessment of biopesticides and 2) the exercise of caution in the use of biopesticides, particularly in organic and agroecological production, until their risks are assessed.

Keywords: biological control agents, pollinators, risk assessment, nontarget organisms

Resumo

É crescente o uso de bioinsumos nas atividades agropecuárias do Brasil, como os “agentes de controle biológico” (Lei nº 15.070/2024), também denominados de pesticidas biológicos ou biopesticidas. Embora utilizados indiscriminadamente, pouco se conhece dos seus possíveis riscos em organismo não-alvos. Assim, o objetivo do trabalho foi investigar os dados relativos ao comércio dos biopesticidas, reguladores de crescimento e microbiológicos, entre outros; seus fabricantes; os possíveis efeitos sobre as abelhas dos biopesticidas já registrados e a pertinência da avaliação dos possíveis efeitos adversos sobre as abelhas. Os estudos já realizados indicam a ocorrência de riscos dos biopesticidas aos polinizadores e aos ecossistemas. Da presente investigação emergem duas necessidades: a primeira é a urgente análise e a ampliação de normas legais que instituam e disciplinem a avaliação de risco de biopesticidas; a segunda, é a cautela no uso dos biopesticidas, em particular na produção orgânica e agroecológica, até que seus riscos sejam avaliados.

Palavras-chave: agentes de controle biológico, polinizadores, avaliação de risco, organismos não-alvos.

Resumen

El uso de productos biológicos en la agricultura brasileña, como los "agentes de control biológico" (Ley N.º 15.070/2024), también conocidos como plaguicidas biológicos o biopesticidas, está en aumento. Si bien se utilizan indiscriminadamente, se sabe poco sobre sus posibles riesgos para organismos no objetivo. Por lo tanto, este estudio tuvo como objetivo recopilar y analizar datos que incluían la producción de biopesticidas, incluyendo reguladores de crecimiento y microbiológicos, fabricantes específicos y los efectos adversos de los biopesticidas actualmente registrados en las abejas y la pertinencia de la evaluación de los potenciales efectos adversos sobre las abejas.

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También comentamos la relevancia de dichos estudios en el contexto de la conservación de las poblaciones de abejas silvestres. Diversos estudios ya han reportado los riesgos que los biopesticidas representan para los polinizadores y los ecosistemas, lo que exige 1) la evaluación y expansión de las normas legales que establecen y regulan la evaluación de riesgos de los biopesticidas y 2) el ejercicio de precaución en el uso de biopesticidas, particularmente en la producción orgánica y agroecológica, hasta que se evalúen sus riesgos.

Palabras-clave: agentes de control biológico, polinizadores, evaluación de riesgos, organismos no blancos.

INTRODUCTION

The publication of Law No. 15,070 of December 23, 2024, heralded the beginning of regulation for all bioinputs used in agricultural activities, including biostimulants or growth or performance inhibitors, semiochemicals, biochemicals, phytochemicals, metabolites, organic macromolecules, biological control agents, soil conditioners, biofertilizers and inoculants. This also includes macroorganisms that function as biological control agents and microorganisms for different modalities. It is important to note that this law does not apply to the mixing of biological products with synthetic pesticides during the production process.

Although widely used in Brazil, the term biopesticide is not included in Brazilian legal standards. However, the term “biological control agents” (hereinafter referred to as biopesticides) is included in item 2, § 2, Art. 1 of Law No. 15,070. Thus, biological pesticides, plant extracts and microbiological agents are included in this law.

In the United States, the Environmental Protection Agency (USEPA, 1982) defined biopesticides, or biological pesticides, as including naturally occurring substances that control pests (biochemical pesticides), microorganisms that control pests (microbial pesticides), and pesticidal substances produced by plants containing added genetic material (plant-incorporated protectant). The United Nations Food and Agriculture Organization (FAO) and the World Health Organization (WHO) define biopesticide as “a generic term generally applied to a substance derived from nature, such as a microorganism or botanical or semiochemical, that may be formulated and applied in a manner similar to a conventional chemical pesticide and that is normally used for short-term pest control” (FAO, 2017).

Owing to their natural origin, biopesticides are sometimes considered less harmful to ecosystems, including flora and fauna, than synthetic pesticides (Haddi *et al*., 2020), particularly beneficial insects such as bees. Therefore, their use has been encouraged in crop protection. In addition, few studies in the literature have addressed the potential risks of biopesticides to pollinators and ecosystems. However, the reviews of Cappa *et al*. (2019; 2022) have indicated that biopesticides cause a multitude of sublethal effects on beneficial insects.

On the other hand, the indiscriminate and excessive use of synthetic pesticides has been shown to have deleterious effects on humans, ecosystems and biodiversity (Augusto *et al*., 2024; Hess *et al*., 2021). Furthermore, concerns have arisen about a decline in the bee population worldwide with considerable consequences for the pollination services they provide for crop production and the integrity of terrestrial ecosystems (Faita: Chaves: Nodari, 2021). Therefore, as an alternative to traditional crop protection methods, biopesticides or biologicals continue to increase in relevance.

At the same time, a general decline in pollinators is in progress, particularly bees, and this decline negatively affects wild and cultivated plant species (Potts *et al*., 2010). Of the 114 main plants used for food production, studies indicate that 87 require animal pollination (Klein *et al*., 2007). For one-third, dependence on pollinators is high or essential (Giannini *et al*., 2015). In the event of a pollinator crisis, production in Brazil would be compromised by 40 to 100%, highlighting the vulnerability of the Brazilian economy which is based on pollination-dependent agriculture (Novais *et al*., 2016). This impending crisis would affect Brazil's gross domestic product (GDP), dropping agricultural inputs by up to 19.36%, equivalent to approximately US$14.56 billion per year. Without pollinators, half of all flowering plants would experience a decline in fertility of more than 80%, while one-third would not produce seeds (Rodger *et al*., 2021).

Bees (Apoideae) are the most important group of pollinators, and they are responsible for pollinating 80% of crops (Wolowski *et al*., 2019). Unlike other animals that perform this ecosystem service, they depend exclusively on floral resources in all life stages (Michener, 2007). Currently, approximately 21,500 species of bees are known to be distributed throughout the world, of which approximately 90% are solitary and wild, while a smaller number of species are managed for pollination and honey production (Potts *et al*., 2016). Among managed bees, *Apis mellifera* stands out and is considered the main pollinator based on the number of bees per swarm (Roubik, 2002) in addition to solitary and eusocial stingless species (Potts *et al*., 2016).

Stingless bee species are distributed throughout tropical and subtropical regions of the world (Michener, 2007). Currently, 605 species have been described, with the greatest diversity occurring in the Americas, approximately 420 species (Engel *et al*., 2023). In Brazil, of the more than 2,000 existing bee species (Moure *et al*., 2008), 330 correspond to stingless bees (Engel *et al*., 2023). Of these, 95 species have potential for rational breeding, according to the National Catalog of Native Stingless Bees (ICMBIO, 2021).

Eusocial bees exhibit collective behavior in which colonies function as a superorganism (Moritz; Fuchs, 1998). Thus, researchers studying eusocial bees need to consider the complexity of interactions between castes and different generations because groups of individuals kept in the laboratory do not replicate their behavior in the colony or the dynamic relationships between the colony and its environment (Faita: Chaves: Nodari, 2021). Thus, to study adverse effects and conserve eusocial bees, the colony, not individuals, should be the focus.

Accordingly, this study aimed to collect and analyze data that included biopesticides production, including growth regulators and microbiologicals, specific manufacturers, and the possible adverse effects of currently registered biopesticides on bees, as well as the need for risk assessment of biopesticides prior to registration and use. We also comment on the relevance of such studies in the context of conserving wild bee populations.

METHODOLOGY

We used 1) the AGROFIT, linked to Ministry of Agriculture and Food Supply to obtain data about pesticides and both biological and microbiological control agents (biopesticides) registered for authorized use in Brazil; 2) the National Health Sanitary Agency (ANVISA) to obtain i) data about pesticides and biological and microbiological control agents (biopesticides) registered for authorized use in Brazil and ii) standards for assessing the safety of these products; 3) the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) to obtain data related to the trade of biological and microbiological pesticides and pesticides; 4) the Brazilian Legal and Legislative Information Portal (https://www4.planalto.gov.br/legislacao) to obtain standards for assessing the safety or risk assessment of biological and microbiological pesticides and 5) Web of Science, Scopus and Google Scholar databases to identify scientific articles that evaluated the search terms “effects of biopesticides on bees” or “effect of biological pesticide on bees”, or “effect of biological control on bees” or “effect of biological control agents on bees” of the most consumed products already registered in Brazil (obtained from AGROFIT). Searches conducted in the databases listed in 5) were carried out in March 2025, and in the other databases the accessed dates are indicated in the bibliographic references.

RESULTS AND DISCUSSION

Marketing of microbiological pesticides in Brazil between 2019 and 2023

As revealed by pesticide marketing reports released by IBAMA (2024), between 2019 and 2023, the quantity of microbiological pesticides sold in Brazil increased by 674.2%, going from 493 t in 2019 to 3,817 t in 2023. At the same time, the national production of these inputs increased by 1,404.0% (from 327 to 4,918 t) (Figure 1). The Brazilian states with the highest sales of microbiological pesticides in 2023 were Mato Grosso (773 t), São Paulo (728 t), Paraná (475 t) and Goiás (446).

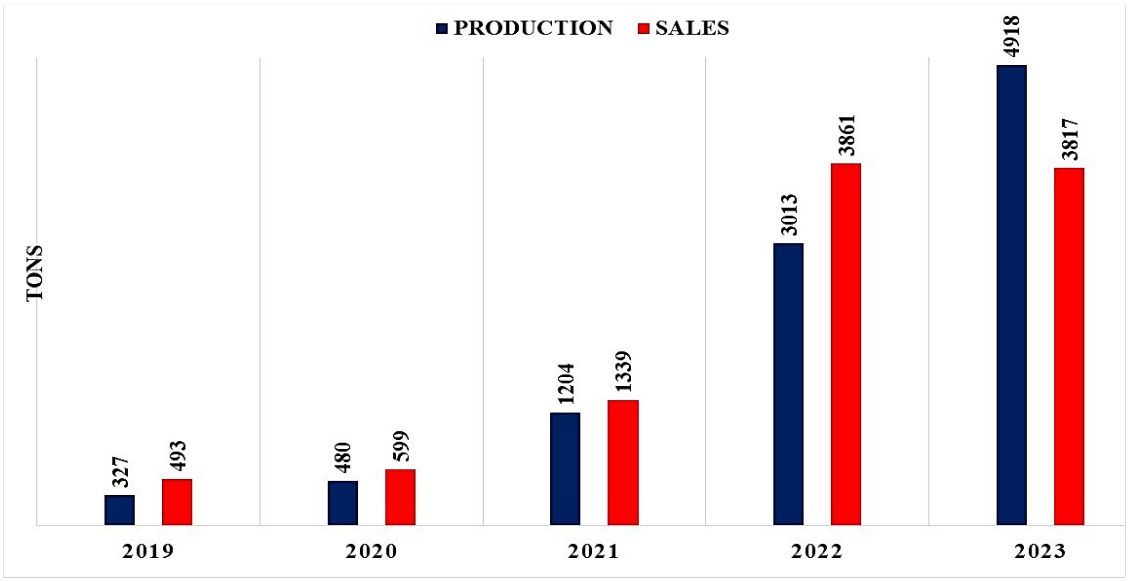

Figure 1 – Evolution of the quantity of microbiological pesticides produced and sold in Brazil (in t) between 2019 and 2023. Source: IBAMA, 2024.

The data in Figure 1 imply that production and sales grew 15 times and 7.7 times, respectively, in the five years between 2019 and 2023. Considering that biological and microbiological pesticides have also been made and used on farms, their use has increased significantly in the last five years. The data in Figure 1 also imply that the use of these products has been considered an alternative to synthetic pesticides. Extensive literature has shown that synthetic pesticides cause many diseases in humans, some fatal, and dangerous damage to the environment (Ayilara *et al*., 2023). Unlike synthetic pesticides, the authors state that microbiological pesticides have specific mechanisms of action, can be easily obtained without the need for expensive chemicals, and are environmentally sustainable with no residual effects. However, the authors do not scientifically demonstrate whether biopesticides are or are not environmentally safe and sustainable. For example, bees do not appear in the cited article at all. The only study cited on bees was based on OECD (Organization for Economic Co-operation and Development) analysis protocols, which are discussed below.

Overview of biological pest control agents authorized for use in Brazil

The registration of pesticides containing biologically or microbiologically active ingredients for pest control in 2019, 2020, 2021, 2022, 2023 and 2024 totaled, respectively, 41, 29, 79, 129, 96 and 98 products (AGROFIT, 2025). In November 2024, 559 pesticides with active ingredients were authorized for use in Brazil. Of these, 368 (65.8%) were chemical products, 95 (17.0%) were microbiological or biological agents, and 95 (17.0%) were synthetic pheromones, growth regulators and synthetic kairomones (ANVISA, 2025a, 2025b). Biological and microbiological pest control agents, including strains, isolates and lineages of microorganisms, totaled 209 active ingredients which presented insecticidal (78) and/or fungicidal and/or nematicidal (49) and/or acaricidal (12) and/or bactericidal (5) activities (ANVISA, 2025a, 2025b; AGROFIT, 2024). Among those biological control agents, 28 were not present in any commercial product registered with AGROFIT, while the others were part of one or more commercial pesticides with biologically active ingredients authorized for use in the country listed in AGROFIT as insecticides (399) and/or fungicides (157) and/or acaricides (109) and/or nematicides (89) and/or bactericides (13) (AGROFIT, 2024).

Among the biological pest control agents, those that were present in the largest number of products registered in AGROFIT in November 2024 were as follows: *Azadiracta indica* A. Juss, 1830; *Bacillus amyloliquefaciens* (ex Fukomoto, 1943) Priest *et al.*, 1987, strains and isolates; *Bacillus subtilis* (Ehrenberg, 1835) Cohn, 1872, strains, lineages and isolates; *Bacillus thuringiensis* Berliner, 1915, strains and isolates; *Bacillus velezensis* Ruiz-García *et al.*, 2005, strains, lineages and isolates; *Beauveria bassiana* (Bals.-Criv.) Vuill., 1912, strains and isolates; *Cordyceps fumosorosea*, synonym *Isaria fumosorosea* (Wize, 1904) Kepler, B. Shrestha and Spatafora, 2017, strains; *Cotesia flavipes* Cameron, 1891; *Metarhizium anisopliae* (Metschn.) Sorokīn, 1883, strains and isolates; *Trichoderma harzianum* Rifai, 1969, strains and isolates; *Trichoderma viride* Pers., 1794, isolates; and *Trichogramma pretiosum* Riley, 1879 (AGROFIT, 2024). Among these, six stand out by having marketed more than 100 t in 2022 (IBAMA, 2025): *Bacillus amyloliquefaciens*, fungicide and nematicide (1,879 t); *Trichoderma* *harzianum*, nematicide (972 t); *Bacillus subtilis*, fungicide, nematicide, insecticide (246 t); *Bacillus thuringiensis*, insecticide, acaricide (160 t); *Isaria fumosorosea*, insecticide (159 t); and *Beauveria bassiana*, insecticide, acaricide (110 t). In the European Union, the species *Cotesia flavipes*, *Trichoderma harzianum*, *Trichoderma viride* and *Trichogramma pretiosum* are not listed among the pesticides with authorized use (European Union, 2025).

The companies holding registrations for more than 10 biopesticides containing biologically or microbiologically active ingredients that were listed in the AGROFIT system in November 2024 were Total Biotecnologia Industria e Comercio S.A. (Biofirst group) - Curitiba/PR, 46 products; Koppert do Brasil Holding Ltda. (Koppert group) - Piracicaba/SP, 43 products; Simbiose Industry and Commerce of Fertilizers and Microbiological Inputs Ltda. – Cruz Alta/RS, 33 products; Ballagro Agro Tecnologia Ltda. - Bom Jesus dos Perdões/SP, 21 products; Vittia Fertilizers and Biologicals S.A. - São Joaquim da Barra/SP, 18 products; Agrobiológica Sustentabilidade S.A. (Cropcare Holding) – Jaguariúna/SP, 15 products; Lallemand Soluções Biológicas Ltda. (Lallemand Inc.) - Piracicaba/SP, 14 products; Solubio Agricultural Technologies S.A. – Jataí/GO, 14 products; Vital Brasil Chemical Industry and Commerce of Chemical Products Ltda. – Barretos/SP, 14 products; Promip Integrated Pest Management Ltda. – Engenheiro Coelho/SP, 12 products; Agrivalle Brasil Industry and Commerce of Agricultural Products S.A. – Indaiatuba/SP, 11 products; Topbio Biological Inputs Industry and Commerce Ltda. – Tibau/RN, 11 products; Bionat Biological Solutions Ltda. (Essere Group, holding) – Olímpia/SP, 10 products; TZ Biotec Ltda. – Ribeirão Preto/SP, 10 products (AGROFIT, 2024). Of these 14 companies, 71.4% (10) are located in the state of São Paulo, while the remaining 4 (7.1%) are located in the states of Paraná, Rio Grande do Sul, Goiás and Rio Grande do Norte. Therefore, although some microorganisms are developed outside Brazil, all companies have facilities in the country, indicating the technical and operational capacity for the national production and/or commercialization of such inputs to replace, or minimize, the expanded use of synthetically active ingredients.

Adverse biological activities of biopesticides on bees

Adverse biological activities are described for 12 biological ingredients of control agents with the highest number of commercial products registered in AGROFIT, Brazil, as well as studies that indicate toxic effects of these ingredients on bees (Table 1). These data are particularly worrying when considering their increasing application in extensive areas in Brazil, including aerial spraying where insecticides based on *Metarhizium anisopliae*, its strains and isolates, are applied in sugarcane plantations in the State of São Paulo (Nodari; Hess, 2023).

Of the 12 biological ingredients of control agents already registered in Brazil listed in Table 1, data from the scientific literature also demonstrate the adverse effects on bees for seven of them. In addition, the number of studies for each one of the various products already registered is wanting (Table 1). Compared to the individual effects of each product, the combined use of two or more products may also present synergism or even antagonism. For example, when bees are exposed to the combination of microbiological pesticides containing *Bacillus thuringiensis aizawai* ABTS-1857 and *B. amyloliquefaciens* QST 713, the average lifespan of bees was reduced to 4.5 days, down from 8.0 and 8.5 days before exposure, respectively (Alkassab *et al*., 2024). Exposure of bees to a mixture of the synthetic fungicides Zignal® and Captan SC® promoted a greater reduction in the density of the adult bee population, the number of open and closed broods, and the amount of stored food compared to the isolated use of the two fungicides (Chaves *et al*., 2022). These results indicate that biopesticides should be tested isolated or in mixtures for their toxicity to nontarget organisms before their release for use.

On the other hand, bees of the genus *Apis* can be used to disperse species in the biological control process, such as *Trichoderma harzianum* in the management of *Botrytis cinerea* in strawberries in the field. Termed as apivectoring, bees act as antagonists to the target (Shafir et al., 2006; Qiu et al., 2021).

In addition to the effects on bees, the scientific literature has also demonstrated effects on nontarget organisms. For instance, *Beauveria bassiana*, which has a generalist predatory habit and is an important biocontrol agent (Brock et al., 2021) can alter individual activity, reduce the survival of exposed workers either isolated or on colonies, impair the reproductive ability of foundresses, and induce the removal of exposed brood, leading to premature failure of colonies of the wasp *Polistes dominula* (Cappa *et al*., 2024). Moreover, in the chronic test, all tested concentrations of the biopesticide Neem (*Azadirachta indica*) affected the reproduction and size of *Daphnia magna* (Maranho *et al.*, 2014), an important component of plankton and the diet of aquatic invertebrates and vertebrates (Antunes; Castro, 2017). These results indicate that biopesticides harm organisms that belong to different trophic networks, causing imbalances with unknown effects.

Both the scientific community and citizens' groups concerned with species conservation are urging the use of bees and other organisms as indicators of environmental contamination. Indeed, both *Apis mellifera* (Cunningham *et al*., 2022) and *Scaptotrigona* aff. *depilis* (Rosa *et al*., 2015), the latter native to Brazil, are considered potential indicators of environmental contamination by pesticides. able 1 – Biological agents for controlling pests or plant diseases with the largest number of commercial products authorized for use in Brazil, their biological activities, the number of registered products and studies in which toxic effects on bees were measured.

In addition to the use of biopesticides in agriculture, urban residents are more likely to use biopesticides inappropriately in gardens, parks, backyards, and farms. Therefore, pollinators are likely to be contaminated by the active ingredients of these biopesticides in urban areas, as is the case with chemical pesticides already in use (Siviter *et al*., 2023). These authors detected residues of 13 different pesticides, some in concentrations known to have sublethal impacts on pollinators of eight genera, including bees.

Table 1 – Biological agents for controlling pests or plant diseases with the largest number of commercial products authorized for use in Brazil, their biological activities, the number of registered products and studies in which toxic effects on bees were measured

Active Ingredient *	Organism/ Origin	Biological Activities*	No. of products*	Affected bee species by toxic effects of active ingredient
Azadirachta indica, azadirachtin	Plant	Fungicide and insecticide	17	*Melipona quadrifasciata* (Barbosa *et al*., 2015); *Partamona helleri* (Bernardes *et al*., 2018); *Apis cerana* (Challa; Firake; Behere, 2019); *Apis mellifera* (Gomes *et al*., 2020); *A. cerana cerana* (Zhao *et al*., 2022).
Bacillus amyloliquefaciens, its strains and isolates	Bacteria	fungicide and/or nematicide and/or acaricide	45	*A. mellifera* (Sabo *et al*., 2020)
Bacillus subtilis, its strains, lineages and isolates		Bactericide and/or fungicide and/or nematicide and/or insecticide and/or plant activator	42	*Bombus terrestris* (Mommaerts *et al*., 2009); *B. impatiens* (Ramanaidu; Cutler, 2013).
Bacillus thuringiensis	Bacteria	Insecticide and/or nematicide	61	*A. mellifera* (Steinigeweg *et al*., 2021, 2023).
Bacillus velezensis, its strains and isolates	Bacteria	Fungicide and/or nematicide	25	Not reported
Beauveria bassiana, its strains and isolates	Fungus ascomycete	Insecticide and/or acaricide	118	*B. terrestris* (Mommaerts *et al*., 2009; Demirozer *et al*., 2022); *B. impatiens* (Ramanaidu; Cutler, 2013); *A. mellifera* e *Meliponula ferruginea* (Omuse *et al*., 2022); *Tetragonisca angustula*, *Scaptotrigona mexicana* e *Melipona beecheii* (Toledo-Hernández *et al*., 2016); *Scaptotrigona* aff. *depilis* (Santos, 2023); *A. mellifera* (Cappa *et al*., 2019; Carlesso *et al*., 2020; Telles Amandio *et al*., 2024); *T. angustula* (Almeida *et al*., 2022); *S. depilis* e *T. angustula* (Leite *et al*., 2022); *M. quadrifasciata*, *Plebeia droryana* e *S. bipunctata* (Faita; Pereira; Poltronieri, 2024).

Active Ingredient *	Organism/ Origin	Biological Activities*	No. of products*	Affected bee species by toxic effects of active ingredient
Cordyceps fumosorosea (*Isaria fumosorosea*, *Paecilomyces fumosorosea*) and its strains	Fungus ascomycete	Insecticide, nematicide	8	*T. angustula, S. mexicana e M. beecheii* (Toledo-Hernández *et al., 2016); M. quadrifasciata, P. droryana* e *S. bipunctata* (Faita; Pereira; Poltronieri, 2024).
Active Ingredient *	Organism/ Origin	Biological Activities*	Number of products *	Affected bee species by toxic effects of active ingredient
Cotesia flavipes	Wasp/ animal	Insecticide	28	Not reported
Metarhizium anisopliae, its strains and isolates	Fungus ascomycete	Insecticide	111	*A. mellifera* e *M. ferruginea* (Omuse *et al*., 2022); *T. angustula*, *S. mexicana* e *M. beecheii* (Toledo-Hernández *et al*., 2016); *S. depilis* e *T. angustula* (Leite *et al*., 2022); *M. quadrifasciata*, *P. droryana* e *S. bipunctata* (Faita; Pereira; Poltronieri, 2024).
Trichoderma harzianum, its strains and isolates	Fungus ascomycete	Fungicide and/or nematicide	74	Not reported
Trichoderma viride	Fungus ascomycete	Fungicide	30	Not reported
Trichogramma pretiosum	Fungus ascomycete	Insecticide	12	Not reported

*Source: AGROFIT, 2025

Some biopesticides on the international market have not yet been registered in Brazil. An example is the biopesticide Spinosad, constituted of spinosyns A and D, extracted from the bacterium Saccharopolyspora spinosa, which are extremely toxic to A. mellifera (Cappa *et al*., 2022). Exposure of bees to Spinosad causes aberrant transcription of genes that encode proteins in important physiological pathways, such as neuronal signaling, regulation of the immune system, oxidative phosphorylation, metabolism, and endocrine regulation (Christen *et al*., 2019). However, the authors of this study, which was carried out in Germany, found that the damage was much less when bees were exposed to pollen containing spinosyns in the summer compared to the spring season.

Relevance of assessing the potential damage of biopesticides to bees and other nontarget organisms

Because they are considered less toxic or even natural, biopesticides used in agriculture have not raised the same concerns when compared to other substances that are potentially harmful to human health and the environment. According to FAO and WHO, for microbial pest control agents or microbial pest control products that are pathogenic to insects, information from high-quality literature or studies on the pathogenicity of microbial pest control agents for bees in relevant environmental compartments should be provided (FAO, 2017).

Both agencies have indicated that non-native species of microbial agents or microbial pest control products that are insect pathogens pose a greater risk because nontarget organisms may never have been exposed to them. Therefore, information on the potential effects of microorganisms on nontarget organisms found in the relevant soil, air or water compartments should be provided (FAO, 2017).

Currently, testing is limited to existing protocols for synthetic chemical pesticides (OECD, 1998a, b; 2013; 2017), whose sublethal effects were documented late, since physiological and/or behavioral changes are not adequately considered for commercial product registration (Cappa *et al.*, 2022). On the other hand, the same authors argue that the literature review demonstrates that biopesticides cause a multitude of sublethal effects on pollinating insects, which is corroborated by the data presented in Table 1.

In the European Union (EU), biopesticides are not treated as a separate category; instead, they are regulated under the general Plant Protection Products (PPP) framework, primarily by Regulation (EC) No. 1107/2009 (EUROPEAN UNION, 2009). This includes specific data requirements for microbially active substances and products, as detailed in Regulations (EU) No. 283/2013 (EUROPEAN UNION, 2013) and No. 284/2013 (EUROPEAN UNION, 2013). The EU also has a two-tier approval system whereby the active microorganism is initially approved at EU level, followed by individual Member State approvals.

In the United States, biopesticides are grouped into three classes: microbial pesticides, plant-incorporated protectants, and biochemical pesticides. The Environmental Protection Agency (USEPA) has determined that pest control organisms, such as predatory insects, nematodes, and macroscopic parasites, as well as pheromones and identical or substantially similar compounds, labeled for use exclusively in pheromone traps and pheromone traps in which these chemicals are the sole active ingredients, are exempt from the requirements of FIFRA (40 CFR 152.20(a)) that apply to synthetic pesticides (USEPA, 1996).

In Brazil, Law No. 15,070 of December 23, 2024 (Bioinputs Law) does not establish any device or obligation for bioinputs for agricultural, livestock, aquaculture and forestry use, either for products already registered or for those that may be registered in the future (BRASIL, 2024). The word risk is only mentioned once in Art. 9, which states that the federal agricultural defense agency may establish exemptions for low-risk products in its own normative act. However, up to now, no guidelines or requirements have been established for a product to be classified as "low risk."

However, the Bioinputs Law, which includes biological control agents, is added to other legal norms that over the last 15 years have encouraged the use of new chemical or biological products without adequate and pertinent assessment of adverse effects on nontarget organisms, such as bees. This absence of specificity calls for the development of legal norms to establish and regulate the risk assessment of biopesticides. Until such codification in law, caution should be exercised in the use of biopesticides, particularly in organic and agroecological production, until the damage these products cause to nontarget organisms has been adequately assessed and products duly registered or not.

CONCLUSION

The use of biopesticides or biological control agents is increasing in Brazil since these products are an alternative to synthetic pesticides, as evidenced by their production, which increased 15 times between 2019 and 2023. In the scientific literature, studies proving damage to bees were found for seven of the twelve most common biological ingredients of control agents registered up to November 2024 in Brazil.

The existing studies of different biological ingredients of biopesticides already authorized in the country were carried out with only a small number of bee species existing in the country (14 of approximately 2,000). This sample should be considered too small to draw firm conclusions about the effects of biopesticides on bee species and colonies. In particular, since it was found that biopesticides used as insecticides can have several modes of action, sublethal effects should be taken into account in the commercial production chain. In addition, *Bacillus thuringiensis* (Bt) toxins incorporated into transgenic plants do not have a complete description of their modes of action, which can cause sublethal effects in nontarget organisms, particularly native bees. Moreover, the effects of the same biopesticide can vary on different pollinators.

Collectively, these circumstances call for additional studies on the potential impacts of these biopesticides on nontarget organisms and pollinators, both for biopesticides already in use and those yet to be registered, aiming at biological control. To this end, regulatory standards must be developed and implemented as soon as possible, avoiding the damages already described, as well as those still unknown.

For a new conventional pesticide to be launched on the market, legal standards require that the product be tested for toxicity, selectivity and potential effects on human health and the environment. However, most biopesticides remain exempt from such requirements and are not subject to risk assessment studies. Our work shows this omission creates risks for individual bees and their colonies and further posits some suggestions to address these gaps.

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