LETTER TO THE EDITOR

Collateral damage of fipronil in economic and ecologically important non-target species

Impactos del fipronil en especies no destino de importancia económica y ecológica

Impactos do fipronil em espécies não-alvo econômicas e ecologicamente importantes

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Abstract

Fipronil is an insecticide and acaricide widely used in agriculture and domestic animals worldwide. Ecotoxicology studies have shown that, even at the low concentrations used on target species, fipronil and its degradation products have a significant impact on non-target species, either by direct toxicity or indirect effects affecting the food chain. The negative effects of fipronil on non-target species of terrestrial and aquatic invertebrates and indirect effects on food chains have led to its use being banned or severely restricted in numerous countries, including all of the European Union, China, and the United States. Some of the species highly susceptible to fipronil are of great economic and ecological importance, including crayfish, brown shrimp, and bees. In particular, the impact on decimating bee hives worldwide is an example of fipronil´s undesirable effects on agriculture. Other species affected by fipronil -for which there are few studies- are biological predators of the same pests controlled by fipronil. Considering all the impacts on non-target species, the commercialization and indiscriminate use of fipronil in agriculture seem irresponsible. In Colombia, as of September 2021 and pressed by local beekeepers, the Instituto Colombiano Agropecuario (ICA) prohibited its use on avocado, coffee, citrus, and passiflower plantations. However, as long as its use is not prohibited in all agricultural applications, farmers could divert its use and continue using it in any other type of plantation. This paper describes the impact of fipronil on some of the beneficial invertebrate species of outmost economic and ecological importance.

Keywords: *acaricide; agriculture; beneficial species; Colombia; ecotoxicity; ecotoxicology; fipronil; honeybees; insecticide; invertebrates; nontarget insects; pesticide; toxicity toxic residues.*

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Resumen

El fipronil es un insecticida y acaricida ampliamente utilizado en la agricultura y los animales domésticos en todo el mundo. Los estudios ecotoxicológicos han demostrado que, aún a las bajas concentraciones utilizadas en las especies destino, el fipronil y sus productos de degradación tienen un impacto significativo en las especies no-blanco, ya sea por efectos tóxicos directos o indirectos que afectan la cadena alimentaria. Los peligros para las especies no-blanco de invertebrados terrestres y acuáticos y los efectos indirectos sobre las cadenas alimentarias han llevado a prohibir o severamente restringir su uso en numerosos países, incluyendo toda la Unión Europea, China y los Estados Unidos. Algunas de las especies altamente susceptibles al fipronil son de gran importancia económica y ecológica, incluyendo cangrejos de río, camarones y abejas. En particular, el impacto en la diezma de las colmenas de abejas en todo el mundo es un ejemplo de los efectos indeseables que tiene el fipronil en la agricultura. Otras especies afectadas por el fipronil -para las que existen pocos estudios- son los depredadores biológicos de las mismas plagas controladas por el fipronil. Teniendo en cuenta su impacto sobre las especies no-blanco, la comercialización y el uso indiscriminado de fipronil en la agricultura parecen irresponsables. En Colombia, a partir de septiembre de 2021 y presionado por los apicultores locales, el Instituto Colombiano Agropecuario (ICA) prohibió su uso en plantaciones de aguacate, café, cítricos y pasifloras. Sin embargo, mientras no esté prohibido su uso en todas sus aplicaciones agrícolas, los agricultores pueden desviar su uso y seguir utilizándolo en cualquier tipo de plantación. Este artículo describe el impacto del fipronil en sólo unas pocas especies de invertebrados beneficiosos de gran importancia económica y ecológica.

Palabras clave: *abejas; acaricida; agricultura; Colombia; ecotoxicidad; ecotoxicología; especies beneficiosas; fipronil; insecticida; insectos no-blanco; invertebrados; pesticida; plaguicida; residuos tóxicos; toxicidad.*

Resumo

Fipronil é um inseticida e acaricídio amplamente utilizado na agricultura e animais domésticos em todo o mundo. Estudos de ecotoxicologia têm demonstrado que em baixas concentrações utilizadas em espécies-alvo, o fipronil e seus produtos de degradação têm um impacto significativo em espécies não-alvo, seja por efeitos diretos de toxicidade ou efeitos indiretos que afetam a cadeia alimentar. Os perigos para espécies não-alvo de invertebrados (terrestres e aquáticos) e efeitos indiretos sobre as cadeias alimentares levaram ao seu uso ser banido ou severamente restrito em vários países, incluindo toda a União Europeia, China e Estados Unidos. Algumas das espécies altamente suscetíveis ao fipronil são de grande importância econômica e ecológica, incluindo lagostim, camarão marrom e abelhas. Em particular, o impacto na dizimação das colmeias de abelhas em todo o mundo é um exemplo dos efeitos indesejáveis que o fipronil tem sobre a agricultura. Outras espécies afetadas pelo fipronil, para as quais há poucos estudos, são predadores biológicos das mesmas pragas controladas pelo fipronil. Considerando todos os impactos sobre espécies não-alvo, a comercialização e o uso indiscriminado do fipronil na agricultura parecem irresponsáveis. Na Colômbia, a partir de setembro de 2021 e pressionada por apicultores, a ICA proibiu seu uso em plantações de abacate, café, cítricos e maracujá. No entanto, desde que seu uso não seja proibido em todas as suas aplicações agrícolas, os agricultores podem desviar seu uso e continuar a usá-lo em qualquer tipo de plantação. Este artigo descreve o impacto do fipronil em apenas algumas espécies com grande importância econômica e ecológica.

Palavras-chave: *abelhas; acaricídio; agricultura; Colômbia; ecotoxicidade; ecotoxicologia; espécies benéficas; fipronil; inseticida; insetos não brancos; invertebrados; resíduos tóxicos; toxicidade.*

As bee populations are dramatically declining worldwide, fipronil has proven to be toxic for bees when they are exposed to the residual concentrations in the pollen and nectar of fipronil-treated plants (Holder *et al.*, 2018). Unlike other pesticides, fipronil bioaccumulates with repeated exposure, becoming lethal to bees within days. Toxicity to beneficial species has been instrumental in banning fipronil for agriculture in the European Union since 2013 (Commission Implementing Regulation of the E.U., 2013) and restricting its use in the United States.

Fipronil has been used in Colombia since 1993. It is marketed in 60 local agricultural products and can be used on more than 40 crops, according to registrations with Instituto Colombiano Agropecuario (ICA, 2021). At least 64,000 hives (each can house 50,000 bees) died from pesticides in Colombia between 2016 and 2020 (ICA, 2021). Laboratory tests on 42 colonies found that 33 (73%) had fipronil and 19 (42%) chlorpyrifos traces. Due to pressure from beekeepers, in March 2021 ICA issued a resolution (No. 092101) suspending fipronil use on avocado, citrus, coffee, and passionflower crops, to be effective from September 2021 (ICA, 2021). The first three crops require pollinators, such as bees, for fertilization and to bear fruit. The six-month period between March and September was considered a grace period for manufacturers to exhaust their stocks; within that period they could apply for new registrations, excluding its use in the four crops mentioned. The ICA would cancel registration for all uses if the product label did not withdraw its usage for the four crops after the six-month grace period. Because the resolution did not prevent fipronil use in other crops, farmers could apply it on any uncontrolled plantations. Although bee mortality has been associated with these four crops, fipronil use would continue to affect other beneficial terrestrial and aquatic macroinvertebrates. A 2021 meta-analysis reported a synergistic increase in bee mortality from agrochemical-agrochemical interactions (Hedge's d=69) and d=172) overall for six classes of interactions between parasites, agrochemicals, and nutrition (Siviter *et al.*, 2021).

Numerous studies have demonstrated that fipronil is extremely toxic to aquatic and terrestrial invertebrates at the ppb concentrations found in municipal wastewaters, urban streams (Weston and Lidy, 2014; Mize *et al.*, 2008; Zhang *et al.*, 2020), and waterways receiving treated rice-field tailwater (USGW, 2003). A study of macroinvertebrates spanning seven taxonomic orders showed total abundance decreased nonlinearly with increasing fipronil concentration (Mize *et al.*, 2008). Also, the total number of taxonomic groups (richness or diversity of species, Y) decreased linearly with the maximum fipronil concentration (µg/L, X), particularly in midge Chironominae and Orthocladinae subfamilies ($Y = 25.45 \pm 1.56 - 2.36 \pm 0.496X$ ($R2 = 0.58$, our values digitized from Mize *et al.*, 2008). The most notable response in the macroinvertebrate-community structure was a shift in dominance from insects (midges, mayflies, and caddisflies) to non-insects (scuds, snails, worms) as rice-cultivation intensity and concentration of fipronil compounds increased. Chironomids, a family of the order Diptera with more than 7,000 described species, are considered indicator species of pollution in river environments (Zhang *et al.*, 2020) and decreased rapidly with small increases in fipronil concentration (Mize et al, 2008). Their larvae and pupae are food for fish, amphibians, and other aquatic animals. Fish and insectivorous birds also eat adults. Although most studies have concentrated on the impact of fipronil in the phylum Arthropoda (insects, arachnids and crustacea), it is also toxic for other taxa in the phyla mollusks and Cnidaria (Figure 1).

Laboratory studies of the coastal brown shrimp, *Farfantepenaeus aztecus*, estimated a fipronil 96-hr LC50 of 1.3 ppb (Al-badran *et al.*, 2018). However, at concentrations from 0.1 to 10 ppb, survival was progressively reduced to the point that all individuals died after 28 days of exposure. The median lethal times (days for 50% of the animals to die) were 6.6 ± 3.51 at 0.1 ppb, 6.33 ± 3.78 at 1.0 ppb, 2.66 ± 1.15 at 3.0 ppb, 3.0 ± 1.0 at 6.4 ppb, and 1.66 ± 0.57 at 10 ppb. The coastal brown shrimp is a good sentinel of water

quality, an important commercial species, and is in the diet of many other marine organisms. In 2016, its commercial value in the United States alone was 166,542 million dollars (National Marine Fisheries Service, 2017). The juvenile stages live in estuaries, making them potentially susceptible to pesticides from agriculture. The 96-h LC50 of fipronil (0.68 ppb) to larval grass shrimp (*Palaemonetes pugio*) is orders of magnitude smaller than imidacloprid (308 ppb), atrazine (>10,000 ppb), and the 3-component mixture was greater than the additive toxicity (Key *et al.* 2007).

Another crustacean that is highly sensitive to fipronil is the freshwater crayfish (*Procambarus clarkki*), which is of great economic importance as it is raised for consumption in the United States and other countries, and is also sold as commercial fish bait. It is also a favorite prey for many birds, including gray herons, cattle egrets, ciconids (storks), and larids (gulls, terns, skimmers). The use of fipronil-treated rice seeds has produced multiple mass mortality incidents of crayfish in the United States (USEPA, 2007). In 8 of 16 monitoring ponds, fipronil concentrations averaged 1.67 ppb and reached 3.2 ppb in some cases. This resulted in the United States banning fipronil use on rice seeds. In a 2020 EPA memorandum on review of fipronil registrations, the chemical company BASF Corporation stated that it would no longer market fipronil for use on rice crops within the United States but would continue its commercialization in other countries (USEPA, 2020).

Most fipronil products are marketed as 20% concentrated suspensions to be applied with spraying equipment. Technical sheets indicate that cattle should not enter the paddocks until 14 days after application. In Colombia, fipronil likely impacts numerous terrestrial species predatory on the target species. For example, fipronil is widely used in Kikuyu pastures in the high Colombian tropics to control the grass bug *Collaria scenica*. Expected non-target effects on pastures treated with fipronil are the disappearance of the two main *Collaria scenica* enemies: the predatory beetle *Eriopis connexa* and spiders of the genus *Alpaida*.

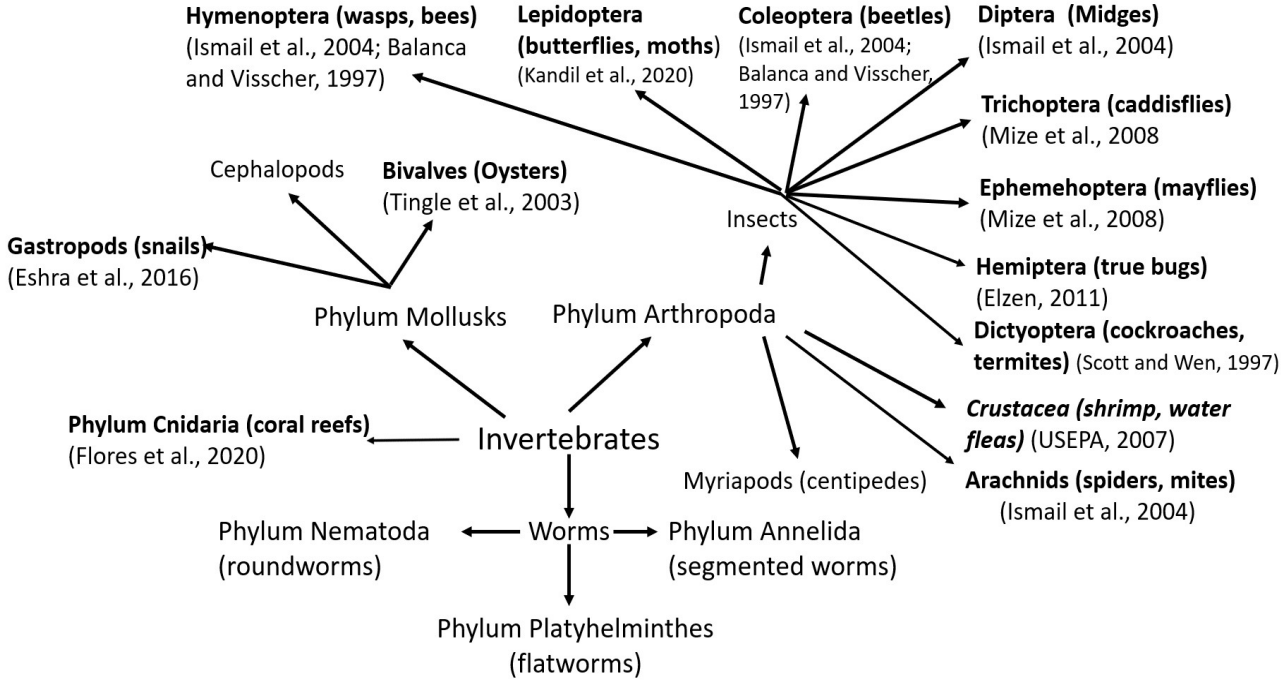

Figure 1. Taxa in bold have numerous species that are very sensitive to fipronil.

The life cycle of *Eriopis connexa* is much longer than that of *Collaria scenica*: adults live 2-3 months compared to 3-4 weeks for *C. scenica* (Zazycki *et al.*, 2015). In addition, the reproduction rate or replacement rate of *E. connexa* is 16 new individuals for each generation, while that of *C. scenica* is around 75 individuals per female (Zazycki *et al.*, 2015). Therefore, it would be expected that if fipronil's efficacy was 100%, *Collaria scenica* would recover more quickly than *Eriopis connexa* populations. Additionally, Elzen (2001) discusses fipronil's effects on other beneficial organisms.

In conclusion, what is occurring with honeybees in Colombia is just the tip of the iceberg on the impacts fipronil has on non-target species. Both terrestrial and aquatic invertebrates have been affected by fipronil worldwide, leading to bans and restrictions of fipronil use in agriculture. In spite of the lack of studies in Colombia (except for honeybees), the harmful effect of fipronil on beneficial non-target species can also be expected to be occurring, as reported elsewhere. Therefore, Colombia should implement similar restrictions as those in other countries.

Declarations

Conflicts of interest

The authors declare they have no conflicts of interest with regard to the work presented in this report.

Author contributions

D.V: Conceptualization and writing of the manuscript. D.J.S: Critical review and editing.

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