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Pesticides and reduced-risk insecticides, native bees and pantropical stingless bees: pitfalls and perspectives

Wagner F Barbosa,[a,b] Guy Smagghe[b] and Raul Narciso C Guedes[a*]

Abstract

Although invertebrates generally have a low public profile, the honey bee, *Apis mellifera* L., is a flagship species whose popularity likely derives from the products it provides and its perceived ecological services. Therefore, the raging debate regarding honey bee decline has surpassed the realm of beekeepers, academia, industry and regulatory agencies and now also encompasses non-governmental agencies, media, fiction writers and the general public. The early interest and concern about honey bee colony collapse disorder (CCD) soon shifted to the bigger issue of pollinator decline, with a focus on the potential involvement of pesticides in such a phenomenon. Pesticides were previously recognised as the potential culprits of the reported declines, particularly the neonicotinoid insecticides owing to their widespread and peculiar use in agriculture. However, the evidence for the potential pivotal role of these neonicotinoids in honey bee decline remains a matter of debate, with an increased recognition of the multifactorial nature of the problem and the lack of a direct association between the noted decline and neonicotinoid use. The focus on the decline of honey bee populations subsequently spread to other species, and bumblebees became another matter of concern, particularly in Europe and the United States. Other bee species, ones that are particularly important in other regions of the world, remain the object of little concern (unjustifiably so). Furthermore, the continuous focus on neonicotinoids is also in need of revision, as the current evidence suggests that a broad spectrum of compounds deserve attention. Here we address both shortcomings.

Keywords: bioinsecticides; biorational insecticides; insecticidal stress; Meliponini; wild pollinators

1 PUBLIC PERCEPTION OF HONEY BEE DECLINE AND PEST CONTROL

Invertebrates are generally not particularly liked or praised in Western society, with a few exceptions, the European honey bee, *Apis mellifera* L., being one of them.[1,2] The reasons for this are deeply ingrained and intuitive. 'Bugs' (i.e. insects) in general are subject to dominionistic and negativistic views owing to the perception that they are pests.[1] This is exemplified by Aesop's view of ants as 'thieves' in his fables (*Zeus and the Ant*). However, honey bees are the target of more naturalistic and utilitarian views, extending even to aesthetics if their social characteristics are considered.[1,2] Again, Aesop comes to mind with his fable *The Bear and the Bees* (*Aesop's Fables*). Therefore, it comes as no surprise that there is still a raging debate over honey bee decline that has moved beyond beekeepers, academia, industry and regulatory agencies, extending to non-governmental organisations (NGOs), mass media, fiction writers and the general public.

The earlier suspicion that the involvement of pesticides was leading to the reported honey bee colony collapse disorder (CCD) added further fuel to the debate, which shifted from the CCD phenomenon (detected mainly in the United States between 2006 and 2008) to honey bee colony decline, particularly in the United States and the European Union.[3–5] Such a heated debate proved to be invaluable in identifying knowledge gaps and led to the mobilisation of resources for scientific research focusing on the spread, amplitude and causes of honey bee colony decline.[6–8] The end results of the ongoing effort to settle this debate show some points of congruence, which include the following: (1) the recognition of honey bee decline in different areas and countries, but not in every area of every country; (2) the multifactorial nature of the phenomenon; (3) the apparent lack of a primary, direct association between honey bee decline and neonicotinoid use.[9–13] This is not to say that pesticides, particularly neonicotinoid insecticides, lack importance in this debate, as they are most likely important components in this scenario, potentiating colony decline in a period where there is a high demand for pollination services.[14,15]

The concern surrounding the potential impact of pesticides, particularly insecticides, on the honey bee and its products and ecological services is justifiable, not only because of the importance of such products and services but also because of the increased demand for pollinators in current agricultural production.[15–17] High-yield agricultural systems and middle-to-high-income countries continue the heavy use of pesticides, with evidence of overuse reflected in average pesticide amounts: above 2.0 kg ha^{-1}

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[*] *Correspondence to: Raul Narciso C Guedes, Departamento de Entomologia, Universidade Federal de Viçosa, Viçosa, MG 36570-900, Brazil. E-mail: guedes@ufv.br*

[a] *Departamento de Entomologia, Universidade Federal de Viçosa, Viçosa, Brazil*

[b] *Department of Crop Protection, Faculty of Bioscience Engineering, Ghent University, Ghent, Belgium*

in the United States, Canada and several European countries, and over 10 kg ha^{-1} in countries such as Brazil and China, among others.[16−18] Among agricultural pesticides, insecticides are also without a noticeable reduction in use, with some having an actual increase in use, even under the intense adoption of genetically modified crops.[17,18] The challenge remains, as always, the effective management of pest insects with minimal non-target impacts.

2 PESTICIDES, REDUCED-RISK INSECTICIDES AND THE HONEY BEE

Pesticide use has remained the basis of crop protection for decades. High efficacy against pest species and fast action, besides competitive costs, leading to improved production quality and yield with attractive economic returns, are characteristics commonly associated with pesticide use that favour its prevalence as a pest management method.[17,19,20] Nonetheless, there are still recognised risks and controversies surrounding pesticides,[21−23] in spite of the progressive change in attitudes and behaviour regarding their use, prompting the search for new compounds with better toxicological and ecotoxicological profiles.[24,25] The end-result is the current prevalence of a broader diversity of pesticidal compounds, some of which are recognised as biopesticides and/or reduced-risk pesticides.

Current pesticides exhibit greater potency against the target pests, requiring lower field application rates and affording higher levels of safety for non-target organisms.[19,20,24,25] However, they usually require more frequent applications owing to their lower field persistence compared with older compounds, leading to a higher rate of consumption, particularly for agricultural production in middle-to-high-income countries.[18,24,25] This scenario has allowed the burgeoning of neologisms and pleonasms in coining alternative references to pesticides, including some fallacious ones, which vary greatly from country to country and include ‘agricultural protectants’, ‘plant protection agents’, ‘phytosanitary products’, ‘agrochemicals’, ‘agrotoxics’, ‘biological pesticides’, ‘biopesticides’, ‘biorational pesticides’ and ‘reduced-risk pesticides’, among others. This colourful semantic exuberance frequently exhibits little scientific or technical value and, worst of all, conveys subliminal and equivocated notions such as the intrinsically higher (or lower) level of safety of a pesticidal compound.

The myriad of pesticide groups currently available and the present societal perceptions of pesticides create new regulatory challenges, as new toxicological tests and endpoints seem necessary. The honey bee provides an interesting paradox because this species is needed throughout the world for basic toxicological assessments aimed at pesticide registration for agricultural use, but it is reported to be suffering from pesticide-influenced decline in different countries, with calls for the restriction or even downright ban of some compounds, notably neonicotinoid insecticides and particularly in Europe and the United States.[26−28] Although a few other insecticides are also considered, including the old organophosphates, pyrethroids and fipronil,[28] the general concern is largely focused on neonicotinoid insecticides.[14,26−28] The plant systemicity of neonicotinoids and the broad scale of their use, with high lethal and pronounced sublethal toxicity to honey bees, are the key reasons for the concern and attention to this group of insecticides, a group that still exhibits the potential for increased use against agricultural arthropod pest species.

The recent expansion and incentives towards the development and use of the so-called reduced-risk pesticides, particularly biopesticides, are reactions to the environmental safety concerns sparked by Western society, and the neonicotinoid risk to honey bee decline illustrates this fact. The increased demand for organically produced food items (i.e. where only natural insecticides are allowed) also reinforces the demand for reduced-risk (bio)pesticides, which are generally perceived as safer than conventional pesticides. Curiously though, current levels of (conventional) pesticide residues on foodstuffs do not appear to be of significance to human health, and pesticide residues are also frequently detected on organically produced food,[29] but the popularity of organically produced food items is a complex issue surpassing the residue concern. The US Environmental Protection Agency defines reduced-risk pesticides as those exhibiting at least one trait of the following six advantageous traits over existing pesticides: (1) low impact on human health; (2) low toxicity to non-target organisms; (3) low potential for groundwater contamination; (4) lower use rates; (5) low pest resistance potential; (6) compatibility with integrated pest management (IPM).[30] Therefore, the concept is not particularly stringent and is likely to fit the majority of insecticides developed and used since the 1970s, even if they are not safe for non-target organisms, such as plant pollinators.

The concept of biopesticides, which may also be considered to be reduced-risk pesticides, is another potential pitfall playing with public perception. Although some authors reserve the term ‘biopesticide’ for living organisms,[31] the more frequently used concept gives a broader definition of biopesticides (or biological pesticides), encompassing all molecules of biological origin.[32,33] The problem with this is the common assumption that biopesticides (or biological pesticides, or natural pesticides) pose a lower risk than synthetic insecticides, which is aligned with public perception and the supporters of respectful production systems, such as Global Good Agricultural Production (GlobalGAP) and the Integrated Production (IP) initiative launched by the International Organisation for Biological and Integrated Control (IOBC).[34,35] The deception lies in the fact that the stated assumption is not necessarily true because the origin (either natural or synthetic) is not a determinant of toxicity, which is a function of the chemical structure and the derived physicochemical properties of the compound.[36−38] In this context, biopesticides and/or reduced-risk insecticides may exhibit significant lethal and/or sublethal toxicity to the honey bee and other pollinator bees, even showing lethality as high as that attributed to the neonicotinoids, a possibility that is usually neglected in spite of some available evidence.[39−42]

3 NATIVE BEES: EXTENDED CONCERNS WITH PESTICIDES

The significant decline in honey bee colonies observed in the United States and in parts of Europe drew attention to wild pollinator communities and their importance.[43−45] Wild pollinators can perform equally well or even better than the honey bee as pollinators in some crops and wild plants.[43,44] Furthermore, wild pollinators are important in maintaining plant diversity in natural landscapes,[45] but they are also potentially affected by pesticide use, and, again, the primary concern has been with the neonicotinoids and their potentially higher toxicity to wild bees.[46−48] The honey bee is routinely used as a surrogate bee pollinator in pesticide risk assessments, but recent meta-analysis indicates the need for more comparative information between the honey bee and non-*Apis* bees, and a tenfold range of variation in pesticide sensitivity exists between both bee groups.[46] Such concern and need have also been expressed in different global surveys and studies,[47,48] and some progress has been achieved.

Higher insecticide use compromises pollinator diversity, and differences between the insecticide susceptibility of honey bees and wild bees have been recognised.[49,50] Neonicotinoids have again been the focus of attention, but although there has been an increase in studies with solitary bees and other wild bee pollinators, bumblebees have been the centre of attention.[50–52] Bumblebees prevail in the Northern Hemisphere, although some species do exist in South America, and they have become increasingly important in agriculture as pollinators of cultivated crops, such as greenhouse tomatoes and strawberry.[53] Bumblebee decline has also been reported, and pesticide use is apparently an important component of this decline, with accumulated evidence on the bee's vulnerability to neonicotinoids in particular.[51,54,55] However, little information is available regarding the potential impact of reduced-risk insecticides to wild bees and even to bumblebees, but the few studies available indicate the potential for the substantial impact of some such pesticidal compounds, which deserves further attention.[39–42]

4 PESTICIDES AND BEES IN THE TROPICS: BEYOND HONEY BEES AND BUMBLEBEES

The tropics deal with a scenario and challenges that are different from the United States and Europe, although similar concerns regarding honey bee decline and neonicotinoid use do exist. Brazil, for instance, is the world's second largest consumer of pesticides in agriculture, with an average yearly consumption of 10 kg ha^{-1} and an intensive use of neonicotinoid insecticides.[17,56] A call for the injunctive suspension of the aerial application of insecticides was issued in 2012 by the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA), from the Brazilian Ministry of the Environment, and was subsequently reviewed with a call for additional studies on the honey bee (DOU No. 192 of 3 October 2012, Ofício Circular/12/CGASQ/DIQUA of November 2012 and DOU No. 3 of 4 January 2013). An important shortcoming is that no records of honey bee decline exist in Brazil or Latin America, or elsewhere. There are a few exceptions, such as South Africa, where nearly 30% of colony losses were registered as being due to a social parasite, suggesting a different set of causes than those experienced in the Northern Hemisphere.[47,57]

Another important issue to consider is that the honey bee subspecies and hybrids prevailing in Europe and North America are distinct from those prevailing in the tropics, which exhibit different habits and likely susceptibility to pesticides and pathogens and seem distinct even among European honey bee subspecies.[58,59] In Latin America, European honey bees were introduced and flourished for several years. The European subspecies were subsequently replaced by hybrids from a Brazilian honey bee breeding effort after the escape of some swarms of the African honey bee subspecies *A. mellifera scutellata*. These Africanised honey bees proved to be dominant, outcompeting their European counterparts in Latin America and quickly spreading throughout the region and becoming the prevailing honey bee genotype in one of the most successful biological invasions currently recorded. While some typical traits that are prevalent in Africanised honey bees, such as a high level of aggressiveness, foraging behaviour, colony hygiene, etc., may minimise their likelihood of decline as observed with European honey bees in the United States and parts of Europe, it remains to be assessed.

The large-scale agricultural use of pesticides and the resource competition imposed by the Africanised honey bee are threats to native bees in Neotropical America, potentially more important than the decline of (Africanised) honey bees in the region,[60–62] a status that largely remains unconfirmed. It is not only the Neotropics, but the whole pantropical region that houses hundreds of wild bee species that are vulnerable to agricultural pesticides.[63,64] Among these wild bee species, the rather diverse and perennially active eusocial stingless bees (Apidae: Meliponini) encompass a variety of pollinators that are very important for wild and cultivated plant species where honey bees exhibit marginal performance.[63,65] The sparse information currently available indicates that pantropical stingless bees are more susceptible to pesticides than the honey bee,[46,62] but such information is based mainly on dose–response (acute) toxicity bioassays, with only recent and scant information on the sublethal effects of pesticides.[46,62] Again, neonicotinoids, in addition to fipronil and a few older insecticides, were the focus of attention, and no information is available regarding the potential impact of the over 150 active ingredients of the agricultural pesticides in use in the tropics today, with only basic dose–mortality lethal acute bioassays in honey bees required for use registration before marketing.[66,67]

The commercial importance of honey bee products is easy to recognise, as is the potential economic impact of their decline, even in the tropics. However, the concern about the ecosystem services (namely pollination) provided by (Africanised) honey bees in the tropics, mainly in Neotropical America, seems to be disputable because wild stingless bees seem to be more important for both wild and cultivated plants in the region[60,61,63] and are vulnerable not only to pesticide use owing to their apparent high susceptibility but also to habitat destruction and competition from the invasive Africanised honey bee.[42,46,60–65] Until recently, a representative of the stingless bees was included in the red list of endangered species of the International Union for the Conservation of Nature and Natural Resources (IUCN 2013; http://www.iucnredlist.org, accessed 2 October 2013), and it remains recognised as such by the Brazilian Ministry of Environment (Normative Instruction No. 3, 27 May 2003; http://www.mma.gov.br/biodiversidade/espécies-ameaçadas-de-extinção/fauna-ameaçada). Attention to the group is therefore necessary and long overdue.

5 CONCLUDING REMARKS

The apparent paradox of the colony decline of the main species used worldwide as the surrogate pollinator species for basic toxicological studies for the use registration of agriculture pesticides is not difficult to understand in light of the knowledge gaps that are likely created precisely by such regulatory requirements.[6] The stated requirements are based on dose–mortality bioassays, thus focusing on lethal acute effects of pesticides on a particular species – the honey bee. In doing so, two shortcomings emerge: (1) the creation of knowledge gaps exploring sublethal insecticide effects; (2) the non-provision of necessary stimuli to pursue the potential indirect effects that are likely to take place under pesticide exposure in a given environment focusing on a single (model) species that is perceived as being of key importance, as well as ignoring other potentially more important species in certain scenarios. This second shortcoming also deters initiatives of studies exploring higher levels of hierarchical impact, including impacts at the population and community levels.

The gaps in regulatory knowledge about bee–pesticide interactions have been subjected to subsequent attention since the onset of CCD in the United States and the realisation of the potential extent of the honey bee colony decline in the United States and parts of Europe. However, the attention remains focused on honey bees, as observed in the main regulatory guidelines for risk assessments on pollinators.[68–75] Only the European Food Safety Authority (EFSA) and the US Environmental Protection Agency (EPA), the latter in a joint effort with Health Canada's Pest Management Regulatory Agency and the California Department of Pesticide Regulation, refer to tiered assessments on other important pollinators such as bumblebees and solitary bees.[68,75] Nonetheless, several of the existing gaps in knowledge regarding honey bees have been scrutinised, and the level of knowledge has improved, allowing some congruence in guiding the regulatory decision-making process. Even the initial and extensive focus on a single group of insecticides has improved, and attention has been shifting, encompassing other groups of insecticides, fungicides and pesticide mixtures, which seems paramount in the whole pollinator–pesticide risk assessment scenario. Nonetheless, misleading semantics of pesticide references and concepts, such as that of biopesticides and reduced-risk pesticides, convey questionable public perceptions of the environmental safety of these compounds, potentially discouraging studies exploring their environmental impact in general and their potential impact on pollinators in particular. This notion deserves revision.

The focus on honey bees also invites careful consideration, particularly where this species is invasive and its benefits (e.g. production of honey, propolis, royal jelly, beeswax, etc.) are outweighed by its potential threat to more important local pollinators. This is potentially the case with tropical stingless bees, particularly in Neotropical America. The potentially higher pesticide susceptibility and vulnerability of stingless bee species in the tropics should not be neglected. Considerable effort has been exerted to meet some of the shortcomings pointed out here, with increasing success. However, several pitfalls and shortcomings remain to be faced when configuring appealing research perspectives that are potentially worth pursuing.

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