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J Stanley
Scientist, ICAR- Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand, India

G Preetha
Assistant Professor, Agricultural Research Station (TNAU), Thirupathisaram, Tamil Nadu, India.

M Mohan
Senior Scientist, ICAR-National Bureau of Agricultural Insect Resources, Bengaluru, Karnataka, India.

Correspondence
J Stanley
Scientist, ICAR- Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand, India

Insecticide resistance in soil arthropod pests: Status and mechanism

J Stanley, G Preetha and M Mohan

Abstract
Soil arthropod pests are those which live in the soil and cause economic loss to humans. Root maggots, wireworms, whitegrubs, termites and ants are important soil pests. Insecticides are used for the management of these pests and the buffering capacity of soil makes difficult for these pests to be managed and warrants high concentration of pesticides with repeated applications. This increases the selection pressure which inturn makes the pest to develop resistance against pesticides. Pesticide resistance in soil arthropod pests is observed as early as 1962 in Anthomyiid flies to cyclodienes. Many soil pests were reportedly developed resistance to organophosphates, organo chlorines and synthetic pyrethroid insecticides. Most of the soil insect pests reportedly developed resistance to insecticides through different mechanisms *viz*., enhanced enzymatic metabolism though detoxifying enzymes, altered target-site sensitivity, penetration resistance and altered behavior.

Keywords: Insecticide resistance, soil pests, status, mechanism of insecticide resistance

1. Introduction
Soil insects are defined as 'any insect, which during its growing or feeding stages, lives on or beneath the soil surface'. If so, many insects fall under this category. However, insects present in the soil during their destructive stage and cause widespread damage to agricultural crops are generally known as soil arthropod pests. The dipterous larvae commonly known as root maggots, eg. the seed corn, onion, cabbage, sugar beet and carrot fly; coleopterous larvae including wireworms, flea beetles, the chafer, Japanese beetle, corn root worm and whitegrubs; the lepidopterous larvae such as cutworms[1] ; the orthopterans like crickets and mole crickets; the isopterans like termites or white ants and the hymenopterans especially of ants are typical soil insect pests. Some of these are noxious pests and usually managed using insecticides. Since insecticides are to be applied in the soil, it requires in higher quantities for effective management. In due course of time, some of them are found to develop resistance to the insecticides and thus resulted in field control failures.

2. Insecticides used Against Soil Pests
The development of DDT in the late 1940s and cyclodienes heralded the era when soil insect control for the first time become practical. The organochlorine insecticides particularly aldrin and heptachlor were remarkably active in soil against most species of soil insects of economic importance and within a few years of their introduction, extensive misuse resulted in the development of resistance in many of the soil insects [1].
Insecticides used against whitegrubs in soil and found effective are parathion on *Melolontha melolontha* [2], carbofuran and isazofos on *Bothynus subtropicus*, *Strategus antaeus*, *Phyllophaga* sp. and *Cyclocephala parallela* [3]. Fensulfothion was reported effective against *Phyllophaga ephilida* [4] and diazinon on *Anomala orientalis* and *Rhizotrogus majalis* [5]. Heptachlor, bifenthrin, isofenphos and decamethrin were used to manage *Maladera matrida* [6]. Chlorpyriphos and isofenphos for *R. majalis* [7], chlorpyriphos for *A. orientalis*, *R. majalis*, *Maladera castanea, Popillia japonica* and *Cyclocephala borealis* [8] were reported effective. Imidacloprid and halofenozide were found effective against *P. japonica* [9]. The neonicotinoids, imidacloprid and thiamethoxam were used for the management of *P. japonica* and *C. borealis* [10] and imidacloprid on *A. orientalis* [11]. Chlorpyriphos and imidacloprid were found effective against *Antitrogus parvulus* [12] and chlorantraniliprole on *P. japonica* and *C. borealis* [13]. Clothianidin on *Amphimallon majale* [14] and chlothianidin, imidacloprid, chlorpyriphos and quinalphos on *Holotrichia consanguinea* were reported as effective

insecticides [15]. Though carbofuran as dry granules directly incorporated in soil is found very effective against melolonthids, *Sphodroxia maroccana,* its non-target effects are much evident [16]. Imdiacloprid 0.3G 20 kg/ha was found very effective against *H. consanguinea* in ground nut [17]. Imidacloprid 70 WS as seed treatment protected potato crop from whitegrubs [18]. Clothianidin 50 WDG 0.12 kg a.i ha^{-1} was reported as the most effective insecticide followed by imidacloprid 70 WG 0.3 kg ai ha^{-1} against whitegrubs infesting soybean [19].

Fensulfothion, carbofuran, chlorfenvinphos and terbufos were reported effective against root maggots [20]. Seed treatment with fipronil, spinosad, clothianidin and cyromazine were effective against onion maggots, *Delia antique* [21]. Seed treatment with thiamethoxam was found effective against cabbage root maggot in broccoli [22]. Zeta-cypermethrin, tolfenpyrad, fenpropathrin, clothianidin, and bifenthrin were reported effective among 29 insecticides tested against cabbage maggot, *Delia radicum* [23]. Fipronil was highly toxic to wireworms followed by chlothianidin, thiamethoxam and chlorpyriphos [24]. Fipronil, imidacloprid, thiamethoxam, bifenthrin, phorate and ethoprop are found effective on wireworms, *Melanotus communis, Conoderus lividus* and *Conoderus vespertinus* [25]. Fipronil as seed treatment in wheat was found to be very effective against wireworms [26].

Cypermethrin was reported as the most toxic insecticide against Formosan subterranean termite workers followed by Chlorpyrifos [27]. Acephate, bifenthrin, fipronil, imidacloprid and indoxacarb are being used for mole cricket control [28]. Ethiozinon 60% EC @ 4.5 L ha^{-1} treated in mounts was reported effective for the control of termites [29]. Novaluron based termite bait system was reportedly effective in controlling *Reticulitermes* sp. and *Coptotermes formosanus* [30].

3. Status of Insecticide Resistance in Soil Pests

Soil insects, particularly of the family Anthomiidae were the first to develop resistance to cyclodienes [31] as early as 1962. Onion maggot, *Hylemya antique,* the seed-corn maggot, *H cilierura* and *H. liturata,* the cabbage maggot, *H. brassicae* and the spotted root fly, *Euxesta notata* exhibited a high degree of tolerance to aldrin and dieldrin [32]. The root maggot, *H. platura* was found highly resistant to cyclodienes and aldrin but have no cross resistance to either diazinon or DDT [33]. However, the aldrin-resistant strains of *H. platura*, *H. anliqua* and *H. brassicae* were also found resistant to chlordane [1]. Later, methyl-parathion and carbaryl resistance was reported in western corn rootworm, *Diabrotica virgifera virgifera.*

The southern potato wireworm and the European chaffer are the first among coleopteran soil pests to develop resistance to insecticides particularly to cyclodienes [34]. A very high level of DDT resistance up to 50x was reported in grass grubs, *Costelytra zealandica* [35, 36]. These resistant strains were not found to have cross resistance to cyclodiene, OC and OP pesticides [37]. Wireworms, *Conoderus vespertinus* and *C. falli* attacking sweet potato and tobacco were found to have developed resistance to widely used cyclodiene insecticides [38, 39].

Enhanced insecticide tolerance to cypermethrin, chlordane and chlorpyriphos occurs unlikely in *Coptotermes formosanus* workers in Orelans and seems not to developed resistance to the insecticides because of the lack of selection pressure on queen termites [27]. However, a colony of *C. formosanus* was reported 16 times more tolerant than others to deltamethrin [40]. The dark-sided cutworm, *Euxoa messoria* was reported to be highly tolerant to dieldrin, DDT and diazinon [32]. In general, soil pests were found to develop resistance to DDT and cyclodienes quickly than OP and other compounds because of the high persistence nature of cyclodienes and organochlorines in the soil.

4. Mechanism of Resistance

4.1. Enhanced Enzymatic Metabolism

The P450-dependent monooxygenases are a vital biochemical system which metabolizes pesticides and regulates the titers of endogenous compounds such as hormones, fatty acids and steroids [41]. Glutothione S- transferase is another complex multigene family of enzymes [42] important for detoxification, conjugating reduced glutathione with a large number of electrophilic metabolites derived from a variety of xenobiotics [43].

The major proteases of the New Zealand grass grub, *Costelytra zealandica* such as trypsin, chymotrypsin, elastase, leucine aminopeptidase and carboxypeptidases A & B is suggested for resistance to ingested proteins [44]. Three species of glutathione S-transferase reported from the grass grub, *C. zealandica* may be the cause of resistance to insecticides [45]. Very high activity of monooxygenase, indicated by dihydroisodrin hydroxylation is reported in black cutworm, *Agrotis ipsilon* [46]. The P450 content and GST activity in *Agrotis ipsilon* were higher than those in *Mythimna separata* [47].

The major detoxication enzyme of two economically important termite species, *Mastotermes darwiniensis* and *Coptotermes acinaciformis* is reported as cytochrome *P*450 monooxygenase which include aldrin epoxidase (AE), 7-ethoxyresorufin *O*-de ethylase (EROD) and 7-ethoxycoumarin *O*-de ethylase (ECOD). AE activity in these two termite species is reported low, EROD as moderate and ECOD as high, compared to other insects. The cytosolic glutathione S-transferase activity of *C. acinaciformis* was found 3 fold higher than that of *M. darwiniensis* [48]. Aldrin epoxidase, cytochrome P450, cytochrome C reductase and methoxyresorufin *O*-demethylase activities were measured in *R. virginicus* [49]. Valles *et al*. [50] showed that microsomal esterases as the major route of detoxication of trans-permethrin in *Reticulitermes flavipes*, which is also present and varied widely between colonies in *Coptotermes formosanus* [27]. Rhinotermitids were found to have glutothione, glutothione disulphide and glutothione transferase levels in the range of those reported for resistant flies [51].

4.2. Altered Target-site Sensitivity

Modification/ alteration of target site does not permit the active interaction of the toxicant with the target site. Cyclodiene resistance has accounted for over 60% of reported cases of insecticide resistance. The resistance mechanism involves both changes in cyclodiene binding site affinity and also a change in the rate of receptor desensitization [52]. A single amino acid replacement within the lining of the chloride ion channel confers insensitivity to the blocking action of cyclodienes and picrotoxinin on GABA gated chloride ion channels. Target site based synergy was reported when bifenthrin and imidacloprid are used in combination against mole crickets, *Scapteriscus vicinus* [28].

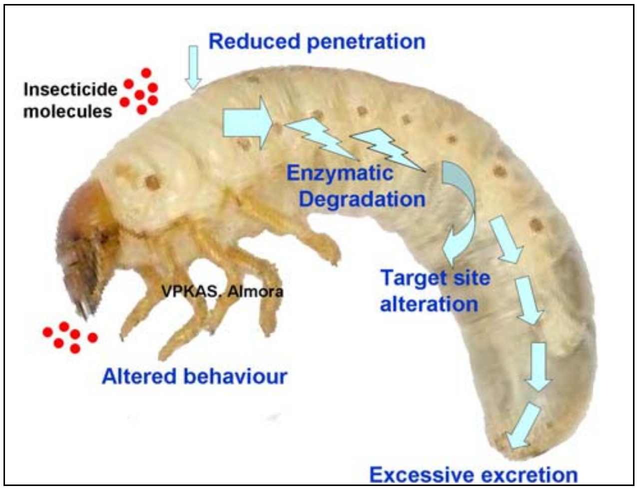

Fig 1: Mechanism of resistance in soil insects

4.3. Penetration Resistance
Later instars of white grubs have a hard cuticle which imparts resistance to contact insecticides. Further reports say that insecticides get accumulated or locked up with the fat tissues beneath the cuticle, not reaching the target site. Field populations of wireworms, *Agriotes* sp. were difficult to control using fipronil because of the low integumental penetration rates in the target larval body[53].

4.4. Altered Behaviour
Larval feeding behaviour of the subterranean pests is of utmost importance for designing a strategy of dietary chemical control. Feeding behaviour in wireworm is regarded as a limiting step in insecticide absorption [53]. Pacific Coast wireworm, *Limonius canus* preconditioned with tefluthrin odour were found to get repelled 4-5 times than that of the naïve, when provided with tefluthirn coated wheat seeds [54]. Detoxication of xenobiotics in Rhinotermitids involves the addition of biological nucleophiles to the electrophilic and unsaturated systems by which the lipophilic compounds are converted into less reactive and more water soluble [55] and thus excreted frequently. Formosan subterranean termites are found to seal off their galleries and move to other side to avoid getting contact with the toxin when treated with pyrethroids *viz*., fenvalerate, permethrin, resmethrin and pyrethrins [56].

5. Conclusion:
Resistance is an adaptive phenomenon which makes the living organism to cope up with the stress in one way or another. Resistant monitoring in crop pests is inevitable to preserve their susceptibility to successful chemical insecticides. Besides, use of chemicals with different modes of action and development of new pesticides with varied mode of action and use of other strategies for pest management are the need of the hour.

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