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REVIEW

Organotin compounds in agriculture since 1980 Part 2.* Acaricidal, antifeedant, chemosterilant and insecticidal properties

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The object of this review paper is to provide a guide to agrochemical research involving organotin compounds which has been performed since 1980. The information is presented in a tabular form and is divided into four main sections as indicated by the title. Each section is then subdivided to cover the various commercial organotin compounds. A final subsection lists investigations involving novel compounds. An additional section covers the effects of organotin agrochemicals on non-target organisms. A table of the contents has been provided to enable ease of reference. Acaricidal, antifeedant, chemosterilant and insecticidal properties are covered here. Fungicidal, bactericidal and herbicidal aspects are covered in Part 1.

Keywords: Agrochemicals, organotin, triphenyltin, tricyclohexyltin, trineophyltin, acaricide, antifeedant, chemosterilant, insecticide, non-target organisms

CONTENTS

Part 2—Acaricidal, antifeedant, chemosterilant and insecticidal properties

*Part 1: Crowe A J *Appl. Organomet. Chem.*, 1987, 1: 143.

INTRODUCTION

A general introduction to the actual and potential agrochemical uses of organotin compounds was given in Part 1,* which in addition covered the recent research into their fungicidal, bactericidal and herbicidal properties.

Mites are small, eight-legged, acarine creatures, some species of which are phytophagous (plant feeding) and are a constant problem in greenhouses, nurseries, and in deciduous and citrus fruit orchards.[1] These mites live exclusively on plant sap and can cause great mechanical damage to leaf tissues on plants. The complete egg-to-adult cycle takes about 14 days and an adult female lives for about three weeks during which time she lays approximately 120 eggs, which hatch within five days. Thus large populations of these mites can rapidly arise.

Three organotin acaricides are currently commercially available, tricyclohexyltin hydroxide (Cyhexatin: Plictran); bis(trineophyltin)oxide (Fenbutatin oxide: Vendex or Torque) and tricyclohexyltin-1,2,4-triazole (Azocyclotin: Peropal). All three are highly effective in the control of phytophagous mites, and cyhexatin in particular is widely used (for structures see Part I). These three compounds are active against mites which are resistant to conventional acaricides such as organophosphates,[1] but show little effect on predacious mites and other beneficial insects, including the honey bee.[1-3]

The organotin acaricides tend to behave as contact poisons and give highly lethal effects to all motile stages, including adult mites. The quiescent stages of development are usually less sensitive to these acaricides, while eggs display the greatest resistance.[1,4]

Table 1.1 Full and common names of the mites included in Section 1

Full name	Common name	Compound[a]
Acaphylla theae	Pink	C
Acarus siro	Stored product	F
Aceria litchii	Erinose	C
Aculus schlectendali	Apple rust	C, F
Glycyphagus destructor	Stored product	F
Panonychus citri	Citrus red	N
Panonychus ulmi	Red	A, C, F
Paracalacarus podocarpi	Rust	C, F
Phyllocoptruta oleivora	Citrus rust	A, C, F
Psoroptes cuniculi	Ear canker	C
Psoroptes ovis	Common scabies	C
Rhizoglyphus robini	Bulb	C
Sarcoptes	Itch	C
Tarsonemus pallidus	Strawberry	C
Tetranychus arabicus	Green	A, F
Tetranychus cinnabarinus	Carmine	N
Tetranychus gloveri	Glover's spider	C, F
Tetranychus urticae	Two-spotted spider	C, F, N
Tetranychus viennensis	Hawthorn	C
Tyrophagous longior	Stored product	F
Tyrophagous putrescentiae	Stored product	F

[a]A, Azocyclotin (Table 1.4); C, Cyhexatin (Table 1.2); F, Fenbutatin oxide (Table 1.3); N, Novel organotin (Table 1.5).

These acaricides, which are compatible with other pesticides,[5] are usually applied as wettable powders which are readily dispersed in water and can therefore be used in conventional sprayers.[2] After application they are resistant to the effects of rain[1] and since they do not exhibit any systemic action their residues remain on the surface of the treated crops.[1,4] Formulations containing low concentrations of the active ingredients produce long effective lifetimes, which may be enhanced, if necessary, by repeat applications.

In recent years the use of broad spectrum pesticides has come under considerable criticism due to their lack of selectivity, which means that both beneficial and non-target insects are also adversely affected. Also such pesticides are often persistent in the environment and thus remain toxic for long periods. In addition, excessive use has led to a build-up of resistance to the toxic effect of these chemicals. Research is now being directed towards the development of compounds which control insect pest populations by more indirect means such as disruption of normal maturation processes (e.g. juvenile hormone analogues) or disruption of behaviour patterns by modifying sensory input (e.g. pheromones). Two other approaches are antifeedants and chemosterilants.

An antifeedant produces a cessation of feeding by preventing the insect from recognizing the normal host plant gustatory stimulus by inhibiting taste receptors.[6] Thus the insect pest starves to death or is eaten by predators.

During field trials to assess the fungicidal activity of triphenyltin acetate (Fentin acetate: Brestan) it was noticed that insect feeding was prevented on treated foliage.[7] A subsequent laboratory study showed that the feeding of larvae of the cotton leaf worm *Spodoptera littoralis* on sugar beet leaves was inhibited by sublethal amounts of both fentin acetate and triphenyltin hydroxide (Fentin hydroxide: Duter).[8] As a direct result of this work the effects of these and other organotins on a variety of surface-feeding insects were investigated.[3,9]

The main advantages of antifeedants over conventional techniques is that beneficial and non-target insects are not affected because (i) they do not eat the treated crop, and (ii) sub-lethal concentrations of the compounds are used. Thus antifeedants may be utilized in integrated pest control methods involving biological control agents, such as predatory insects. In addition, antifeedants act faster than conventional insecticides to restrict feeding damage, since an insect may continue to feed during the time it takes for an insecticide to kill it.

Organotins do not exhibit systemic activity and so are unable to protect plants as antifeedants against sucking insects and internal leaf eaters.[6]

A chemosterilant is a chemical which interferes with the reproductive cycle of an insect. The first detailed report of organotins displaying this property was by Kenager,[10] who demonstrated that various types of insects showed diminished or no reproduction after feeding on triphenyltin derivatives. The majority of the subsequent studies have concentrated on the common housefly (*Musca domestica*) but a number of other species have also been studied and promising results obtained.[2,3]

The triphenyltins appear to produce a reduction in both egg-laying and in the percentage of larvae which hatch out. This effect, however, appears to be reversible with time. An additional effect of these compounds was to prolong the larval–pupal duration. Thus in an integrated pest control system the triphenyltins would enable increased predation of the larvae to occur.

Both antifeedants and chemosterilants are preferred forms of insect control since sub-lethal concentrations are used. In addition, the fact that doses which are lethal to the pest insects are often tolerated by non-target species suggests that such compounds would be suitable for commercialization and it may well be that in future years organotin compounds will become available for use in one or both of these applications.

The insecticidal properties of various triorganotin compounds have been known for many years and yet to date none of them has reached practical use. One of the main reasons for this is that the most potent organotin insecticides tend to be the trimethyltins which also possess high mammalian toxicity, which precludes their use.[11] Other effective organotins, with lower mammalian toxicities, such as the tributyltin derivatives, are phytotoxic and so their use would be limited. Even the triphenyltins mentioned previously display phytotoxicity to certain crops, although this may be reduced by formulation.[2] However, the investigation of their insecticidal properties has continued and a suitable organotin insecticide may yet be found.

The main advantages of the organotin agrochemicals are considered to be their low phytotoxicity; compatibility with other pesticides; ability to undergo environmental degradation; and a generally low toxicity to non-target organisms. This latter property is being investigated with respect to integrated pest control, where biological control agents, such as mite predators and entomopathogenic fungi or bacteria, are used in combination with organotins. Research in this area is collated in Section 3.

SECTION 1 ACARICIDAL PROPERTIES

The full and common names of the mites included in this section are listed in Table 1.1. The acaricidal investigations of the commercial organotins appear in Tables 1.2–1.4 and are listed alphabetically with regard to the crop on which they were tested. The studies involving novel organotins, Table 1.5, are divided into tricyclohexyltin derivatives (1.5.1); anionic complexes (1.5.2) and miscellaneous compounds (1.5.3).

SECTION 2 ANTIFEEDANT, CHEMOSTERILANT AND INSECTICIDAL PROPERTIES

Table 2.1 gives the names of all the insects on which these studies have been performed and indicates in which Table they appear.

Antifeedant properties are listed, alphabetically with respect to the insect on which the tests were performed, in Table 2.2, which is divided into two subsections: triphenyltins (2.2.1) and other commercial organotins (2.2.2).

Chemosterilant investigations are listed in Table 2.3.

Insecticidal studies are given in Table 2.4 which is divided into three subsections: triphenyltin compounds (2.4.1) other commercially available organotins (2.4.2) and novel organotins (2.4.3).

SECTION 3 EFFECTS OF ORGANOTIN COMPOUNDS ON BIOLOGICAL CONTROL AGENTS AND BENEFICIAL ORGANISMS

In Tables 3.1, mite predators, and 3.2, entomopathogenic fungi, the biological control agents are listed alphabetically. The third and final Table of this section includes a variety of other non-target species.

Table 1.2 Acaricidal investigations involving Cyhexatin

Crop/Product	Mite	Comments	Reference
Apple	*A. schlechtendali*	Applied as a 25% wettable powder at a rate of 280 g na^{-1} gave control	12
Apple	*A. schlechtendali*	Was only effective when applied post-blossom	13
Apple	*A. schlechtendali* *P. ulmi*	Controlled both mites. Best time to apply was found to be pink flower bud stage	14
Apple	*P. ulmi*	A single spray controlled the mite 95–98%	15
Apple	*T. urticae*	Application of 1.8 g per tree in spray volumes ranging from 0.225 to 9.0 dm^3 per tree gave complete control	16
Apple	*T. urticae*	Controlled mites by 90–100% and protected trees for 1.5–2.0 months	17
Apple	*T. urticae*	Under field conditions was highly effective	18
Apple	*T. viennensis*	A four-spray system incorporating a cyhexatin–sumicidin mixture controlled the mite, as well as codling moth, and resulted in greatly increased fruit yields	19
Apple	Mites	Superior oil in early spring and cyhexatin were most commonly used control materials in 18/19 commercial orchards in Ohio, during 1979/1980 respectively	20
Apple	Mites	Cyhexatin was the most predominantly used acaricide in 36 Pennsylvanian commercial orchards during 1978/1979	21
Cattle	*P. ovis*	At 0.1% gave 100% kill	22
Cotton	*T. urticae*	Spraying with 200 dm^3 0.3% cyhexatin per ha controlled mites by *ca* 96%. Also prevented oviposition of the mite and the bollworm	23
Eggplant	*T. gloveri* *T. urticae*	Treatments of 0.4 and 0.8 lb per 100 gal. gave good control of both species[a]	24
Gladiolus	*R. robini*	Gave 60–80% control; other chemicals were superior	25
Grape	Mites	Was used in first spray in combination with rubigan to combat *Oidum* and mites	26
Grape	*P. ulmi*	1.6 kg ha^{-1} gave complete control of organophosphorus-resistant mites	27
Intensive gardens	*P. ulmi*	A single spray with 0.2% kept mites below damaging level during an entire season	28
Litchi	*A. litchii*	At 0.05% gave promising results in minimizing infestation	29
Orange	*P. oleivora*	Gave partial control after foliar spraying	30
Pear	*T. urticae*	Under field conditions was highly effective	18
Pig	*Sarcoptes*	One or two sprayings with 0.1% controlled the mite in 3–4-month-old pigs	31
Podocarpus macrophyllus	*P. podocarpi*	Population of this important pest in nursery and landscape culture in Florida was reduced to <1 mite per leaf after a single application	32
Rabbit	*P. cuniculi*	At 0.01% gave 100% kill	22
Roses	*T. urticae*	The control of powdery mildew or of the mite was not affected when applied in combination with Bayleton, neither was the mixture phytotoxic in the greenhouse	33
Strawberry	*T. urticae*	Of 23 pesticides tested cyhexatin consistently gave the best results	34
Strawberry	*T. urticae*	A two-year greenhouse study showed cyhexatin to be an effective miticide	35
Strawberry	*T. pallidus*	Dipping transplants in 0.2% solution controlled the mite and increased transplant survival rate	36
Tea	*A. theae*	Spraying twice as a 50% wettable powder at 500–1000 g ha^{-1} gave control for eight weeks	37
Vine	*T. urticae*	Controlled mite 100% as determined 20 days post treatment. Was especially effective due to its high ovicidal activity	38
Vine	*T. urticae*	Under field conditions was highly effective	18
Vine	*T. urticae*	Three New Caledonian strains were found to be susceptible to cyhexatin	39
Vine	*T. urticae*	Concentrations of 0.025–0.5% were preferred for controlling mobile stages and periodic application did not cause resistance	40

[a]Imperial measures were given in the original reference. For conversion to SI units, 1 lb = 0.454 kg; 100 gal. = 455 dm^3.

Table 1.3 Acaricidal investigations involving Fenbutatin oxide

Crop	Mite	Comments	Reference
Apple	*A. schlechtendali* *P. ulmi*	Controlled both mites. The best time of application was the pink flower bud stage	14
Apple	*A. schlechtendali* *P. ulmi* *T. urticae*	Concentrations of 750–1100 g ha^{-1} gave good control of all three species	41
Apple	*T. urticae*	Mites were controlled by 90–100% and trees were protected for 1.5–2.0 months	17
Beans	*T. urticae*	In combination with 2-sec-butylphenyl-*N*-methylcarbamate, curbed the mites	42
Eggplant	*T. gloveri* *T. urticae*	Applications of 1 and 2 lb per 100 gal. gave good control of both mites[a]	24
Grapefruit	*P. oleivora*	Applied at 10 week intervals, 2.0 lb $acre^{-1}$ gave full season mite suppression[a]	43
Irish shamrock	*T. urticae*	Formulations containing 30–60 g dm^{-3} controlled both mites and eggs for ≤2 weeks in greenhouses	44
Orange	—	A slight increase in the photosynthesis rate of leaves was observed after treatment	45
Pear	*T. urticae*	Was less effective than cyhexatin	18
Podocarpus macrophyllus	*P. podocarpi*	The population of this important mite pest in nursery and landscape culture in Florida was reduced to <1 mite per leaf by a single application	32
Soya beans	*T. arabicus*	Mite numbers were reduced	46
Strawberries	*T. urticae*	Was usually effective but cyhexatin performed better	34
Vine	*T. urticae*	Was less effective than cyhexatin	18
Wheat	*A. siro* *G. destructor* *T. longior* *T. putrescentiae*	At 20 ppm was unable to give complete mortality to any of these stored product mites	47
—	*T. urticae*	Found to be faster-acting than cyhexatin and azocyclotin. It killed more than 50% of the mites in 24 h	48

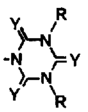
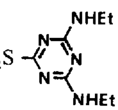
[a]Imperial measures were given in the original reference. For conversion to SI units, 1 lb = 0.454 kg; 100 gal. = 455 dm^3, 1 acre = 0.405 ha.

Table 1.4 Acaricidal investigations involving Azocyclotin

Crop	Mite	Comments	Reference
Apple	*P. ulmi*	Excellent control was exhibited in greenhouse experiments	49
Soya beans	*T. arabicus*	Produced a reduction in the mite population	46

Table 1.5 Acaricidal investigations involving novel organotin compounds

1.5.1 Tricyclohexyltin derivatives, Cy_3SnX

X	Comments	Reference
 $R=Cy_3Sn$, $Y=O, S$	Acaricidal and insecticidal activity was claimed	50
—OCO.R	28 such compounds were effective miticides at 500 ppm	51
$—OCO.C(Me_2)(CH_2)_5CH_3$	A suspension containing 250 ppm completely controlled *T. urticae*	52
$—OCO.(CHMe_2)CH.C_6H_4.CMe_3—4$	Useful as a miticide for oranges	53
$—OCO.CH_2S$  (and similar)	At 100 ppm gave 100% kill of *T. urticae* adults after 2 days	54
$—OCO.C_6H_5$	Was effective against *T. urticae*	55
$—OCO.C_6H_4.NH_2$	The *ortho* derivative at 0.15 or 0.2 nmol dm^{-3} on bean resulted in 100% mortality of *T. urticae* after 48 h. No phytotoxicity was observed at 2–4 nmol dm^{-3}	56
$—OSO_2.NH_2$	At 0.0075, 0.01 and 0.0125% on bean gave 100% mortality of *T. urticae* after 48 h. No phytotoxicity was observed	57
$—S(CH_2)_{11}CH_3$	Tricyclohexyltin mercaptides showed acaricidal properties	58

1.5.2 Anionic complexes

Complex	Comments	Reference
$[Me_3NCH_2CH_2Br]^+[Cy_3SnClBr]^-$ and analogues	100% kill of *T. cinnabarinus* larvae was achieved with a 25 ppm treatment	59
$[Me_3NCH_2CH_2Br]^+[Ph_3SnClBr]^-$ and similar	Controlled *T. urticae* and *T. cinnabarinus* at 50 and 25 ppm respectively on bean plants	60
Bis(dicyclohexylneophyltin) oxide	Controlled *T. urticae* on beans within eight days	61
Tricyclopentyltin hydroxide	Behaved as a simultaneous fungicide and miticide. Controlled *T. urticae* on bean and downy mildew on grape	62
Trioctyltin fluoride	At 250 ppm controlled *P. citri* on mandarin for 30 days and was not phytotoxic	63

Table 2.1 Insects mentioned in the antifeedant, chemosterilant and insecticidal tables

Insect	Table
Aedes aegypti	2.4
Anthonomous grandis	2.4
Aphis fabae	2.4
Aphrastasia pectinatae	2.4
Attagenus megatoma	2.4
Callosobruchus chinensis	2.4
Carpocapsa	2.4
Ceratitis capitata	2.3, 2.4
Chilo suppressalis	2.4
Cholodovskya viridana	2.4
Chrotogonous trachypterus	2.2, 2.4
Cotton boll worm	2.3
Diacrisia obliqua	2.2
Epilachna vigintioctopunctata	2.2
Green peach aphids	2.4
Heliothis	2.4
Keiferia lycopersicella	2.4
Lasioderma sericorne	2.4
Leptinotarsa decemlineata	2.2
Mindarus abietinus	2.4
Musca domestica	2.3, 2.4
Papilio demoleus	2.2
Periplanata americana	2.4
Plusia pepanis	2.2
Plutella xylostella	2.4
Polyphagot arsonemus	2.4
Porthetria dispar	2.2
Prodenia	2.4
Scirpophaga incertulas	2.2
Spodoptera littoralis	2.2, 2.4
Termite	2.4
Tetranychus chinensis	2.4
Tetranychus urticae	2.3
Tribolium castaneum	2.4
Tribolium confusum	2.2, 2.4
Trichoplusia ni	2.4
Trogoderma granarium	2.4

Table 2.2 Antifeedant properties
2.2.1 Antifeedant investigations involving triphenyltin compounds, Ph_3SnX

X	Insect	Comments	Reference
OAc	*Chrotogonus trachypterus* (surface grasshopper)	At 0.4% was lethal and 100% mortality was recorded within 48 h Significant protection was afforded at 0.025–0.2%	64
Cl OH	*Diacrisia obliqua*	Treatment with 0.09% Ph_3SnCl provided the maximum protection for sugar beet foliage. Both compounds increased top, root and sucrose yield	65
OAc OH	*Diacrisia obliqua*	The hydroxide was superior to the acetate and was most effective at 0.05%	66
OAc	*Epilachna vigintioctopunctata*	Feeding of final-instar grubs was inhibited by 0.0125–0.1% treatments (at 0.2–0.4% the acetate was 100% lethal)	67
OH	*Leptinotarsa decemlineata* (Colorado beetle)	In laboratory studies feeding was reduced by 95%, while in small field plots the larval densities were reduced. Beetle populations on potato were significantly reduced in a commercial-scale experiment and fewer insecticide applications were required for control where the hydroxide was used regularly	68
Cl OAc	*Papilio demoleus* and *Plusia pepanis*	Triphenyltin chloride ranked first in both antifeedant (against larvae) properties and field persistence on plants and was followed by the acetate	69
OH	*Scirpophaga incertulas*	The feeding activity of first-instar larvae was inhibited 50–70% by applications of 0.02–0.1%. The percentage of deaths due to starvation increased with higher concentrations	70
Cl Cy (2—OHCy)	*Tribolium confusum* (Confused flour beetle)	The chloride was the most active. Larval growth retardation was believed to be due to antifeedant effect	71

2.2.2 Antifeedant investigations involving other commercial organotins

Compound	Insect	Comments	Reference
Cyhexatin	*Porthetria dispar* (Gypsy moth)	Caterpillar development was retarded	72
Azocyclotin	*Spodoptera littoralis* (cotton leafworm)	An antifeedant effect was observed when applied to cotton leaves	73

Table 2.3 Chemosterilant properties

Compound	Insect	Comments	Reference
Fentin hydroxide	*Ceratitis capitata* (Mediterranean fruit fly)	A promising sterilizing agent of female flies treated as larvae; 20–400 ppm reduced the number of daily deposited eggs, decreased the hatchability percentage of eggs and reduced the reproductive potential	74, 75
Fentin acetate Fentin hydroxide	*Musca domestica* (housefly)	At 0.1% level the process of vitellogenesis was inhibited and ovaries were only in second phase of development at 5–10 days, whereas controls had mature eggs present	76
Cyhexatin	*T. urticae* (spider mite) and cotton boll worm	Prevented oviposition of both	23
Cyhexatin	*T. urticae*	Gave 100% control. Was especially effective due to its high ovicidal activity	38
Fentin hydroxide	*T. urticae*	Caused suppression of the reproductive potential of female mites	77

Table 2.4 Insecticidal properties
2.4.1 Insecticidal investigations involving triphenyltin compounds, Ph_3SnX

X	Insect	Comments	Reference
Cl OH	*Callosobruchus chinensis* (stored product pest)	Both compounds caused >90% mortality. An increase in rate of germination of red gram (*c.cajan*) seeds from 60 to ≧70% and a decrease in seed loss weight from 19.2 to ≦5% were observed	78
OH	*Ceratitus capitata* (Mediterranean fruit fly)	Showed high larvicidal activity. Prolonged larval duration, reduced full grown larval weight, reduced weight of pupae treated as larvae, decreased the percentage emergence of adults treated as larvae, and also reduced the life span of these emerged adults	75
OAc	*Chrotogonous trachypterus* (surface grasshopper)	At 0.4% was lethal and 100% mortality was recorded within 48 h	64
OH	*Keiferia lycopersicella* (tomato pinworm)	Survival and development of larvae were reduced in laboratory experiments. While in the field, there was a reduction of foliage and fruit damage on tomato plants	79
Cl	Termite	A piece of pine board coated with a PVC formulation containing the chloride was not attacked during 1 yr in a termite nest. Hence potential use as electric cable insulation and building material	80

2.4.2 Insecticidal investigations involving other commercial organotins

Compound	Insect	Comments	Reference
Cyhexatin	*Aphrastasia pectinatae* and *Cholodovskya viridana* (insect pests of Canadian spruce)	At 0.8% gave 98–100% control of both species	81
Cyhexatin	*Carpocapsa* (codling moth)	A four-spray system incorporating a mixture of cyhexatin and sumicidin controlled the moth as well as mites and resulted in greatly increased apple yields	19
Cyhexatin	*Heliothis* and *Prodenia* (moths)	In combination with permethrin gave good control of both and doubled the cotton yield	82
Cyhexatin	*Keiferia lycopersicella* (tomato pinworm)	Survival and development of larvae were reduced in laboratory experiments. While in the field, reduction of foliage and fruit damage on tomato plants was seen	79
Cyhexatin	*Mindarus abietinus* (balsam twig aphid)	Only slight toxicity was shown	83
Fenbutatin oxide	—	Insecticidal properties are claimed	42
Tributyltin fluoride	*Aedes aegypti* (mosquito)	Use as a slow-release larvicide. At 20 and 100 ppb LC_{50} for larvae occurred ≦2 days. At 200 ppb LC_{50} occurred in 7 days. Larval development was partially blocked at 20 ppm and totally blocked at ≧100 ppm	84, 85
Tributyltin chloride, oxide and phthalate	Termite	A composition containing TBTP>4, TBTCl>2, TBTO>1, and chlordene>3 parts is a termite control agent and rodenticide	86

Table 2.4.3 Insecticidal investigations involving novel organotin compounds

2.4.3.1 Insecticidal investigations involving tricylohexyltin compounds, Cy_3SnX

X	Comments	Reference
	At 0.05 wt % gave 100% kill of houseflies after 3 h whereas azocyclotin gave only 40% kill	87
 (and others)	At 50 ppm gave 70–100% kill of *Spodoptera littoralis* larvae	88
—OCO (CR′CHR″) (synthetic polymers)	For example, Cy_3Sn methacrylate was impregnated on to a filter paper disc which was then placed into a jar containing 100 termites, all of which died within 48 h	89
—	Materials formulated from synthetic resins or natural or synthetic rubbers and tricyclohexyltin compounds were not attacked by termites over a two-year period	90
—OCO . R	Twenty-eight such compounds were effective insecticides	51
—OCO . C_6H_5	Was effective against *Polyphagot arsonemus* and *Plutella xylostella*	55
—$S(CH_2)_{11}CH_3$ (and similar mercaptides)	Show insecticidal properties	58

2.4.3.2 Insecticidal investigations involving other organotin compounds

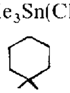
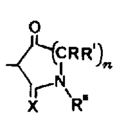
Compound	Comments	Reference
Tributyltin sucrose phthalate	Gave maximal activity against the mosquito *Aedes aegypti* fourth-instar larvae	91
Tricyclopentyltin fluoride	At 400 ppm gave 100% control of the cabbage looper *Trichoplusia ni*	92
Hexamethyldistannane	Tested as a fumigant against the stored product pests *Attagenus megatoma* (black carpet beetle); *Lasioderma sericorne* (cigarette beetle) and *Triboleum confusum* (confused flour beetle). It was more effective than methyl bromide, when exposed in free space and in a grain mass at 27° or 13 °C.	93
$Me_3Sn(CH_2)_3NH.CO.NH.CO.C_6H_4Cl$-2	At 50 ppm gave 70–100% kill of *Spodoptera littoralis* larvae	94
 NH_2 CR=CHR′ R,R′ = H, Me_3Sn R ≠ R′	A mixture of the *cis* and *trans* isomers gave 92–100% mortality against larvae or eggs of *Spodoptera littoralis*	95
 HO CH=$CHSnMe_3$	The *cis* isomer at 0.2% gave 90–100% mortality of *Spodoptera littoralis* larvae within 24 h. Similar results were obtained against *Aedes aegypti* larvae, and adults of *Musca domestica* and *Aphis fabae*	96
—$SnMe_3$	Controlled flies *Chilo suppressalis* and mite *Tetranychus chinensis* at 500 ppm	97
$Ph_3SnNCSe$. TMEN (TMEN = tetramethylethylene diamide)	Showed high activity against the cockroach *Periplanata americana*	98
Ph_3SnN_3 . L	The parent azide and its complexes (with various ligands L) were effective against *Periplanata americana*. Complexes with oxygen donor ligands tended to show highest activity	99
Ph_3Sn 	Insecticidal activity is claimed	100, 101
$Ph_3SnSC(SMe)NNC(H)$ (and other Schiff base complexes)	Show higher activity against cockroach *Periplanata americana* than Ph_3SnCl	102

Table 2.4.3.2 (*continued*)

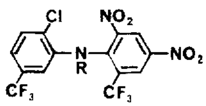
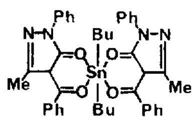
Compound	Comments	Reference
$(MeC_6H_4)_3SnCl.L_n$ $L=Ph_3PO$, Py; $n=0, 1$	Gave maximal activity against fourth-instar larvae of the mosquito *Aedes aegypti*	92
	$R=SnBu_3$ at 0.01% in acetone gave 100% kill of 25 houseflies $R=SnPh_3$ and $SnCy_3$ are also claimed	103
$ROP(O)(OSnR_3)H$ (R = Me, Ph, Cy)	At 100–400 ppm killed 100% *Spodoptera littoralis* L_3 larvae and *Anthonomous grandis* adults	104
$BuMe_2SnCl$ [and other $R_nR'_{(3-n)}SnCl$	Controlled green peach aphids on marigold at 250 ppm	105
$Me_2OctSnOAc$ $Et_2OctSnOAc$	Gave maximal activity against fourth-instar larvae of the mosquito *Aedes aegypti*	92
$[R_4N^+]_2[(CH_2)_nSnX_2X_2]^{2-}$ ($n=4, 5$; X, X′ = halogen or NCS)	Such complexes exhibit higher activity than either parent towards adult cockroaches *Periplanata americana*	106
	Compound is toxic (contact) to the stored product pests, *Trogoderma granarium and Tribulium castaneum.* LD_{50} values were 0.6112% and 0.6432% respectively	107

Table 3.1 Effects on mite predators

Compound	Predator	Comments	Reference
Cyhexatin	*Amblyseius bibens*	Was found to be moderately toxic	108
Fenbutatin oxide	*A. bibens*	Considered to be harmless	108
Azocyclotin and Cyhexatin	*A. ehari*	Both showed low toxicity to adult females, but were highly toxic to eggs and immature stages for 10 days after treatment	109
Fenbutatin oxide	*A. ehari*	Was not toxic	109
Cyhexatin	*A. fallacis*	At 0.2 g dm^{-3} prolonged the hatching time of eggs from 2 to 8 days, but 100% hatch occurred. Residues caused an avoidance (repellency) and also suppressed egg deposition	110
		Was considered to be moderately toxic	111
Azocyclotin	*A. finalandicus*	At 0.0375% gave 88% mortality (cf. *C. septempunctata*)	112
Azocyclotin	*A. potentillae*	Was harmful to this mite	113
Cyhexatin	*A. potentillae*	Was found to be moderately toxic	108
Fenbutatin oxide	*A. potentillae*	Classified as harmless	108
Azocyclotin	*Coccinella septempunctata*	At 0.0375% was spared or was only moderately affected	112
Cyhexatin	*Euseius hibisci*	Showed high toxicity towards mite	114
Fenbutatin oxide	*E. hibisci*	Showed low toxicity	114
		Was moderately toxic to two different strains	115
Cyhexatin	*Metaseinulus occidentalis*	Compound was used to adjust spider mite:predator ratio to assist the control of the mite by *M. occidentalis*	116
Azocyclotin	*Phytoseiulus persimilis*	Classified as harmless	48
		Recommended to be used in conjunction with this beneficial mite	117
Cyhexatin	*P. persimilis*	Considered to be harmless	48
		Showed low toxicity (0–29% mortality)	118

Table 3.1 (*continued*)

Compound	Predator	Comments	Reference
Fenbutatin oxide	*P. persimilis*	Showed low toxicity (0–29% mortality)	118
		Classified as harmless, despite showing appreciable (50%) adult toxicity	48
		Could be safely used in combination with this beneficial mite	117
Cyhexatin	*Typhlodromus occidentalis*	Ar 0.2 g dm^{-3}, prolonged the hatching time of eggs from ~2 to 8 days but 100% hatch occurred. Residues caused an avoidance (repellence) and also suppressed egg deposition.	110
Cyhexatin	*T. pyri*	Was considered to be moderately toxic	108
		Showed low toxicity and was suitable for corrective treatment in combination with *T. pyri.*	119
Fenbutatin oxide	*T. pyri*	Classified as harmless	108
Cyhexatin	—	Showed low toxicity to beneficial entomoacariphages on cotton	23
Fenbutatin oxide	—	Was non-toxic to arthropod predators of *T. urticae* on peanut	120

Table 3.2 Effects on entomopathogenic fungi

Compound	Fungus	Comments	Reference
Fentin acetate	*Beauveria bassiana*	*In vitro* was inhibiting by contact and by spraying	121
Fentin acetate	*Entomophthora aphidis*	In combination with maneb at a concentration recommended for field use, the mixture inhibited germination of conida and furthermore the fungus was killed. A decrease in infectivity of *E. aphidis* on living pea aphids (*Aphis pisum*) was observed 6 h after topical application. This activity was still present 48 h after treatment	122
Fentin hydroxide	*Neozygites floridana*	The efficacy of this fungus which infects *T. urticae* was unaffected	121, 123
Fentin hydroxide	*Nomuraea rileyi*	Infection of lepidoptera larvae with this fungus was inhibited to some degree	124
Fentin acetate	*Paecilomyces farinosus*	Was unaffected	121
Fentin acetate	*Verticillium lecanii*	*In vitro* was inhibiting by contact, but not by spraying	121
Fenbutatin oxide	*V. lecanii*	Had little effect on spore germination and mycelial growth *in vitro*	125

Table 3.3 Effects on other biological control agents and beneficial organisms

Compound	Organism	Comments	Reference
Cyhexatin and Fenbutatin oxide	*Aphidoletes aphidimyza* aphid predator	Both compounds showed low toxicity	126
Cyhexatin	Spiders	Was amongst the armoury of insecticides/acaricides, which reduced the spider populations (hunters being more affected than web-builders), used in Quebec apple orchards during 1979–1981	127
Cyhexatin	Spider, *Chiracanthium mildei*, predator of *S. littoralis*	Did not kill spiders at a dose as high as $30 mg g^{-1}$ body weight	128
Cyhexatin	*Anthocris nemoralis*, valuable predator of pear *Psylla*	Very low toxicity was shown when it was examined on its own or in combination with benzomate, and it was classified as harmless	129
Cyhexatin	*Cotesia melanoscelus*, larval parasite of the gypsy moth	Had minimal effects on larval survival, adult longevity and progeny production of the parasite With low doses of *B. thuringiensis* it retards caterpillar growth and so would enable greater parasitization by *C. melanoscelus* to occur	130
Fenbutatin oxide	*Encarsia formosa*, greenhouse white fly parasite	Was considered to be harmless	131
Cyhexatin and Fenbutatin oxide	*Pygadeuon trichops*, arthropod parasite (*ichneumon*)	Cyhexatin at 0.1% and fenbutatin oxide at 0.05% were both classifed as harmless	132
Fenbutatin oxide	*Trichogramma cacoeciae* egg parasite	Was observed to be harmless towards adult parasites	133
Cyhexatin	*Bacillus thuringiensis*, larval growth retarder	No harmful effects were observed. Cyhexatin itself retarded larval growth and so increased parasitization by *B. thuringiensis*, since this can only successfully attack small hosts	130
Fentin acetate	*Rhizobia*, nitrogen-fixing root-nodule bacteria	Concentrations of $700 \mu g cm^{-3}$ were required to completely inhibit growth. This was less inhibitory than other pesticides studied	134
Fentin hydroxide	*Colletotrichum gloeosporoides aeschynomene*, microbial herbicide	At $0.56 kg ha^{-1}$ did not reduce disease development of *C.g.a.* on northern joint vetch (*Aeschyomene virginica*) and so is suitable for integrated control programes of *A. virginica* in rice	135
Fentin acetate	*Eisenia foetida* earth worm	A formulation with maneb was found to have an LC_{50} of $27 mg kg^{-1}$ (dry weight of soil substrate)	136, 137
Fentin acetate	*Lumbricus terrestris* earth worm	In combination with maneb was found to have an LC_{50} of $44 mg kg^{-1}$ (dry weight of soil substrate)	138
Cyhexatin	Honey bee	Showed low toxicity	139
Fenbutatin oxide	Honey bee	Was non-toxic by ingestion and slightly toxic by contact	140
Fentin acetate	Redwinged blackbirds	Had an acute oral $LD_{50} > 100 mg kg^{-1}$ and an avian repellency value $R_{50} > 1\%$	141
Fentin hydroxide	Redwinged blackbirds	$LD_{50} > 100 mg kg^{-1}$; $R_{50} > 1\%$	141
Fentin acetate	Coturnix quail	LD_{50} 100–117 $mg kg^{-1}$	141

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