SUBLETHAL EFFECTS OF INSECTICIDES ON LONGEVITY, FECUNDITY AND BEHAVIOUR OF INSECT PESTS: A REVIEW

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Abstrak: Kesan submaut insektisid merupakan satu aspek penyelidikan dalam bidang toksikologi insektisid yang kurang diterokai dan difahami. Tinjauan ini menyimpulkan kebanyakan maklumat kesan submaut insektisid pada kefekunan, jangka hayat and kelakuan serangga, yang telah diterbitkan sejak tahun 1940. Penekanan diberikan ke atas serangga yang penting dari segi pertanian, perubatan dan bandar. Satu ringkasan dan huraian berkenaan dengan aspek penyelidikan yang patut diberi keutamaan pada masa hadapan disertakan.

Abstract: Sublethal effects of insecticides is a research area in insecticide toxicology that is less explored and understood. This review summarizes most published information on sublethal effects of insecticides on fecundity, longevity and behaviour of insects, since 1940. Emphasis has been placed on insects of agricultural, medical and urban importance. A short summary and description on several research priorities for future studies are also included.

INTRODUCTION

Despite numerous novel control agents available at present, insecticides remain as the most effective and reliable method for insect control. As the chance of an insect receiving a lethal exposure from an insecticide deposit is a result of complicated and dynamic interaction between abiotic and biotic factors (Rust 1995, Lee *et al.* 1998), insecticide performance can often be greatly reduced. The insects may contact the insecticide deposit, but only at sublethal levels which may not kill them.

Insecticidal effects on insects can generally be divided into: (1) direct toxic effects which cause mortality and (2) sublethal effects. Of these two, the sublethal effects are not well studied. The sublethal effects of an insecticide is defined as the biological and behavioural changes of surviving insects following contact with a sublethal amount of the insecticide. According to Moriarty (1969), sublethal doses of insecticides can affect populations of insect in the following ways, ie, through changes in: (1) survivorship, (2) reproductive capability and (3) the genetic constitution of successive generations (however, Lee *et al.* [1998] demonstrated that it is not possible to cause an increase in tolerance in F_1 generation in *Blattella germanica* upon selection with sublethal doses). Only two reviews on the sublethal effects of insecticides on insects have been published. Moriarty (1969) has dealt with a broader scope of the sublethal effects of insecticides covering latent toxicity, reproductive potential, behaviour and enzyme induction, while Haynes (1988) covered the effects of sublethal doses on insect behaviour. Since the last review, there have been substantial information added to this area of interest. This present paper will discuss the sublethal effects of insecticides on fecundity, longevity and behaviour of insect pests, to date. Physiological and behavioural effects that arised from exposure to insect growth regulators are not included in this review.

SUBLETHAL EFFECTS ON INSECT FECUNDITY

There has been a substantial wealth of information on this aspect of study. Hunter *et al.* (1958) has reported that DDT and diazinon caused reduction in offspring production of a resistant strain of *Musca domestica* which was in contrast to the findings with a susceptible strain. Working with the same species, Georghiou (1965) found that Isolan®, dimetilan, carbaryl and propoxur resulted in reduction of egg production, but the egg fertility was not affected. The fecundity, mating and longevity of pink bollworm (*Pectinophora gossypiella*) were reduced when treated with sublethal doses of DDT (Adkisson & Wellso 1962). Similar findings were registered when Bariola (1984) tested the same species with various insecticides including pyrethroids (cyfluthrin, fenpropathrin, fenvalerate, flucythrinate and permethrin), organophosphates (azinphosmethyl, methyl parathion and trichlorfon) and others (carbaryl, chlordimeform and avermectin B_1). In the diamond-back moth (*Pluttella xylostella*), Kumar & Chapman (1984) showed that fenvalerate, methamidophos and carbaryl at LD_{50} reduced its reproductive capability, but no significant effect was detected with permethrin. Cypermethrin was found to reduce egg numbers laid in the mustard beetle, *Phaedon cochleariae* (Hajjar & Ford 1989). In addition, the fecundity of black carpet beetles, *Attagenus megatoma* was reduced in those surviving LD_{50} doses of malathion and dichlorvos (Zettler & LeCato 1974).

In mosquitoes, egg laying of *Aedes aegypti* was reduced with sublethal doses of dieldrin (Duncan 1963), Abate® (Reyes-Villanueva *et al.* 1990), d-phenothrin and d-allethrin (Liu *et al.* 1986). Similar findings were also observed in *Culex quinquefasciatus* with malathion (Robert & Olson 1989) and in *Anopheles quadrimaculatus* with aldrin, chlordane, DDT, BHC and rotenone (DeCoursey *et al.* 1953).

While many reports showed that insecticides reduced the fecundity of the affected insects, others seem to provide contradictory findings. Afifi & Knutson (1956) reported that the dieldrin dose that normally caused 60-90% mortality increased the oviposition rate of the surviving *M. domestica* by 69% when compared to that of control insects. Further studies on a malathion dose that caused 40-60% mortality showed similar findings (Ouye & Knutson 1957). Ball & Su (1979) found that carbofuran & carbaryl caused significantly higher fecundity in the western corn rootworm (*Diabrotica virgifera*). Chelliah *et al.* (1980) also reported similar findings when methyl parathion and decamethrin (=deltamethrin) at LD_{25} were applied to the 5th instar of the brown planthopper, *Nilaparvata lugens*. In *Ae. aegypti*, Sutherland *et al.* (1967) observed an increase in basal follicles upon treatment of the insect with sublethal doses of DDT, dieldrin and malathion. The egg production of *Ae. aegypti* also increased with a sublethal dose of tetramethrin (Liu *et al.* 1986).

There are comparatively few reports on the sublethal effects of insecticides on the longevity and fecundity of the German cockroach (*Blattella germanica*). Cochran (1985) reported that adult females which were fed and survived an avermectin B_1 concentration of $\geq$6.5 mg/l became sterile. Doses of <6.5 mg/l also inhibited mating and reproduction. Hamilton & Schal (1990) found that sublethal doses of chlorpyrifos-methyl at LD_{10}, LD_{20} and LD_{60} applied topically to 2-day old adult females reduced fecundity and hatchability of the first ootheca. However, no effect was found on fecundity and longevity in chlorpyrifos-ethyl treated adult female cockroaches. Abd-Elghafar & Appel (1992) reported the sublethal effects of three insecticides (cyfluthrin, chlorpyrifos-ethyl and hydramethylnon). By crossing adult males and females of the German cockroach treated with the same level of sublethal doses (e.g. LD_{20} x LD_{20}, LD_{30} x LD_{30}, etc.), they found that increasing sublethal doses of cyfluthrin and hydramethylnon caused a decline in reproductive capabilities (e.g. oothecal production, oothecal hatchability and nymphal production). In contrast to the report by Hamilton & Schal (1990), they showed a positive linear relationship between the sublethal doses of chlorpyrifos-ethyl and fecundity. Recently, using reciprocal crossing method, Lee *et al.* (1998) demonstrated that oothecal production, oothecal hatchability and nymphal production of *B. germanica* declined with increasing doses of propoxur and deltamethrin applied on both sexes.

Besides affecting fecundity, sublethal doses of insecticides also cause oothecal drop and hatchability of the German cockroach. Parker & Campbell (1940) recorded that oothecae which were dropped onto household insecticide residues were less likely able to hatch when compared to those dropped onto an untreated surface. Harmon & Ross (1987) demonstrated that exposure to propoxur caused an increase in oothecal drop in susceptible insects and prolonged the incubation period. The number of nymphs which failed to emerge from oothecae that fell onto treated surface also increased. Further studies on malathion confirmed this findings. On the other hand, diazinon exposure led to an increase in nymphal emergence. The authors concluded that premature oothecal drop is a phenomenon associated with susceptibility (Harmon & Ross 1988).

Zhou & Patourel (1990) reported that female German cockroaches which received lethal oral doses of hydramethylnon retained their oothecae even at death, while a proportion of those killed by boric acid dropped their oothecae prematurely. Sulfluramid, when applied topically to gravid females, caused oothecal drop and reduced oothecal hatchability of both dropped and retained oothecae (Appel & Abd-Elghafar 1990). Further studies on gravid females (using ten insecticides, namely bendiocarb, chlorpyrifos, cyfluthrin, cypermethrin, fenvalerate, hydramethylnon, malathion, propetamphos, propoxur and pyrethrins) showed that oothecal drop increased with increasing insecticide concentration. Propoxur was shown to cause the greatest oothecal drop and the lowest oothecal hatch from retained oothecae (Abd-Elghafar *et al.* 1991).

SUBLETHAL EFFECTS ON INSECT LONGEVITY

The longevity of the insects treated with sublethal doses of insecticides may increase, decrease or remain unchanged. Kumar & Chapman (1984) reported that adult longevity of *P. xylostella* was reduced by 36% when larval stages were treated with LD_1 of permethrin and fenvalerate and LC_{50} of methamidophos. However, LC_1 of carbaryl increased the longevity of the adult by 40%. In the house fly, female longevity was reduced in a resistant strain when treated with DDT, while no difference in longevity was observed in treated insects from a susceptible strain (Hunter *et al.* 1958). Carbofuran and carbaryl caused significantly longer longevity of *D. virgifera* when compared to that of the control (Ball & Su 1979). Reyes-Villanueva *et al.* (1990) also found increased longevity in adult female *Ae. aegypti* mosquitoes when it was treated with temephos during larval stages.

In the German cockroach, the longevity of adult females was reduced by 12% upon topical treatment with LD_{10}, LD_{20} and LD_{60} of chlorpyrifos-methyl. With chlorpyrifos-ethyl, the longevity of adult female cockroaches was shortened by 22%, only at a high concentration (Hamilton & Schal 1990). Conversely, Abd-Elghafar & Appel (1992) found that sublethal doses of chlorpyrifos-ethyl were positively correlated with the longevity of female German cockroaches, and this parameter was negatively correlated with sublethal doses of cyfluthrin and hydramethylnon. Negative effects of sublethal doses of propoxur and deltamethrin on insect longevity has been demonstrated recently by Lee *et al.* (1998).

SUBLETHAL EFFECTS ON INSECT BEHAVIOUR

Haynes (1988) has reviewed the sublethal effects of insecticides on insect behaviour. Reduced mating activity was shown in *P. gossypiella* with DDT (Adkisson & Wellso 1962) and 14 other insecticides (Bariola 1984). Feeding activity and behaviour were either reduced or disrupted in several species: e.g. diamond-back moth (*P. xylostella*) upon contacting permethrin and fenvalerate at LC_1 and LC_{50} (Kumar & Chapman 1984), spruce budworm *Choristonuera fumiferana* with carbaryl, aminocarb and fenitrothion exposures (Alford 1991), and *Drosophila melanogaster* with permethrin (Armstrong & Bonner 1985).

The V-shaped daily probing activity rhythm in tsetse fly (*Glossina austeni*) and blow fly (*Protophormia terraenovae*) was not affected when the insects were treated with LC_{15} of endosulfan, but DDT and permethrin caused temporary doubling and long-lasting reduction in responsiveness, respectively, in tsetse flies (Chadd & Brady 1982). Blood-feeding activity of *Ae. aegypti* decreased upon treatment with tetramethrin, d-phenothrin and d-allethrin (at 0.002%, 0.003% and 0.010%, respectively) (Liu *et al.* 1986). In another study, the blood-feeding activity of *Cx. quinquefasciatus* was decreased by 90% after a 20-minute exposure to the smoke from a burning mosquito coil containing d-allethrin as active ingredient (Lim 1995, Yap *et al.* 1996).

In addition, chemical communication in relation to courtship and mating in pink bollworm moths (*P. gossypiella*) was disrupted by sublethal doses of permethrin (Floyd & Crowder 1981, Haynes & Baker 1985, Haynes *et al.* 1986), cypermethrin, chlordimeform and fenvalerate (Haynes *et al.* 1986). Cypermethrin and chlordimeform also affected the chemical communication of cabbage loopers, *Trichoplusia ni* (Clark & Haynes 1992a, 1992b).

Very few studies have been conducted on the effect of sublethal doses of insecticides on the behaviour of the German cockroach. Ebeling *et al.* (1966) found that German cockroaches were capable of learning to avoid insecticide exposure in choice boxes. Adult male German cockroaches increased their water consumption for the first 2 days after sublethal propoxur exposures, but feeding behaviour did not change (Kramer *et al.* 1989). However with avermectin doses of $\geq$6.5 ppm, feeding behaviour was greatly affected (Cochran 1985). Lee *et al.* (1998) reported that female German cockroach became sexually unreceptive upon treatment with LD_{50} of deltamethrin, despite courting behaviours demonstrated by male cockroaches.

CONCLUSION AND FUTURE RESEARCH PRIORITIES

In summary, sublethal doses of insecticides have been shown in many studies to induce physiological and behavioural changes in insect pests. Most insect pests showed reduction in fecundity and longevity, and disruption in concerted behavioural activities upon contacting sublethal doses of insecticides. The usage of sublethal doses, albeit provides positive effects on pest management, should not be practiced. Several studies have shown that sublethal amounts of insecticides can cause dispersal of insects from contacting treated surfaces, thus rendering control failure (Bret & Ross 1985, 1986a, 1986b, Wooster & Ross 1989). Several research priorities are proposed for future studies. As insect reproduction is regulated by hormones, it is essential to understand changes in neurohormonal regulation upon sublethal dose exposures. In addition, there is also a need to address the effect of sublethal doses of insecticides on the age-class distribution of insect pest populations; the information obtained will be useful for the better planning of insecticide application.

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