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Brazilian Legislation Leaning Towards Fast Registration of Biological Control Agents to Benefit Organic Agriculture

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Abstract

Brazil is one of the main users of chemical pesticides in the world. These products threaten human and environmental health, and many of them are prohibited in countries other than Brazil. This paradigm exists in contrast with worldwide efforts to make the need for food production compatible with biodiversity conservation, preservation of ecosystem services, and human health. In this scenario, the development of sustainable methods for crop production and pest management such as organic agriculture and biological control are necessary. Herein, we describe how the process of registration of natural enemy–based products in organic agriculture is simpler and faster than the conventional route of chemical insecticides and can favor the development of the biological control market in Brazil. Since the regulatory mechanisms have been established in Brazil for organic agriculture, the number of biological control products registered has increased exponentially. Today, 50 companies and associations are marketing 16 species/isolates and 95 natural enemy–based products. Although this scenario presents a series of new opportunities to increase and stimulate a more sustainable agriculture in the country, biological control is not always aligned with the aims and philosophy of organic agriculture and agroecology. Therefore, we also argue that new research efforts are needed on understanding how conservation biological control strategies can be integrated with augmentation biological control to promote a sustainable agriculture under the concepts of organic agriculture and agroecology.

Introduction

The expansion of Brazilian agricultural production has positioned the country as one of the largest producers of food and fiber in the world (FAO 2016). The technological development of large-scale agribusiness, which expanded into regions previously inaccessible to agriculture, such as the Cerrado biome and ecotones with neighboring biomes at the northern border, has made this position possible (Vieira Filho 2016). Together with the expansion of the cropped area, an increase has occurred in problems caused by several native and invasive arthropod pests (Oliveira *et al* 2013). To deal with most of these pests, chemical pesticides are used as the main line of crop defense in the country. In fact, Brazil is one of the main users of chemical pesticides in the world (Carneiro *et al* 2015).

The United Nations (UN) recently released a special report on the right to food, indicating how pesticide use in agriculture threatens human rights due to its impacts on human health, environment, and society (UN 2017). These concerns are also related to the Convention on Biological Diversity (CBD). The CBD states that all parties should create national strategies for using and conserving biodiversity at all its levels of organization to achieve a sustainable development perspective (CBD 2010). Although the use of pesticides is not explicit in the CBD documents, a reasonable assumption is that if pesticides impose a risk to biodiversity conservation, the use of such products is contradictory to this convention, of which Brazil is a signatory.

In contrast to what is being done in other countries where the reduction of pesticides is a goal to achieve in agriculture (UN 2017), Brazilian politicians are proposing changes in the current legislation to loosen the registration of chemical pesticides. They argue that the current laws delay the registration process of new pesticides or active ingredients, which, in turn, slows down agricultural development in the country. Currently, in short, all pesticides must be evaluated by the Ministry of Agriculture Livestock and Food Supply (MAPA) in conjunction with the National Agency of Health Surveillance (ANVISA) and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). Bill 6299/2002 and its attachments propose that the only organization responsible for the registration of pesticides and related products to be used in agriculture should be the MAPA (Brazil 2002). Moreover, if the process of registration analysis takes more than 1 year, the product would be automatically registered and released for use, even without a technical analysis by a competent institution (IBAMA 2018).

We do not intend to discuss the problems inherent in this proposition; we intend instead to discuss other ways for sustainable pest management in Brazil to move forward using the already established laws and registration pathways in the country, without the need for a new chemical products registration law. Sustainable pest management can be achieved by reconciling the demand for food production with biodiversity conservation to provide important ecosystem services to crop production, such as biological control. This could be achieved by managing agricultural lands using an ecological process in pest management instead of with artificial and external inputs.

First, it is necessary to consider biological control, regardless of the strategy used, which has a strong scientific background with several successful cases in Brazil and is suitable for conventional and organic cropping systems (Parra and Zucchi 2004, Venzon and Sujii 2009, Parra 2014, Venzon *et al* 2015, van Lenteren *et al* 2018). Second, organic agriculture is dependent on several ecosystem services for crop production because chemical products are not allowed, and biological control can be used in this competitive and profitable segment of the Brazilian agriculture (Willer and Lernoud 2016). Third, the Joint Normative Instruction SDA/SDC/ANVISA/IBAMA 1/2011 established the legislative routes to register natural enemy–based products for organic agriculture in a simple, fast, and prioritized way in relation to the conventional route of registration. Thus, the scenario to invest and support the pathway to a more sustainable agriculture in the country is already established.

However, although different biological control strategies exist, the augmentative biological control is the only strategy covered by the actual Brazilian legislation for organic agriculture. After the Normative Instruction (NI) 5/2016 from IBAMA (IBAMA 2016)**,** the importation of arthropod natural enemies to Brazil is not possible, which limits the development of new strategies of classical biological control in the country. Conservation biological control can be combined with augmentative biological control to improve the efficiency and the long-term control of target pest species (Sujii *et al* 2010, Venzon *et al* 2015), but this is rarely done. These facts demonstrate that old problems are related to the lack of new perspectives for integrating biological control strategies through a truly sustainable agriculture. However, those facts also indicate that new scientific opportunities are available to make biological control a more consistent and reliable strategy. Our aim was to stimulate the debate on the registration of biological control agents in Brazil and discuss how researchers can move toward a truly sustainable agriculture in the country, using biological control strategies mainly in organic agriculture.

Are Chemical Pesticides the Only Alternative to Control Pests in Brazil?

The evolution of pesticide use in the country has increased exponentially, whereas the cropped area has increased slowly in the past 5 years (Carneiro *et al* 2015). In 2015, 21 crops were estimated to occupy an area of 71.227 million ha in Brazil. These crops alone used 899 million liters of pesticides (Pignati *et al* 2017). Another major concern is that many pesticides used in Brazil are prohibited in several countries. For example, 150 pesticides are registered for soybeans in Brazil, and among these, 33 are prohibited in the European Union due to the possible side effects on human and environmental health (Bombardi 2017).

One can argue that the use, development, and registration of pesticides are justified due to pest incidence and damage in most crops throughout the year in the tropical region. In fact, only the exotic invasive insect pests introduced in Brazil, such as *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), *Anthonomus grandis* Boheman (Coleoptera: Curculionidae), and *Ceratitis capitata* Wiedemann (Diptera: Tephritidae), have caused annual losses of US$12.0 billion to the Brazilian economy (Oliveira *et al* 2013). These species, along with the stinkbugs *Euschistus heros* (Fabricius), *Dichelops melachantus* (Dallas) (Hemiptera: Pentatomidae), the caterpillars *Helicoverpa* *armigera* (Hübner), *Chrysodeixis includens* (Walker), *Heliothis virescens* (Fabricius), *Anticarsia gemmatalis* Hübner, and *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae), and the fruit flies *Anastrepha grandis* (Macquart), *Anastrepha fraterculus* (Wiedemann), and *Bactrocera carambolae* (Drew & Hancock) (Diptera: Tephritidae), are listed as economically important pests with a major phytosanitary risk to Brazilian agricultural crops (MAPA 2018). However, pest resistance to pesticides also costs billions of dollars to all countries in the world, because new products and formulations must be developed every year. Currently, pests are evolving resistance to many active ingredients more rapidly than companies and researchers are able to develop new efficient products (Gould *et al* 2018), regardless of the time taken for registration. Pesticides are also very hazardous to the environment and endanger the provision of several important ecosystem services to agricultural production, such as pollination and biological control (Garibaldi *et al* 2016, Togni *et al* 2018).

Therefore, new approaches to the problem are needed. As phytophagous insects have evolved for millions of years with their natural enemies, the logical approach is to invest in using natural enemies of pests by addressing their ecological importance and usage in agriculture (Michaud 2018). A viable route to accomplish this, as well as compatible food production with biodiversity conservation, provisioning of ecosystem services, and human health, is the promotion of agroecology (UN 2017). The term agroecology is difficult to define because the local and regional perceptions of it vary in each country. We will use the term agroecology as the ecological study of food systems, which also includes the interactions with social and economic dimensions to maintain long-term human and environmental health. According to FAO (2018), independent of each country definition, policymakers, practitioners, and stakeholders can use the following 10 interlinked and interdependent elements in its own definitions of agroecology: (1) diversity within the farm; (2) cocreation and sharing of knowledge; (3) identification of synergies to support food systems and ecosystem services; (4) efficient production of more with fewer external resources; (5) use of recycling to reduce the economic and environmental costs; (6) resilience of people and ecosystems; (7) promotion of human and social values; (8) respect for culture and food tradition; (9) responsible governance; and (10) circularity and solidarity of economy.

Agroecological movements and organic agriculture have a long history in Brazil (Costa *et al* 2017), but organic agriculture was not officially defined and recognized in the country until 2003. The law 10831/2003 defines organic agriculture as all cropping systems that adopt specific techniques that optimize the use of natural and socioeconomic resources with the aim of achieving economic and ecological sustainability. After that, the Decree 7794/2012 created the National Policy of Agroecology and Organic Production, in which one of the goals is the national reduction of pesticide use (Brazil 2012). This is in line with the perspectives of the UN and the objectives of CBD (UN 2017).

Regarding pest management in organic systems, replacing external inputs by ecological process and enhancing and conserving local biodiversity to optimize the ecosystem service of biological control should be prioritized (Zhender *et al* 2007, Sujii *et al* 2010, Venzon *et al* 2015). However, in some situations, preventive strategies are not enough to avoid insect pest outbreaks, and curative strategies, such as spraying botanical insecticides and the augmentative release of natural enemies, can be used (Zhender *et al* 2007).

The use of these non-chemical pest control strategies in organic agriculture is regulated by NI 46/2011, which has been modified by NI 17/2014 and NI 35/2017, from the MAPA, which establishes and constantly updates the list of substances allowed for use in pest management in organic agriculture (MAPA, 2011, 2014, 2017). This list allows the use of biological control agents in augmentative strategies, including predators, parasitoids, and microorganisms. Predators and parasitoids are included in the category of Biological Control Agents (BCA) and microorganisms in the category of Microbial Control Agents (MCA). To better understand the registration process and stimulate debate among biological control practitioners, we will focus on the registration of biological and microbial agents in organic agriculture.

How Are Natural Enemy–Based Products in Organic Agriculture Registered?

In a recent paper, van Lenteren *et al* (2018) argue that to accelerate and stimulate the registration of biological control products over chemical pesticides, a fast track and priority process and the development of specific protocols for biological control agent registration would be good choices. In this sense, the actual Brazilian legislation has advanced a step forward. The actual legislation gives priority to the registration of phytosanitary products to be used in organic agriculture because they are less hazardous to the environment and to human health (Joint NI SDA/SDC/ANVISA/IBAMA 1/2011,MAPA/ANVISA/IBAMA, 2011).

To make the registration process easier, faster, and a priority, MAPA, ANVISA, and IBAMA can use the scientific and technical information already available and published as a background to create and establish a reference specification for a given active ingredient (e.g., plant extract) or biological control agent species. The reference specification should be published by the MAPA before the registration of a given product. After that, other parties interested in registering products using the same active ingredient or species could request its registration and use the available information in the reference specification.

To request the generation of a reference specification, the interested party should request it from the local Commission of Organic Production (CPOrg) (a social organization formed by governmental and non-governmental entities involved with the local production in each state). The CPOrg will develop a prioritized list of products according to the local demands and send it to the MAPA. The MAPA, together with ANVISA and IBAMA in a working group, is then responsible for creating the demanded reference specification. These specifications will indicate, for each product to be registered, the valid species name, taxonomic classification, class of use, type of formulation, target pest to be controlled, crops where the products can be used, and other general recommendations on how to use the product efficiently. When a product is registered based on a new established reference specification, the entire process of subsequent registration requests is faster because the information for registration is already available to the competent institutions.

The specific information needed to register a BCA or an MCA is described in the Joint NI 2/2006 MAPA/ANVISA/IBAMA. The first information needed is the biological characterization for each organism to be registered. This includes the taxonomic classification, the previous synonyms, morphological traits, biology, and geographical distribution. The ANVISA also requires information about the possible side effects on human health and toxicological tests. The IBAMA demands information regarding the possible effects on the native vegetation and wild animals and analyzes the suitability of ecotoxicological tests with model organisms in terrestrial and aquatic ecosystems. When available, other information, such as previous use or registration in other countries, should also be provided. Product efficiency is also essential information that is demanded. Field studies are prioritized in the decision making, whereas laboratory and semifield assays are treated as evidence for efficiency. Therefore, researchers must be stimulated to provide more field studies to support the decision making.

Other important information are the description of the mass rearing of each species/isolate, including the physical environment necessary to rear the natural enemy; details about how these organisms will be fed; and other related procedures, such as cleaning and safety level of the facilities and avoidance of external contamination. Information about the rearing methods can be obtained in the scientific literature. For some well-studied species, such as *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae), *Dygliphus begini* (Ashmed) (Hymenoptera: Eulophidae), *Trichogramma* spp. (Hymenoptera: Trichogrammatidae), *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae), *Chrysoperla externa* (Hagen) (Neuroptera: Chrysopidae), and *Orius insidiosus* Say (Hemiptera: Anthocoridae), this information is easy to find (e.g., van Lenteren *et al* 2002, Bueno 2009). However, the development of rearing methods for indigenous species or the adaptation of current rearing systems of related species, followed by the publication of these techniques, is needed (but see Parra *et al* 2002, Bueno 2009).

Finally, quality control guidelines should be provided for mass production and commercialization. This information can be found on the document produced by the International Organization for Biological Control (IOBC) for some species of predators and parasitoids (van Lenteren *et al* 2002). The main difficulties lie in these parameters having been developed mainly for species and populations used in temperate regions. An opportunity exists for Brazilian biological control practitioners to develop national guidelines according to the studies performed in Brazil using the international material as background (but see Bueno 2009).

All data and studies cited above can be provided by the interested party, and the information provided will be analyzed by the competent institutions. In case some test or information is missing in the scientific or technical literature, the MAPA will request it from the interested parties. After that, the product is registered and labeled as "phytosanitary product with permitted use in organic agriculture." These products will be commercially available to any farmer, independently of his/her production system.

Has the Registration of Biological Control Agents Increased in Organic Agriculture Since Its Regulation?

As of August 2018, 36 reference specifications had been published, of which 27 were related to natural enemy species/isolates. The reference specifications about natural enemies were related to fungi isolates (9), followed by parasitoids (6), predators (6), bacteria (4), and viruses (3). The other eight reference specifications are products other than natural enemies. As the prioritization list is elaborated by the CPOrgs, these products can reasonably be assumed to be the most used and demanded by organic growers in the different regions in Brazil. The complete list and details about these reference specifications can be accessed at the following website: http://www.agricultura.gov.br/assuntos/sustentabilidade/organicos/produtos-fitossanitarios/especificacao-de-referencia.

For an overview on the evolution of the registration of natural enemies in organic agriculture in comparison with the conventional agriculture in Brazil, we consulted the AGROFIT database (AGROFIT 2018). The AGROFIT database is a publicly available database on the agrochemicals, including pesticides, registered by the MAPA in Brazil in the conventional and organic agriculture. This database is the official registration system for all chemical and non-chemical pesticides in Brazil which provides the technical information and a detailed description of each product registered. Using this database, we made a search of the formulated products in the class of BCA and MCA registered to the organic and conventional agriculture. We assessed the date of registration for each product reported by the database. After that, we classified the BCA and MCA products according to the cropping system (i.e., conventional or organic) and calculated the cumulative number of products registered for each category from 2008 to July 2018.

Since the registration of natural enemy–based products was regulated in 2011, the number of products registered increased rapidly and consistently (Fig 1). It means that all Brazilian agriculture has benefited by this route of registration because the number of these products more than doubled in the past 5 years (Fig 1). Another interesting pattern occurred in the registration of products for organic agriculture, which surpassed the registration of products for conventional agriculture (Fig 1). Most likely, this is related to the priority, fast-track registration process and because, by following this route to registration, the product will be available to organic and conventional growers. As more reference specifications are published, more products tend to be registered.

In 2012, van Lenteren (2012) reported a "frustrating lack of uptake" in the use of new species commercially available for augmentative biological control from 1900 until 2010. However, in 2018, the same author and colleagues published a new study indicating that biological control strategies have "plenty of new opportunities" (van Lenteren *et al* 2018). The period between the studies coincides with the period of normalization of the registration of biological control products for organic agriculture in Brazil. We argue that, together with the increasing interest in biodiversity-friendly pest management strategies around the world (Ferreira *et al* 2012, Melo *et al* 2013, UN 2017), Brazil has contributed to the change in perspective illustrated by the studies of van Lenteren (2012) and van Lenteren *et al* (2018) due to the route of registration established for organic agriculture.

Biological Control Agents Registered for Organic Agriculture in Brazil

To explicitly evaluate the availability of natural enemy–based products in Brazilian organic agriculture, we consulted the list of phytosanitary products registered for organic agriculture per company, and the list of companies with products registered for organic agriculture published on the MAPA website (http://www.agricultura.gov.br/assuntos/sustentabilidade/organicos/produtos-fitossanitarios, accessed on 18 October 2018). We assessed the AGROFIT database to survey the states where the companies are based, the target pests of each product registered in the organic agriculture, and the crops for which the products were registered (AGROFIT 2018). First, we used the registration number of each product in the list for the basic search in this database. Using the default result generated, we evaluated the active ingredient of each product, the target pest of each product registered, the crops for which the product is registered, and the state where each company is based. We then counted the number of products registered by category of natural enemy (predators, parasitoids, bacteria, fungi, and virus). Data from other products, such as botanical extracts, were excluded from our analysis. We found 50 companies and associations marketing 16 species of natural enemies, which accounted for 95 products with active registration for use in Brazilian agriculture (Table 1).

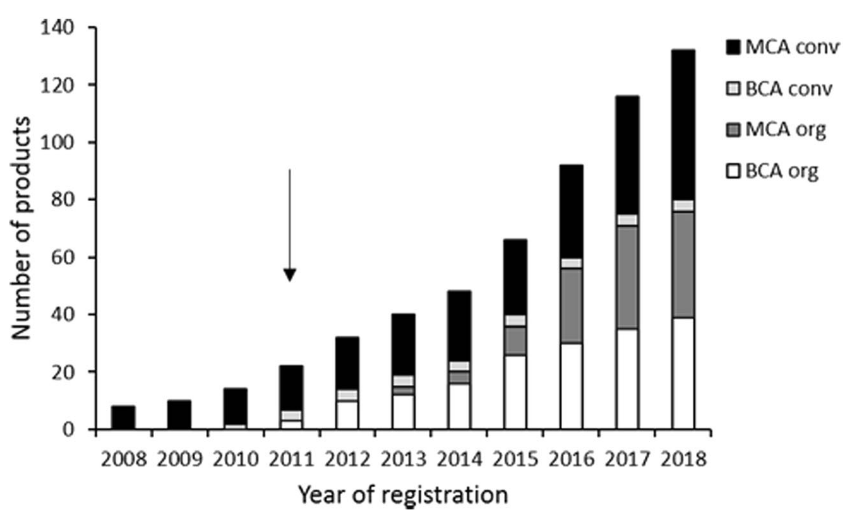

Fig 1 Evolution of the registration process of biological control agent (BCA) and microbial control agent (MCA) products in conventional (conv) and organic (org) agriculture in Brazil, based on cumulative number of products registered over time. The arrow indicates when the registration of natural enemy–based products was regulated in Brazil for organic agriculture.

Table 1 Natural enemy species commercially available with permitted use in organic agriculture in Brazil, with the number of commercial products available, states where the companies are based, crops in which the products are registered, and target pest of the products.

Natural enemies	Commercial products	Crops	Target pest	States (number of companies)
Predators				
Cryptolaemus montrouzieri	1	All crops where the target pest occurs	*Maconellicoccus hirsutus*	SP (1)
Neoseiulus californicus	2	All crops where the target pest occurs	*Tetranychus urticae*	SP (2)
Orius insidiosus	2	All crops where the target pest occurs	*Frankliniella occidentalis*	SP (2)
Phytoseiulus macropilis	3	All crops where the target pest occurs	*Tetranychus urticae*	SP (2)
Stratiolaelaps scimitus	2	All crops where the target pest occurs	*Bradysia matogrossensis*	SP (2)
Parasitoids				
Cotesia flavipes	27	Sugarcane, all crops where the target pest occurs	*Diatraea saccharalis*	AL (2) / SP (14) / GO (2)
Trichogramma galloi	5	All crops where the target pest occurs, sugarcane	*Diatraea saccharalis*	AL (1) SP (4)
Trichogramma pretiosum	5	Corn, soybean, tomato, all crops where the target pest occurs	*Helicoverpa zea*, *Spodoptera frugiperda*, *Crysodeixis includens*, *Anticarsia gemmatalis*, *Tuta absoluta*, *Pseudoplusia includens*	SP (4), MG (1)
Bacteria				
Bacillus methylotrophicus UFPEDA 20	1	All crops where the target pest occurs	*Meloidogyne javanica*, *Pratylenchus brachyurus*	MG (1)
Bacillus subtilis UFPEDA 764	1	All crops where the target pest occurs, soybean	*Meloidogyne javanica*, *Pratylenchus brachyurus*	MG (1)
Fungi				
Beauveria bassiana IBCB 66	17	Banana, corn, strawberry, cucumber, soybean, all crops where the target pest occurs	*Cosmopolites sordidus*, *Dalbulus maidis*, *Tetranychus urticae*, *Bemisia tabaci* biotype B	BA (1)/ MG (2)/ RS (2)/ SP (9)/ GO (1)
Metarhizium anisopliae IBCB 425	24	All crops where the target pest occurs, pasture, sugarcane	*Mahanarva fimbriolata*, *Zulia entreriana*, *Deois flavopicta*	AL/ AL (1)/ BA (2)/ RS (1)/ MG (2)/ GO (1)
Trichoderma asperellum URM 5911	1	Bean, cotton	*Rhizoctonia solani*, *Fusarium solani f.sp. phaseoli*	MG (1)
Virus				
Baculovirus *Anticarsia gemmatalis*	1	Soybean	*Anticarsia gemmatalis*	PR (1)
Baculovirus *Spodoptera frugiperda*	2	Corn, all crops where the target pest occurs	*Spodoptera frugiperda*	RS (1)/ MG (1)
Baculovirus *Condylorrhiza vestigialis*	1	Alamo	*Condylorrhiza vestigialis*	PR (1)

Microbial Control Agents

Fungal isolates accounted for 44.2% of the total number of products registered as biological control agents and 87.5% of the total number of microbiological products available. Together, *Metarhizium anisopliae* and *Beauveria bassiana* products represented 43.16% of the total number of products available and 85.42% of the MCA products (Table 1). This is probably because these products are used in large-scale crops such as sugarcane and pasture (Table 1) and were recognized as efficient tools to control several species of spittlebugs including *Mahanarva fimbriolata* (Stål) and *Deois flavopicta* (Stål) (Hemiptera: Cercopidae), even before their use in organic agriculture (Alves and Lopes 2008). These same products dominated the Brazilian market of microbial insecticides before the regulation of their registration in organic agriculture (Michereff-Filho *et al* 2009). Today, 20 companies are operating in seven different states, composing the country's most representative market of biological control agents in organic agriculture (Table 1). This indicates that the species commercialized before 2011 are still present in the Brazilian market, but now farmers have more options for suppliers in conventional and organic systems.

The formulation and application of microbiological products are very similar to chemical pesticides, and growers in the transition process to organic agriculture are more familiar with them than with other products such as predator- and parasitoid-based products (Sousa *et al* 2016). Nevertheless, only two bacterial-based products have active registrations for organic agriculture. These products are restricted to the control of nematode species, and they are produced in only one state (Table 1). Therefore, the market for these products may have been restricted. Moreover, the target species are very restricted in comparison with fungal targets. It is also necessary to consider other well-known products based on *Bacillus thuringiensis* (*Bt*) which were registered and used in Brazil before the registration route in organic crops was available. A single published reference specification exists for *Bt* var. kurstaki HD-1, and that publication indicates that new products will be registered. Additionally, *Bt* products are commonly and widely used in the world (Lacey *et al* 2015).

Regarding viruses, four *Baculovirus* products are registered for the control of three lepidopteran species. Most target species are key pests of large-scale crops such as soybeans and corn (Table 1). Brazil has been one of the leading countries of the world in the use of *Baculovirus*. By the mid-1990s, *Baculovirus* was applied in approximately 1 million ha of soybean in Brazil to control *A. gemmatalis* (Moscardi 1999). After that, governmental agencies stimulated the on-farm production of this virus, and many growers used it constantly. In the international market, only baculoviruses are commercially available to a significant extent compared to other viruses (Lacey *et al* 2015). Today, all the knowledge and technology generated and accumulated in the past years are available for use in organic and conventional systems.

Arthropod Control Agents

The BCA products account for 49.47% of the products with active registration. Among these, products using the parasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) represent 28.42% of the natural enemy–based products available and 57.45% of the BCA products available (Table 1). This species is released to control larvae of the sugarcane borer *Diatrea saccharalis* (Fabr.) (Lepidoptera: Crambidae) in all crops where the pest occurs, and this species has the largest numbers of companies commercializing it in the different regions of Brazil (Table 1). The augmentative biological control program of the sugarcane borer in Brazil is one of the largest and most successful programs in the world (Botelho & Macedo 2002). Until 2014, 3.3 million ha was being treated with *C. flavipes* in Brazil (Parra 2014).

Trichogramma species are also very important egg parasitoids in the country, and the two species available are used on different target species. *Trichogramma galloi* Zucchi (Hymenoptera: Trichogrammatidae) has the same target species as *C. flavipes*, and it is commercialized in similar states (Table 1). The combined release of *C. flavipes* with *T. galloi* can be 3.7 times more efficient in controlling *D. saccharalis* than a single release of *C. flavipes* (Botelho 1999, Parra & Zucchi 2004). Therefore, the use of *T. galloi* was boosted by the already available market to *C. flavipes* in sugarcane (Parra 2014). *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae) has five products registered to control lepidopteran pests in several crops (Table 1). The species was successfully used in Brazil to control *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in tomato fields (Haji *et al* 2002) and has stimulated research in several crops to control other lepidopteran species (Parra & Zucchi 2004). In fact, *T. pretiosum* was considered an important mortality factor of *T. absoluta* eggs in conventional (Bacci *et al* 2018) and organic tomato fields (Medeiros *et al* 2011). Moreover, Figueiredo *et al* (2015) demonstrated that the release of *T. pretiosum* to control *S. frugiperda* eggs in organic maize increased maize productivity by 19.4% in Brazil.

Among the predators, the number of products per species is more balanced than the other BCAs, with five species of predators being associated with 10 different products (Table 1). Most commercial products using predators use predatory mites, and they are registered for specific target pests in all crops where the pest occurs (Table 1). Predatory mites, especially Phytoseiidae species, are well studied in Brazil and globally (Moraes 2002, McMurtry *et al* 2013, Demite *et al* 2018).

Phytoseiulus macropilis (Banks) is a Type Ia Phytoseiidae predator (specialized predators of *Tetranychus* species) (McMurtry *et al* 2013) that is naturally occurring in several plant species in Brazil and widely distributed in the Americas (Demite *et al* 2018). This species is considered equivalent to *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) (which does not occur in Brazil), which controls *T. urticae.* However, the predation rate of *T. urticae* by *P. macropilis* is higher than that of *P. persimilis* (Oliveira *et al* 2007). Conversely, *Neoseiulus californicus* (McGregor) is a Type II Phytoseiidae predator (selective predator of Tetranychidae mites, which are usually associated with dense web-producing prey) (McMurtry *et al* 2013), that is widely distributed in the world (Demite *et al* 2018). The estimated year of its first use was 1985 in Europe, North and South Africa, all Americas, and Asia to control mites (van Lenteren 2012). Another predatory mite species, *Stratiolaelaps scimitus* (Womersley) (Acari: Laelapidae), has showed promising results in controlling Sciaridae flies (Diptera) on mushroom cultivations (Castilho *et al* 2009). This species was found in association with *Bradysia matogrossensis* (Lane) (Diptera:

Sciaridae) in a greenhouse in SP when researchers were screening for biological control candidates of Sciaridae flies (Freire *et al* 2007).

The only two predatory insects with commercial products registered are the pirate bug *O. insidiosus* and the ladybeetle *Cryptolaemus montrouzieri* (Mulsant) (Coleoptera: Coccinellidae) (Table 1). *Orius insidiosus* was used in Europe from 1991 to 2000 to control Thrips species, but it was replaced by *Orius laevigatus* (Fieber), which is indigenous to that region. However, as *O. insidiosus* is very common from North to South America and native of this region, it has been used in the Americas since 1985 (van Lenteren 2012). The ladybeetle *C. montrouzieri* is native from the Australasian region (Kairo *et al* 2013) and was introduced to Brazil from Chile in 1997 to control citrus pests. In 2010, the pink hibiscus mealybug *Maconellicoccus hirsutus* (Green) (Hemiptera: Pseudococcidae) was recorded in Brazil and *C. montrouzieri* was used to control this pest because it was the only natural enemy found associated with the invasive pest (Kairo *et al* 2013, Fornazier *et al* 2017). This species is also commercially available in Europe (*van Lenteren et al* 2018) and North America (Heimpel & Lundgren 2000).

Limitations and Perspectives

In comparison with the international market, Brazil has grown substantially, but it is still taking the first steps toward the use of biological control as a pest management tool in organic agriculture. Whereas Brazil has only 16 species/isolates of natural enemies registered, approximately 440 species are commercially available in the world (van Lenteren *et al* 2018). Another important issue is that most companies are based in the southeast region of Brazil (Table 1), where most universities and research entities that have previously developed biological control strategies in Brazil are based (Parra 2014). This means that the biological control trade is not completely accessible to other regions such as the Midwest, where most of the Brazilian agricultural production is concentrated. At the same time, an opportunity exists for the growth of this market to other states.

Other limitations of the use of augmentative biological control were discussed by Parra (2014) who identified 11 problems and challenges in implementing it in Brazil. Among them are those problems and challenges also common to organic agriculture; these include pest monitoring, technology transfer, quality control of natural enemies (which demands specific guidelines), logistic of storage and transport, and release technology. We would also add that local natural enemy population differentiation is a bottleneck because the differentiation in the efficiency of natural enemies can vary within regions (Michaud 2018), especially in a country with continental dimensions, such as Brazil. Most likely, as augmentative biological control and products became more available in the country, this scenario is expected to change because more biological control practitioners will fill these gaps.

Moving Forward

Although the use of augmentative biological control in organic agriculture is a promising tool for insect control, the "rear-and-release treadmill" criticized by some (Michaud 2018) and stimulated by others (e.g., Parra 2014, van Lenteren and Bueno 2003; van Lenteren *et al* 2018) is not completely aligned with the objectives and perspectives of organic agriculture and agroecology (Rosset and Altieri 1997), especially if one considers the use of augmentation biological control merely as a replacement of inputs, with the same philosophy of chemical pesticide use in conventional agriculture. In this sense, we suggest that biological control should be used in specific cases, as we will discuss here.

First, it is necessary to promote conservation biological control and popularize the great amount of techniques and strategies generated by researchers in the country to understand how to make conservation biological control compatible with augmentative releases. According to Wyckhuys *et al* (2013), among the 15 developing countries evaluated, Brazil has the second-largest number of studies in conservation biological control after China. However, the study underestimated the number of papers published in Brazil, because they included neither the papers published in local journals nor the studies published in Portuguese.

Nevertheless, the studies performed in Brazil include several features that can promote natural enemy abundance, diversity, and functionality in agroecosystems at different spatial scales. For example, at the landscape scale, non-crop habitats surrounding wheat crops are positively associated with hoverfly species richness in the south region of Brazil (Medeiros *et al* 2018). At the farm scale, farm diversity within and between crops and a reduction in the use of phytosanitary products with permitted use in organic agriculture increased the abundance and richness of whitefly predators, resulting in a more efficient and reliable whitefly biological control in organic tomato in the midwest region of Brazil (Togni *et al* 2018). At the plot level, many studies have been published, but the use of coriander intercropped with horticultural crops has been studied by several research groups in the country including the south, southeast, and midwest regions. Coriander plants attract many predators of aphids (Lixa *et al* 2010, Resende *et al* 2017, *Togni et al* 2016) and predators and parasitoids of whiteflies (Togni *et al* 2009), increase the parasitism of the tomato pinworm by *Trichogramma* spp. (Medeiros *et al* 2011), and provide pollen as a food source for lacewings (Resende *et al* 2017) and coccinellids (Togni *et al* 2016). Another promising intercrop for horticultural crops is basil (*Ocimum basilicum*). It attracts a generalist predator (green lacewings), and its flowers provide food that sustains a predator population before the pest population can build up in the crop area (Batista *et al* 2017).

The maintenance of non-crop plants among chili pepper plants, such as billygoat weed (*Ageratum conyzoides*), beggar tick (*Bidens pilosa*), and sow thistle (*Sonchus oleraceus*), provides food resources that increase aphid predator survival and reduces the aphid population in chili pepper plants (Amaral *et al* 2013, 2016). Another remarkable example is an agroforestry system that includes trees bearing extrafloral nectaries. For instance, the leguminous *Inga* spp., used in coffee agroforestry systems for shade, improvement of soil fertility, wood, and human and animal feeding, produce extrafloral nectar that attracts and increases the survival of coffee pest's natural enemies, thereby decreasing the pest population (Rezende *et al* 2014).

These are some examples, among several, of studies performed in Brazil that can be applied or have been developed in organic crops. However, we are not aware of any study that used such knowledge and combined it with augmentative biological control strategies. Conservation biological control relies on management strategies at different spatial scales that can favor the abundance and functionality of the local natural enemies in controlling pests. In this sense, combining conservation biological control with augmentative releases can increase the efficiency of the introduced natural enemies, with direct benefits to farmers. Considering that conservation biological control studies usually share common ground in the use of applied ecology as a way to understand the interaction among natural enemies, habitats, and agronomic practices, we should promote more deeply the integration of agronomists with ecologists in the country. Using this perspective, the integration of different biological control strategies will be possible, with a framework for truly sustainable agriculture being conceivable (Michaud 2018).

Augmentative biological control can be the first step in building agriculture based on ecological process instead of on artificial and external inputs and can be a valuable tool during the transition from conventional to organic agriculture. During this phase, farmers experience a series of changes in the production system. Therefore, the use of MCA and BCA can be the first step in changing the apply and kill paradigm from conventional agriculture. As we discussed earlier, the use of some natural enemy–based products, especially MCA, is very similar to the use of conventional pesticides (Sousa *et al* 2016). However, to be efficiently applied, such products demand a certain knowledge about the natural enemy's biology and ecology. Due to this, natural enemy–based products could be viewed as the first contact of farmers with biodiversity components. The registration of indigenous natural enemies should be prioritized because farmers will gain experience with the biodiversity components that naturally occur on their lands, making the transition from input substitution to agroecological management easier. To the extent that farmers will gain experience with the organic system, the conservation biological control strategies can be incorporated and gradually may become the main pest management option.

The recent breakthroughs, demonstrated in successful cases of biological control of pest insects in commodities in Brazil, have encouraged farmers to produce biological products on their farms. It is estimated that the area sprayed with these products could be several folds higher than the amount sprayed with registered products commercialized by Brazilian companies. This procedure is recognized as legal by a loophole in the Brazilian law through NI 46/2011 from MAPA. The natural enemy-based products used in conjunction with habitat manipulation strategies are expected to be more effective than each single strategy separately. However, researchers should be stimulated to test these assumptions to improve the efficiency and safety of the available products and those that will be registered, thereby promoting the integration of biodiversity conservation and food production.

We agree with Michaud (2018) who has stated: "Modern, industrial-scale agricultural practices are the primary selective forces driving the evolution of our pest problems" and "Rather than singling out particular species for rear-and-release programs, we should devote more attention to understanding and characterizing ecological impediments to the timely, natural colonization of our crops by beneficial species." However, the way to accomplish this involves more than changing researcher's minds. It also involves changing the pest management thoughts of farmers, extension agents, technicians, and policymakers. We believe that the registration of natural enemy–based products in organic agriculture in Brazil can be an alternative to the pesticide paradigm in the country and a way to change and promote biodiversity use and conservation on agricultural lands. Whether the way will be a "rear-and-release treadmill" or a tool for promoting a truly sustainable agriculture will be determined by the point of view on how to use the technology and the legislative pathways available. We can use the registration of phytosanitary products in organic agriculture as a tool to start the changes needed and contribute to ecosystem functioning, human health, and social benefits associated. This could be achieved by moving from the perspective of pest control (i.e., apply and kill) to the perspective of pest management (i.e., understand pest ecology to regulate their populations).

Author Contribution PHBT, ACGL, ERS, and MV conceived the study. PHBT and ACGL collected the data and analyzed the data. PHBT, ERS, and MV carried out the legislation survey. PHBT led the writing of the manuscript. All authors contributed critically to the drafts and gave approval for the final version.

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References

Agrofit (2018) Phytosanitary agrochemicals system – Ministry of Agriculture, Livestock and Food Supply, Brazil, 2018. http://http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons. Accessed 28 Oct 2018

Alves SB, Lopes RB (2008) Controle microbiano de pragas na América Latina. FEALQ, Piracicaba, p 414

Amaral DSSL, Venzon M, Duarte MVA, Sousa FF, Pallini A, Harwood JA (2013) Non-crop vegetation associated with chili pepper agroecosystems promote the abundance and survival of aphid predators. Biol Control 64:338–346

Amaral DSSL, Vezon M, Santos HH, Sujii ER, Schimitd J, Harwood JD (2016) Non-crop plant communities conserve spider populations in chili pepper agroecosystems. Biol Control 103:69–77

Bacci L, Silva EM, Martins JC, Soares MA, Campos MR, Picanço MC (2018) Seasonal variation in natural mortality factors of *Tuta absoluta* (Lepidoptera: Gelechiidae) in open-field tomato cultivation. J Appl Entomol 00:1–13

Batista MC, Fonseca MCM, Teodoro AV, Martins EF, Pallini A, Venzon M (2017) Basil (*Ocimum basilicum* L.) attracts and benefits the green lacewing *Ceraeochrysa cubana* Hagen. Biol Control 110:98–196

Bombardi LM (2017) Geografia do uso de agrotóxicos no Brasil e conexões com a união europeia. FFLCH-USP, São Paulo, p 291

Botelho PSM, Macedo M (2002) *Cotesia flavipes* para o controle de *Diatraea saccharalis*. In: Parra JRP, Botelho PSM, Corrêa-Ferreira BS, Bento JMS (eds) Controle biológico no Brasil: parasitoides e predadores. Editora Manole, São Paulo, pp 409–425

Botelho PSM, Parra JPR, Chagas-Neto JF, Oliveira PB (1999) Associação do parasitóide de ovos *Trichogramma galloi* Zucchi (Hymenoptera: Trichogrammatidae) e do parasitóide larval *Cotesia flavipes* (Cam.) (Hymenoptera: Braconidae) no controle de *Diatraea saccharalis*, (Fabr.) (Lepidoptera: Crambidae) em cana-de-açúcar. Na Soc Entomol Bras 28:491–496

Brazil (2002) Projeto de Lei No. 6.299, de 13 de março de 2002. https://www.camara.gov.br/proposicoesWeb/prop_mostrarintegra?codteor=1654426&filename=Tramitacao-PL+6299/2002. Accessed 03 Aug 2018

Brazil (2003) Lei No. 10.831, de 23 de dezembro de 2003. http://www.planalto.gov.br/ccivil_03/LEIS/2003/L10.831.htm. Accessed 01 Aug 2018

Brazil (2012) Decreto No. 7.794, de 20 de agosto de 2012. http://www.planalto.gov.br/ccivil_03/_Ato2011-2014/2012/Decreto/D7794.htm. Accessed 01 Aug 2018

Bueno VHP (2009) Controle biológico de pragas: produção massal e controle de qualidade. Editora UFLA, Lavras, p 429

Carneiro FF, Pignati W, Rigotto RM, Augusto LGS, Rizollo A, Muller NM, Alexandre VP, Friedrich K, Mello MSC (2015) Dossiê ABRASCO – Um alerta sobre os impactos dos agrotóxicos na saúde. Associação Brasileira de Saúde Coletiva, Rio de Janeiro, p 623

Castilho RC, Moraes GJ, Silva ES, Freire RAP, Da Eira FC (2009) The predatory mite *Stratiolaelaps scimitus* as a control agent of the fungus gnat *Bradysia matogrossensis* in commercial production of the mushroom *Agaricus bisporus*. Int J Pest Manage 55:181–185

CDB – Convention on Biological Diversity (2010) Global biodiversity outlook 2. Convention on Biological Diversity, Montreal, p 81

Costa MBB, Souza M, Júnior VM, Comin JJ, Lovato PE (2017) Agroecology development in Brazil between 1970 and 2015. Agroecol Sust Food 41:276–295

Demite PR, Moraes GJ, McMurtry JA, Denmark HA, Castilho RC (2018) Phytoseiidae Database. www.lea.esalq.usp.br/phytoseiidae (accessed 12 Jul 2018)

FAO - Food and Agriculture Organization of the United Nations (2018). Agroecology knowledge hub: the 10 elements of agroecology. http://www.fao.org/agroecology/knowledge/10-elements/en/ Accessed 15 Sep 2018

FAOSTAT - Food and Agriculture Organization of the United Nations (2016) Production crops 2016. http://www.fao.org/faostat/en/#data/QC Accessed 05 Jun 2018

Ferreira J, Pardini R, Metzger JP, Fonseca CR, Pompeu PS, Sparovek G, Louzada J (2012) Towards environmentally sustainable agriculture in Brazil: challenges and opportunities for applied ecological research. J Appl Ecol 49:535–541

Figueiredo MLC, Cruz I, Silva RB, Foster JE (2015) Biological control with *Trichogramma pretiosum* increases organic maize productivity by 19.4%. Agron Sustain Dev 35:1175–1183

Fornazier MJ, Martins DS, Souza CAS, Culik MP, Chipolesch JMA, Fornazier DL, Ferreira PSF, Zanuncio JC (2017) Invasion of the main cocoa-producing region of South America by *Maconellicoccus hirsutus* (Hemiptera: Pseudococcidae). Fla Entomol 100:168–171

Freire RAP, Moraes GJ, Silva ES, Vaz AC, Castilho RC (2007) Biological control of *Bradysia matogrossensis* (Diptera: Sciaridae) in mushroom cultivation with predatory mites. Exp Appl Acarol 42:87–93

Garibaldi LA, Carvalheiro LG, Vaissiere BE, Gemmill-Herren B, Hipolito J, Freitas BM, Ngo HT, Azzu N, Saez A, Astrom J, An J, Blochtein B, Buchori D, Garcia FJC, Oliveira da Silva F, Devkota K, Ribeiro MF, Freitas L, Gaglianone MC, Goss M, Irshad M, Kasina M, Filho AJSP, Kiill LHP, Kwapong P, Parra GN, Pires C, Pires V, Rawal RS, Rizali A, Saraiva AM, Veldtman R, Viana BF, Witter S, Zhang H (2016) Mutually beneficial pollinator diversity and crop yield outcomes in small and large farms. Science 351:388–391

Gould F, Brown ZS, Kuzma J (2018) Wicked evolution: can we address the sociobiological dilemma of pesticide resistance? Science 360:728–732

Haji FNP, Prezotti L, Carneiro JS, Alencar JA (2002) *Trichogramma pretiosum* para o controle de pragas do tomateiro industrial. In: Parra JRP, Botelho PSM, Corrêa-Ferreira BS, Bento JMS (eds) Controle biológico no Brasil: parasitoides e predadores. Editora Manole, São Paulo, pp 477–494

Heimpel GE, Lundgren JG (2000) Sex ratios of commercially reared biological control agentes. Biol Control 19:77–93

IBAMA - Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (2016) Instrução Normativa IBAMA 5/2016. https://www.ibama.gov.br/sophia/cnia/legislacao/IBAMA/IN0005-260816.pdf. Accessed 20 Oct 2018

IBAMA - Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (2018) Nota Técnica 2/2018/CGASQ/CGFIN. https://www.ibama.gov.br/phocadownload/noticias/noticias2018/SEI_02000.000406_2016_93.pdf Accessed 14 Jul 2018

Kairo MTK, Paraiso O, Gautam RD, Peterkin DD (2013) *Cryptolaemus montrouzieri* (Mulsant) (Coccinellidae: Scymninae): a review of biology, ecology, and use in biological control with particular reference to potential impact on non-target organisms. CAB Rev 8:1–20

Lacey LA, Grzywacz D, Shapiro-Ilan DI, Frutos R, Brownbridge M, Goettel MS (2015) Insect pathogens as biological control agents: back to the future. J Invertebr Pathol 132:1–41

van Lenteren JC (2012) The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. BioControl 57:1–20

van Lenteren JC, Bueno VHP (2003) Augmentative biological control of arthropods in Latin America. BioControl 48:123–139 van Lenteren JC, Bigler F, Burgio G, Hokkanen HMT, Thomas MB (2002) Risks of importation and release of exotic biological control agents: how to determine host specificity? IOBC/ WPRS Bulletin 25:281–284

van Lenteren JC, Bolckmans K, Köhl J, Ravensberg WJ, Urbaneja A (2018) Biological control using invertebrates and microorganisms: plenty of new opportunities. BioControl 63:39–59

Lixa AT, Campos JM, Resende ALS, Silva JC, Almeida MMTB, Aguiar-Menezes EL (2010) Diversidade de Coccinellidae (Coleoptera) em plantas aromáticas (Apiaceae) como sítios de sobrevivência e reprodução em sistema agroecológico. Neotrop Entomol 39:354–359

MAPA - Ministério da Agricultura, Pecuária e Abastecimento (2011) Instrução Normativa MAPA 46/2011. http://www.agricultura.gov.br/assuntos/insumos-agropecuarios/insumos-agricolas/agrotoxicos/legislacao/arquivos-de-legislacao/in-46-2011-regulamento-tecnico-para-sistemas-organicos-de-producao. Accessed 06 Sep 2018

MAPA - Ministério da Agricultura, Pecuária e Abastecimento (2014) Instrução Normativa MAPA 17/2014. http://www.agricultura.gov.br/assuntos/sustentabilidade/organicos/legislacao/portugues/instrucao-normativa-no-17-de-18-de-junho-de-2014.pdf/view. Accessed 05 Sep 2018

MAPA - Ministério da Agricultura, Pecuária e Abastecimento (2017) Instrução Normativa MAPA 35/2017. http://www.agricultura.gov.br/assuntos/insumos-agropecuarios/insumos-pecuarios/produtos-veterinarios/in-35.pdf/view. Accessed 20 Oct 2018

MAPA - Ministério da Agricultura, Pecuária e Abastecimento (2018) Portaria MAPA 112/2018. http://pesquisa.in.gov.br/imprensa/jsp/visualiza/index.jsp?data=15/10/2018&jornal=515&pagina=4. Accessed 20 Oct 2018

MAPA/IBAMA/ANVISA - Ministério da Agricultura, Pecuária e Abastecimento/Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis/Agência Nacional de Vigilância Sanitária (2006) Instrução Normativa Conjunta SDA/ANVISA/IBAMA 02/2006. http://www.agricultura.gov.br/assuntos/insumos-agropecuarios/insumos-agricolas/agrotoxicos/legislacao/INSTRUONORMATIVACONJUNTAN2de2006_pdf. Accessed 18 Jul 2018

MAPA/IBAMA/ANVISA - Ministério da Agricultura, Pecuária e Abastecimento/Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis/Agência Nacional de Vigilância Sanitária (2011) Instrução Normativa Conjunta SDA/SDC/ANVISA/IBAMA 01/2011. http://www.agricultura.gov.br/assuntos/insumos-agropecuarios/insumos-agricolas/agrotoxicos/legislacao/arquivos-de-legislacao/inc-01-2011-organicos. Accessed 09 Jul 2018

McMurtry JA, Moraes GJ, Sourassou NF (2013) Revision of the lifestyles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies. Syst Appl Acarol 18:297–320

Medeiros MA, Sujii ER, Morais HC (2011) Fatores de mortalidade na fase de ovo de *Tuta absoluta* em sistemas de produção orgânica e convencional de tomate. Bragantia 70:72–80

Medeiros HR, Hoshino AT, Ribeiro MC, Morales MN, Martello F, Pereira Neto OC, Carstensen DW, Menezes Junior AO (2018) Non-crop habitats modulate alpha and beta diversity of flower flies (Diptera, Syrphidae) in Brazilian agricultural landscapes. Biodivers Conserv 27:1309–1326

Melo FPL, Arroyo-Rodríguez V, Fahrig L, Marínez-Ramos M, Tabarelli M (2013) On the hope for biodiversity-friendly tropical landscapes. Trends Ecol Evol 28:462–468

Michaud JP (2018) Problems inherent to augmentation of natural enemies in open agriculture. Neotrop Entomol 47:161–170

Michereff Filho M, Faria M, Wraight SP, Silva AFAS (2009) Micoinseticidas e micoacaricidas no Brasil: como estamos após quatro décadas? Arq Inst Biol 76:769–779

Moraes GJ (2002) Controle biológico de ácaros fitófagos com ácaros predadores. In: Parra JRP, Botelho PSM, Corrêa-Ferreira BS, Bento JMS (eds) Controle biológico no Brasil: parasitoides e predadores. Editora Manole, São Paulo, pp 225–238

Moscardi F (1999) Assessment of the application of baculoviruses for control of Lepidoptera. Annu Rev Entomol 44:257–289

Oliveira H, Janssen A, Pallini A, Venzon M, Fadini M, Duarte V (2007) A phytoseiid predator from the tropics as potential biological control agent for the spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae). Biol Control 42:105–109

Oliveira CM, Auad AM, Mendes SM, Frizzas MR (2013) Economic impact of exotic insect pests in Brazilian agriculture. J Appl Entomol 137:1–15

Parra JRP (2014) Biological control in Brazil: an overview. Sci Agric 71: 345–355

Parra JRP, Zucchi RA (2004) *Trichogramma* in Brazil: feasibility of use after twenty years of research. Neotrop Entomol 33:271–281

Parra JRP, Botelho PSM, Corrêa-Ferreira BS, Bento JMS (2002) Controle biológico no Brasil: parasitoides e predadores. Editora Manole, São Paulo, p 635

Pignati WA, Lima FANS, Lara SS, Correa MLM, Barbosa JR, Leão LHC, Pignatti MG (2017) Distribuição espacial do uso de agrotóxicos no Brasil: uma ferramenta para a Vigilância em Saúde. Cien Saude Colet 22:3281–3293

Resende ALS, Souza B, Fereira RB, Aguiar-Menezes EL (2017) Flowers of Apiaceous species as sources of pollen for adults of *Chrysoperla externa* (Hagen) (Neuroptera). Biol Control 106:40–44

Rezende MQ, Venzon M, Perez AL, Cardoso IM, Janssen A (2014) Extrafloral nectaries of associated trees can enhance natural pest control Agric Ecosyst Environ 188: 198203, 198, 203

Rosset PM, Altieri MA (1997) Agroecology versus input substitution: a fundamental contradiction of sustainable agriculture. Soc Nat Resour 10:283–295

Sousa AATC, Souza LM, Togni PHB, Vieira L, Harterreiten-Souza ES, Carneiro RG, Fontes EMG, Pires CSS, Sujii ER (2016) Diagnóstico dos problemas fitossanitários na agricultura de base ecológica no Distrito Federal e Entorno. Embrapa Recursos Genéticos e Biotecnologia, Brasília, p 30

Sujii ER, Venzon M, Medeiros MA, Pires CSS, Togni PHB (2010) Práticas culturais no manejo de pragas na agricultura orgânica. In: Venzon M, Júnior TJP, Pallini A (eds) Controle alternativo de pragas e doenças na agricultura orgânica. EPAMIG, Viçosa, pp 143–168

Togni PHB, Frizzas MR, Medeiros MA, Nakasu EYT, Pires CSS, Sujii ER (2009) Dinâmica populacional de *Bemisia tabaci* biótipo b em tomate monocultivo e consorciado com coentro sob cultivo orgânico e convencional. Hortic Bras 27:183–188

Togni PHB, Venzon M, Muniz CA, Martins EF, Pallini A, Sujii ER (2016) Mechanisms underlying the innate attraction of an aphidophagous coccinellid to coriander plants: implications for conservation biological control. Biol Control 92:77–84

Togni PHB, Venzon M, Souza LM, Santos JPCR, Sujii ER (2018) Biodiversity provides whitefly biological control based on farm management. J Pest Sci. https://doi.org/10.1007/s10340-018-1021-x

UN - United Nations. (2017). Report of the special rapporteur on the right for food. General assembly: Human rights council

Venzon M, Sujii ER (2009) Controle biológico conservativo. Informe Agropecuário 30:7–16

Venzon M, Togni PHB, Amaral DSSL, Rezende MQ, Fonseca MCM, Martins EF (2015) Manejo agroecológico de pragas. Informe Agropecuário 36:19–30

Vieira Filho JE (2016) Expansão da fronteira agrícola no Brasil: desafios e perspectivas. Texto para discussão n. 2223. IPEA, Brasília & Rio de Janeiro, p 36

Willer H, Lernoud J (2016) The world of organic agriculture: statistics and emerging trends 2016. FiBL-IFOAM Report, Bonn and Frick, p 340

Wyckhuys KAG, Lu Y, Morales H, Vazquez LL, Legaspi JC, Eliopoulos PA, Hernandez LM (2013) Current status and potential of conservation biological control for agriculture in the developing world. Biol Control 65:152–167

Zhender G, Gurr M, Kühne S, Wade MR, Wratten SD, Wyss E (2007) Arthropod pest management in organic crops. Annu Rev Entomol 52: 57–80