Environmental Toxicology and Pharmacology 40 (2015) 915–923

Contents lists available at ScienceDirect

Environmental Toxicology and Pharmacology

journal homepage: www.elsevier.com/locate/etap

Review

Toxicological effects of pyrethroids on non-target aquatic insects

Frank B. Antwi*, Gadi V.P. Reddy*

Western Triangle Agricultural Research Center, Montana State University, 9546 Old Shelby Road, P.O. Box 656, Conrad, MT 59425, USA

ARTICLE INFO

Article history:
Received 26 August 2015
Received in revised form
26 September 2015
Accepted 30 September 2015
Available online 23 October 2015

Keywords:
Pyrethroids
Toxicity
Aquatic insects
Toxicokinetics
Susceptibility
Non-target

ABSTRACT

The toxicological effects of pyrethroids on non-target aquatic insects are mediated by several modes of entry of pyrethroids into aquatic ecosystems, as well as the toxicological characteristics of particular pyrethroids under field conditions. Toxicokinetics, movement across the integument of aquatic insects, and the toxicodynamics of pyrethroids are discussed, and their physiological, symptomatic and ecological effects evaluated. The relationship between pyrethroid toxicity and insecticide uptake is not fully defined. Based on laboratory and field data, it is likely that the susceptibility of aquatic insects (vector and non-vector) is related to biochemical and physiological constraints associated with life in aquatic ecosystems. Understanding factors that influence aquatic insects susceptibility to pyrethroids is critical for the effective and safe use of these compounds in areas adjacent to aquatic environments.

Contents

1. Introduction

Pyrethroids are insecticides with high biological activity and low dose application rates, characterized by low water solubility and strong sorptive properties, which reduce their bioavailability in natural environments (Davies, 1985). They are also relatively photolabile (Leahey, 1985). Because of increased use of these compounds, concern over their possible ecological non-target effects has increased (Antwi and Peterson, 2009; Elliott et al., 1978; Hill, 1989; Merivee et al., 2015; Palmquist et al., 2011; Weston and Lydy, 2010). Aquatic insects are inherently susceptible to pyrethroids, but the mechanism behind their extreme sensitivity to these compounds is not completely clear (Tang and Siegfried, 1995). The extreme toxicity of pyrethroids to aquatic organisms hinders their wider use in agriculture (Coats et al., 1989; Mugni et al., 2013).

* Corresponding authors. Tel.: +1 406 278 7707.
E-mail addresses: frank.antwi@montana.edu, fbantwi@gmail.com (F.B. Antwi), reddy@montana.edu (G.V.P. Reddy).

http://dx.doi.org/10.1016/j.etap.2015.09.023
1382-6689/

Aquatic insects are highly sensitive to insecticide poisoning from even extremely low concentrations (often less than 1 ppb) (Coats et al., 1989; Anderson, 1982, 1989; Mian and Mulla, 1992). The high acute toxicity of pyrethroids to aquatic invertebrates and fish restricts their use in areas near aquatic habitats and has raised concerns over the registration of new pyrethoids by the U. S. Environmental Protection Agency (Anonymous, 1990).

Aquatic organisms are exposed to toxicants dissolved in water or compounds bound to food, particulate or dissolved organic matter. Even though most contamination sources are from runoff (Khan, 1983) or aerial drift (Crossland, 1982), pyrethroid contamination levels in surface water in general are within the range that produces toxic effects in aquatic invertebrates (McLeese et al., 1980; Stehle and Schulz, 2015; Weston and Lydy, 2010; Zitko et al., 1977, 1979). In the aquatic environment, a large number of non-target organisms (including predators of pests) are mixed with target pests and disease vectors (such as mosquitoes, midges, and black flies).

Toxicological tests on aquatic organisms are limited by a lack of information on the toxicant concentration at the biological response end point in question (Friant and Henry, 1985), and it is therefore difficult to estimate the dose to which the animal is actually exposed. In view of the problems in determining the lethal dose for particular insecticides to aquatic insects and of standardizing bioassay conditions, it is difficult to compare tests results from different laboratories. Moreover, different aquatic insects vary considerably in their response to insecticides in static exposure tests (Anderson, 1989). Here, we summarize the available data on the impacts of pyrethroids on non-target aquatic insects.

2. Ecological effects

The understanding of physical, chemical, and physiological processes, including the toxicity of mixtures, varying bioavailability, the impact of intermittent exposures and chemical residues in field-collected organisms are critical in addressing aquatic toxicity problems. Spray-drift or run-off may cause minor effects on some aquatic organisms (Hill, 1989; Weston et al., 2011). According to Hill (1989), for realistic field studies with pyrethroids the effects are mostly transient, and they are not likely to cause adverse changes in aquatic ecosystems with respect to population or productivity.

Esfenvalerate sprayed directly on water boatmen (Corixidae) in the laboratory at low levels intended to simulate spray drift from field applications caused observable effects (knockdown) at doses well below the lowest recommended field dose. Moreover, the use of formulated product was more toxic than the technical grade material, suggesting that the additives, like surfactants, increased the toxicity (Samsoe-Petersen et al., 2001). These findings correlate well with the results of several pond studies in which dead, surface-living beetles were collected after pyrethroids were applied to the water surface (Crossland, 1982) or injected into the water column (Woin, 1998) to assess biological effects.

Picket® (a permethrin product) was found to cause a significant drop in larval densities and emergence of adult midges, *Chironomus riparius* (Meigen) (Diptera: Chironomidae) in ponds treated at >10 μg/L. Older larvae (third and fourth instars) survived to emergence, but younger larvae did not (Conrad et al., 1999). The recovery of midge population levels observed in this study may be owing to the short life cycle of midges, the close proximity of the study site to untreated ponds that likely acted as sources of midge adults and the reduction of permethrin toxicity within the pond ecosystems as a result of rapid degradation or reduction in bioavailability from the water column. Conrad et al. (1999) observed that emergence of adult midges from treated ponds resumed within four weeks and that emergence levels were comparable to that in the control pond within two months, a finding consistent with the work of Mulla et al. (1982), who found that synthetic pyrethroids caused 50–100% mortality of non-target arthropods in experimental field ponds and that recovery to pre-treatment levels took place within 2–4 weeks after treatment. Similarly, permethrin applications to lakes, streams and ponds affected aquatic insect populations (Ephemeroptera and Odonata) for only brief periods, with recovery occurring a few weeks to a few months after treatment (Mian and Mulla, 1992). Based on intrinsic sensitivity, biological traits, mode of action, and on invertebrate vulnerability index rankings Ephemeroptera, Plecoptera, Tricoptera, and Odonata genera were potentially most vulnerable to pyrethroids in aquatic ecosystems (Rico and Van den Brink, 2015). Prior studies also support this pattern of the impact of synthetic pyrethroids on aquatic insects (Leahey, 1985; Smith and Stratton, 1986; Hill, 1989; Coats et al., 1989; Mian and Mulla, 1992).

The study by Kingsbury and Kreutzweiser (1980), stated that the diet of brook trout fish (*Salvelinus fontinalis* (Mitchill) (Salmoniformes: Salmonidae) was made up of 75% total volume of aquatic insects before permethrin application. Just after spraying permethrin (8.8, 17.5, 35.0, and 70.0 g a.i./ha) to streams the trout consumed large numbers of mayflies, stoneflies, and caddisflies and that this demonstrates the utilization of post spray drift organisms (Kingsbury and Kreutzweiser, 1980). According to Kingsbury and Kreutzweiser (1980) after 11 and 58 days post treatment more than 80% of the trout feeding was mainly on terrestrial arthropods for its diet with the use of chironomid larvae and other aquatic invertebrates accounting for the rest. Moreover this feeding trend continued at the end of the season after 112 days post treatment indicating continued dependence on terrestrial arthropods. Brook trout and slimy sculpins (*Cottus cognatus* (Richardson) Scorpaeniformes: Cottidae) utilize alternate food sources when aquatic insects became unavailable (Kingsbury and Kreutzweiser, 1980). These series of field trials carried out in Canada to examine the side-effects of aerial application of permethrin used to control forests pests also found that two applications at 17.5 g a.i./ha resulted in substantial reductions of invertebrate (ephemeroptera, heptagenidae, plecoptera, and chironomid) populations (Kingsbury and Kreutzweiser, 1980). Recovery in some invertebrate abundance began six weeks after the second treatment. Measured permethrin residue levels never exceeded 2.6 μg/L in the treated streams and ponds, and were below 0.25 μg/L two days after treatment. The ability of an aquatic ecosystem to recover from insecticide contamination is affected by many factors, including the insecticide's persistence, bioavailability, the life-history attributes of the affected organisms and the proximity of recolonization sites (Fairchild et al., 1992).

Mathias and Schulz (1996) observed that larvae, pupae, and adults of the caddisfly *Limnephilus lunatus* Curtis (Trichoptera: Limnephilidae) exposed to pyrethroids showed decreased survival with increasing pesticide concentration, while emergence was reduced and delayed. The acute toxicity (LC_{50}) of fenvalerate for *L. lunatus* over a 24-h observation period after a one hour exposure was 22.6 μg/L, reflecting the fact that pyrethroids break down much more slowly in fish and aquatic insects than in warm blooded vertebrates (Coats et al., 1989). Direct lethal effects of acute pyrethroid contamination mostly appear immediately after exposure, and chronic elevated lethality following short term contamination is relatively slight. Insects possess a relatively low capacity for the hydrolysis of both *cis and trans*-pyrethroids and, consequently, the toxicity of both groups of isomers is high. However, comparing the toxicity of different pyrethroids is complicated due to differences in species, sex, and application methods employed by studies.