# EFFECT OF CHITIN SYNTHESIS INHIBITORS ON RICE SWARMING CATERPILLAR, *Spodoptera mauritia* (Boisduval) AND RICE MOTH, *Corcyra cephalonica* (Stainton) AND A LARVAL PARASITOID, *Bracon brevicornis* (Wesmael)

By

**PRATHAPAN, K. D.**

**THESIS**

submitted in partial fulfilment of the
requirement for the degree

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# D E C L A R A T I O N

I hereby declare that this thesis entitled "Effect of chitin synthesis inhibitors on Rice Swarming Caterpillar, Spodoptera mauritia (Boisduval) and Rice Moth, Corcyra cephalonica (Stainton) and a larval parasitoid, Bracon brevicornis (Wesmael)" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

PRATHAPAN, K.D.

Vellayani,
14 February, 1991.

# C E R T I F I C A T E

Certified that this thesis entitled "Effect of chitin synthesis inhibitors on Rice Swarming Caterpillar, Spodoptera mauritia (Boisduval) and Rice Moth, Corcyra cephalonica (Stainton) and a larval parasitoid, Bracon brevicornis (Wesmael) is a record of research work done independently by Sri. PRATHAPAN, K.D. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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# Introduction

# INTRODUCTION

The insecticidal activity of benzoyl phenyl urea analogues was accidentally discovered around 1970 in the laboratory of Philips-Duphar, the Netherlands. The first analogue which was shown to be effective against insects was code-named as DU 19111. Subsequent research led to the discovery of analogues with higher insecticidal activity. Diflubenzuron was the first benzoyl phenyl urea to be used against a wide range of insect pests (Elings and Dieperink, 1974; Turnipseed et al., 1974; Granett and Dunbar, 1975; Donabauer, 1976; Schroeder et al., 1976). The precise mode of action of benzoyl phenyl ureas i.e. inhibition of chitin synthesis, makes them highly selective "insecticides" against the broad spectrum "biocides" of the chlorinated, phosphatic and carbamate groups which were, and still are, being extensively used in the past three decades. Increasing awareness of the ecological and environmental ill-effects of the broad spectrum, synthetic organic insecticides led to the development of revised pest management strategies. Chitin synthesis inhibitors are suitable substitutes of conventional broad spectrum insecticides in the integrated pest management programmes. They are safe to fish, birds and mammals. Toxic effect on beneficial arthropods is less than that of the conventional insecticides.

A major drawback of benzoyl phenyl ureas is lack of systemic action, which renders them ineffective against internal feeders. Attempts are being made to overcome this defect with the synthesis of newer analogues with systemic activity.

In developed countries, considerable work has been done on chitin synthesis inhibitors and compounds like diflubenzuron and chlorfluazuron are used against insect and acarine pests on a wide range of crops. In India, the feasibility of using chitin synthesis inhibitors for insect management is being tried for the management of a variety of pests in the laboratory and of a few in the field. Many of the newer analogues are known to possess higher insecticidal action than diflubenzuron. With this view, three benzoyl phenyl urea analogues viz. chlorfluazuron, PH 70-23 and BASF LAB 153 959 I were compared with diflubenzuron in the present study for their various biological activities on:

(i) the rice swarming caterpillar Spodoptera mauritia (Boisduval), a major pest of rice in the field,

(ii) rice moth Corcyra cephalonica (Stainton) a pest of rice and other cereals in the store and

(iii) its larval parasitoid Bracon brevicornis (Wesmael).

# Review of Literature

# REVIEW OF LITERATURE

The insecticidal activity of benzoyl phenyl ureas was discovered accidentally during the synthesis of a super herbicide from dichlobenil and fenuron in the laboratory of Philips-Duphar-B.V. of Netherlands (Van Daalen et al., 1972). Following the discovery of the first benzoyl phenyl urea with insecticidal activity, which was later termed as Du-11191, a number of phenyl ureas were evaluated for their insecticidal property (Wellinga et al., 1973a). Mono-and diortho substituted benzoyl derivatives alone showed larvicidal acitivity. PH 6038 and PH 6040 (diflubenzuron) were the outstanding ones among them, exhibiting very high levels of toxicity than Du-11191. Further trials by Wellinga et al. (1973b) confirmed the efficacy of benzoyl phenyl ureas as specific insecticides that interfere with chitin deposition during ecdysis leading to disruptive moult.

## 1. Ovicidal action

Many workers have reported ovicidal action of chitin synthesis inhibitors. Inhibition of eclosion depends on the species of the insect, age of the eggs and time of exposure. Diflubenzuron has been reported as a disrupting chemical of oogenesis and embryonic development in insects (Schmutterer, 1976).

Order: Lepidoptera

Ovicidal action of chitin synthesis inhibitors against Spodoptera littoralis was studied by many workers. Salama and El-Din (1977) have reported inhibition of development of eggs of S. littoralis by diflubenzuron. The same was reported with triflumuron (Ascher et al., 1979) and penfluron (Ascher et al., 1982). But some other benzoyl phenyl ureas viz. PH 6045, Dowco 401 and Dowco 439 had very little effect (Ascher et al., 1982). El-Guindy et al. (1983) stated that among four insecticides, three insect growth regulators and their combinations, diflubenzuron was the most toxic compound followed by triprene, methoprene, chlorpyrifos, cypermethrin, fenvalerate and methomyl. Among the mixtures, highest synergism was shown by fenvalerate plus diflubenzuron (El-Guindy et al., 1983). Synergism was also reported with combinations of triflumuron and chlorpyrifos against eggs of S. littoralis (Radhwan et al., 1983). Ascher and Nemny (1984) found that teflubenzuron was a less effective ovicide than diflubenzuron and triflumuron against S. littoralis. Diflubenzuron was found to be an effective ovicide against two closely allied species viz. S. mauritia (Beevi, 1979) and S. litura (Natesan and Balasubramanian, 1983) also.

Ascher et al. (1978a) obtained moderate levels of mortality of eggs of Earias insulana when dipped in diflubenzuron and the results were inconsistent.

Diflubenzuron was toxic to the eggs of Ostrinia nubilalis (Faragalla et al., 1980), Laspeyresia pomonella / Cydia pomonella (Hoying and Riedl, 1980 and Elliott and Anderson, 1982, Stigmella malella (Ciglar, 1981), Leucoptera scitella (Ciglar, 1981; Injac, 1981), Phyllonorycter blancardella / Lithocolletis blancardella (Injac, 1981), Rhyacionia frustrana (Richmond and Cunningham, 1983) and Mamestra brassicae (Velcheva, 1983). In addition to diflubenzuron, TH 6043 and penfluron were also reported to be toxic to the eggs of Cydia pomonella (Moffit et al., 1984). Mayuravalli et al. (1985) have reported complete inhibition of development of eggs of the arctiid Pericallia ricini when dipped in triflumuron, at concentrations of 0.0325% or more.

Diflubenzuron was found non-toxic to the eggs of Choristoneura rosaceana (Anderson and Elliott, 1982). Besides diflubenzuron, triflumuron and teflumuron were also effective against eggs of Stigmella malella (Maciesiak, 1985). BASF LAB 153 959 I was non-toxic to eggs of Spodoptera litura (Gujar and Mehrotra, 1986).

Order: Coleoptera

Ovicidal action of diflubenzuron was reported against Diapreps abbreviatus (Schroeder et al., 1976), Melolontha melolontha, Gastroidea viridula (Buchi and Jossi, 1979) and Halotrupes bajulus (Doppelreiter, 1982) and that of triflumuron was reported against Diapreps abbreviatus (Schroeder et al., 1980). Reduction in hatch rate and further mortality of developing insects were reported when eggs of Tribolium castaneum were treated with A 13-63223 or diflubenzuron (Saxena and Mathur, 1981). Triflumuron completely inhibited hatching of eggs of Hylobitelus abietis while only 19.2% eggs of the insect hatched when exposed to diflubenzuron (Kolbe and Hartwig, 1982). Ovicidal action of triflumuron and diflubenzuron was reported against Oryzaephilus surinamensis, Tribolium castaneum, Rhizopertha dominica (Mian and Mulla, 1982), and Leptinotarsa decemlineata (Ammar, 1984). Susceptibility of the eggs of Leptinotarsa decemlineata decreased with increasing age of the eggs and when chitin synthesis inhibitors were combined with methoprene.

Ascher et al. (1986) have found that chlorfluazuron, diflubenzuron or teflubenzuron had no direct effect on Carpophilus hemipterus eggs when dipped in 1000 ppm solutions, but the larvae that hatched died within two days.

Order: Diptera

Exposure of eggs of Simulium vittatum (Lacey and Mulla, 1977) and Zaprionus paravittiger (Rup and Chopra, 1985) to 1 ppm diflubenzuron almost completely inhibited eclosion.

Hatching of the eggs of Ceratitis capitata, topically applied with diflubenzuron was reduced and a few larvae that emerged from the treated eggs died soon after hatching, but there was no latent effect on the subsequent development or reproduction in the survivors (Santiago-Alvarez and Sarasua, 1983).

Order: Orthoptera

Eleven to twelve day-old eggs of Schistocerca gregaria when treated with 0.5 ug/egg of diflubenzuron hatched normally (Mariy et al., 1981). But when the eggs of Acheta domestica were treated with diflubenzuron, the embryogenesis was disrupted and hence the shape of the eggs changed. Susceptibility of the eggs decreased with their age (Matolin and Chudakova, 1983).

Order: Acarina

Diflubenzuron when applied to the eggs of Phyllocoptruta oleivora had no effect on hatching, but was found to inhibit

moulting in the second nymphal stage at doses of 0.04 to 0.30 g ai/litre (Mc Coy, 1978). PH 70-23 was reported as a potent ovicide against Tetranychus cinnabarinus, T. turkestani, T. urticae and Panonychus ulmi (Grosscurt et al., 1988).

2. Growth-disrupting property

Chitin synthesis inhibitors interfere with the normal development and metamorphosis of insects. So they are included under growth regulators.

Order: Lepidoptera

Lepidopterans are the most susceptible test insects to chitin synthesis inhibitors. Many workers have worked on the effects of benzoyl phenyl ureas on lepidoptera.

Growth disrupting property of diflubenzuron and TH 6048 was reported on Manduca sexta by Oliver et al. (1976). Later on synergistic action by the dual application of diflubenzuron Metarrhizium anisopliae against M. sexta larvae has been reported (Hassan and Charnley, 1983).

Granett and Dunbar (1975) assessed the $EC_{50}$ of diflubenzuron against 3rd instar larvae of Porthetria (Lymantria) dispar as 0.013 ppm of artificial diet.

Donaubauer (1976) obtained promising results with diflubenzuron in laboratory trials against L. dispar and L. monacha. Among those moult inhibitors evaluated against L. dispar, the order of toxicity was L 7063 diflubenzuron L 1215 (Abdelmonem and Mumma, 1981).

El-Tantawi et al. (1976) have reported that diflubenzuron was more active than DC 201 against Spodoptera littoralis. Thirty to fifty ppm of diflubenzuron in artificial diet prevented the development of S. littoralis whereas sublethal doses reduced development and induced deformities similar to those produced by juvenile hormones (Salama and El-Din, 1977). Contact effect of triflumuron on S. littoralis larvae was greater than that of diflubenzuron (Ascher and Eliyahu, 1981), while teflubenzuron was five times as active as triflumuron (Ascher and Nemny, 1984).

Consumption and utilisation of food and growth rate of S. littoralis fed on diflubenzuron or triflumuron-treated castor leaves decreased whereas approximate digestibility coefficient increased considerably (Radhwan et al., 1986). Sundaramurthy (1977) has reported various degrees of morphological deformity in the pupae formed from diflubenzuron-treated final instar larvae of S. litura. The treatment also reduced the amount of food consumed, weight gained by larvae and adult emergence. Adults emerged were malformed

and non-functional. Balasubramanian and Natesan (1979) observed malformations on larval, pupal and adult stages of S. litura and Beevi (1979) on S. mauritia, when larvae and pupae were treated with diflubenzuron. Pupal mortality, partial emergence and malformed adults were observed when pupae of S. litura were treated, but susceptibility of pupae decreased with advance in age (Natesan and Balasubramanian, 1980). Combined application of methoprene and diflubenzuron on final instar larvae of S. litura inhibited larval-pupal transformation, whereas diflubenzuron under hyperhormonal condition resulted in a high degree of inhibition by producing more larval-pupal deformities and inhibited moulting in supernumerary larvae (Sundaramurthy and Balasubramanian, 1978). Sublethal doses of diflubenzuron had no effect on the development of S. frugiperda (Ross and Brown, 1982). Segistan and Almeida (1983) found that fifth instar larvae of S. fugiperda was the most susceptible stage to diflubenzuron than first, third and sixth instar at which time food consumption was maximum. Granett et al. (1983) conducted laboratory tests using five moult inhibitors against the larvae of S. exigua. UC-62644 was the most toxic compound, followed by penfluron, EL-1215, diflubenzuron and triflumuron. Larvae at different instars were equally susceptible to the compounds.

Heavy mortality occurred when larvae of Agrotis segetum and Mamestra brassicae were fed on artificial diets containing

diflubenzuron (0.0025 to 25 ppm). A. segetum was more susceptible than M. brassicae (Lipa, 1976). Velcheva (1983) studied dose-effect relations of diflubenzuron on the larvae of M. brassicae. Total larval mortality was caused within 4-10 days depending on the dose of 25-750 ppm. Teflubenzuron by topical application was about five times as toxic as diflubenzuron against M. brassicae and had a $LC_{50}$ value of 0.016 µg/larva. The $LD_{50}$'s of the compounds were similar when administered through the diet (0.02 ppm), but comparison of $LD_{100}$ values showed that teflubenzuron was about twice as toxic as diflubensuron (Tada et al., 1986).

First instar larvae of Pectinophora gossypiella when exposed to 1 ppm diflubenzuron, adult emergence was reduced by 64% (Flint and Smith, 1977).

Wolfenbarger et al. (1977) assessed the oral $LC_{50}$ of diflubenzuron for neonate larvae of Heliothis virescens as $1.3x10^{-3}$% of diet. The $LC_{50}$ for pupae was $1.3x10^{-4}$% in the larval diet. Mortality of larvae reared on a diet containing $1x10^{-2}$% was 86-100%. $ED_{10}$, $ED_{25}$ and $ED_{50}$'s of diflubenzuron on fourth instar larvae of H. armigera were $3x10^{10}$, $3.3x10^{9}$ and $2x10^{8}$ µg/mg body weight respectively (Morallo-Rajesus and Alcala-Carilo, 1981). Herbert and Harper (1985) conducted laboratory bioassay of teflubenzuron against H. zea by continuous feeding on treated diet. $LC_{50}$'s following seven days

of exposure were 21.9, 18.2 and 24.0 /ug/ml diet for 1st, 3rd and 4th instar larvae respectively. $LC_{50}$'s based on total larval and pupal mortality in insects that were initially exposed as 1st, 3rd and 4th instar larvae were 2.8, 2.2 and 3.7/ug/ml medium respectively.

Larvae of Earias insulana treated with diflubenzuron exhibited inability to shed moult along with abnormalities in the mouth parts, thoracic region and abdominal areas (Abid et al., 1978). Mortality of E. insulana treated with 0.005 to 0.1% diflubenzuron through artificial diet was 76-100% (Ascher et al., 1978a). Meisner et al. (1986) have assessed the comparative efficacy of different moult-inhibitors against the larvae of E. insulana. Teflubenzuron was active at 0.1 ppm, chlorfluazuron at 0.77 ppm and PH 6038 at 10 ppm, but triflumuron and diflubenzuron were active only at 50 ppm and the other compounds PH 6043, penfluron, PH 6045 and Dowco 439 were even less active. Saradana and Tewari (1987) have reported delayed ecdysis, partial and abnormal emergence of adults from diflubenzuron-treated pupae of E. insulana.

Severe developmental disturbances were reported in the larvae of Boarmia selenaria fed on diflubenzuron-treated leaves (Ascher et al., 1978b), but at 0.05%, all treated larvae pupated and a few adults emerged, whereas at 1.0% total larval mortality occurred (Dieter-Steigra, 1978).

Larvae of cabbage butterfly Pieris brassicae were not susceptible to topical treatment with diflubenzuron or PH 6038 (Mulder and Gijswijt, 1973). Similar evidence of low cuticular absorption was presented by Retnakaran and Smith (1975) for the Eastern spruce bud worm Choristoneura fumiferana.

The Egyptian cotton leaf worm Spodoptera littoralis was susceptible to both feeding and contact with diflubenzuron in the larval stage (Ascher and Nemny, 1976). Cuticular application of chitin synthesis inhibitors was more effective than ingestion on the larvae of Artogeia rapae (Kolesova et al., 1978), Spodoptera mauritia (Beevi and Dale, 1980) and S. exigua (Granett et al., 1983). But ingestion was found to be the more effective mode of application than external application in the cases of triflumuron against Pericallia ricini (Mayuravalli et al., 1985) and diflubenzuron against Hendecasis duplifascialis (Winstone and David, 1986).

Massorial et al. (1978) have reported that diflubenzuron had no effect on the larvae of Plusia sp. (Pseudoplusia oo).

Diflubenzuron at 200 ppm caused malformations in 80% of the larvae of Cnaphalocrocis medinalis (Natesan et al., 1980). Rao et al. (1987) have reported 20-100% mortality of C. medinalis larvae with 1-500 ppm of diflubenzuron and triflumuron.

Rabindra and Balasubramanian (1981) have reported abnormal moulting in larvae and morphological deformities in the pupae of Achoea janata treated with diflubenzuron.

Five moult inhibitors viz. SIR 6874, SIR 8514, TH 75331, EL 494 and diflubenzuron were evaluated against Choristoneura occidentalis and Orgyia pseudotsugata, the latter species was generally susceptible than the former one to these compounds. SIR 6874 was the most toxic compound to C.occidentalis and diflubenzuron the least toxic. All the compounds, except EC 494 was equally toxic to O. pseudotsugata, which was inferior to other compounds (Rapport and Robertson, 1981). Robertson (1982) found EL-127063 more toxic to C.occidentalis than TH 6044 and UC 62644. Triflumuron was more toxic than diflubenzuron to the eggs and larvae of C. rosaceana (Broadbent and Pree, 1984a).

Robertson et al. (1984) studied compatibility of the juvenile hormone analogue methoprene and moult inhibitors against C. occidentalis. Ingestion of methoprene combined with diflubenzuron or triflumuron resulted in significantly lower mortality, but methoprene with EL-127063 caused higher toxicity.

$LC_{50}$ of diflubenzuron to 4th and 5th instar larvae of Dendrolimus tubulaeformis and D. spetabilis was 2-9 ppm (Song et al., 1985).

Roychoudhury and Chakravorty (1985) studied the effects of topical application of the moult inhibitors A 13-63604, A 13-63629 and A 13-63701 to final instar larvae, prepupae and pupae of Corcyra cephalonica. The life span of the treated larvae were significantly prolonged, extra larval moults were induced, and some of them developed into larvoid adults and adultoids. A few adultoids developed when individuals under prepupal stage were treated. The treatment resulted in the induction of extra pupal instars and development of adultoids which either died or did not emerge.

Sublethal doses of triflumuron applied on the larvae of Platynota sultana decreased the larval survivorship, but did not affect the survivorship, life span or fecundity of adults, whereas those of chlorfluazuron decreased larval, pupal and adult survival and fecundity of the insect (Hejazi and Granett, 1986).

Order: Coleoptera

Several coleopteran insects were susceptible to chitin synthesis inhibitors. Growth disrupting property of some analogues of diflubenzuron and TH 6038 against Tribolium confusum was reported by Oliver et al. (1976). Triflumuron inhibited pupation of T. castaneum at 0.2 ppm and

diflubenzuron at 0.4 ppm, but Hercules-24108 was less potent (Ishaaya et al., 1981). Mathur and Saxena (1984) found penfluron more effective than diflubenzuron against T.castaneum.

Diflubenzuron was effective against Diapreps abbreviatus only through ingestion, not by contact. Larval death was due to defective moulting (Beavers et al., 1976).

Diflubenzuron when applied in soil reduced population and adult emergence of Conotrachelus renuphar (Calkins et al., 1977).

Diflubenzuron (Grosscurt, 1977; Tamaki et al., 1984) and triflumuron (Ammar, 1984) had pronounced effects on the development of Leptinotarsa decemlineata.

The $LC_{50}$ of diflubenzuron against Hypothneumus hampei by dipping infested green coffee berries was 0.11 to 0.012% (Rhodes and Mansingh, 1981).

Diflubenzuron was reported to prevent the development of Dermestes maculatus and Callosobruchus maculatus on peas and Acanthoscelides obtectus on kidney beans dusted at 1-5 mg/kg. The compound was very effective against early instar larvae of Trogoderma granarium also (Webley and Airey, 1982).

When diflubenzuron was treated on the pupae of Tenebrio molitor, death occurred before or at adult ecdysis or first few days after emergence (Soltoni et al., 1983). Soltoni et al. (1984) have described four different types of abnormalities in diflubenzuron-treated pupae of T. molitor. They were blocked pupae, adults unable to ecdyse, adults partially ecdysed and adults completely ecdysed.

Direct treatment of first instar larvae of the rice water weevil Lissorhoptrus oryzophilus with diflubenzuron or triflumuron caused no mortality (Smith et al., 1985).

Sudhakara Reddy and Kameswara Rao (1987) studied the effect of diflubenzuron on the various life stages of Henosepilachna vigintioctopunctata. Ingestion produced higher mortality than external application. Pupae and pre-pupae were less susceptible to the action of diflubenzuron compared to larvae.

Triflumuron, UC-76724, UC-75118, UC-75150 and UC-84572 at concentrations of 0.001 to 0.125% produced mortality of Alphitobius diaperinus larvae (Weaver and Kondo, 1987).

Order: Hymenoptera

Hymenopterans, in general, are less susceptible to chitin synthesis inhibitors. Still, diflubenzuron was

effective against the sawflies Prestiphora abictina and Neodiprion sertifer (Donaubauer, 1976).

Order: Diptera

Promising results with a number of analogues of diflubenzuron and TH 6038 were reported against Aedes aegypti and Musca domestica (Oliver et al., 1976).

Diflubenzuron showed pronounced growth-disrupting property against the fruit flies Dacus oleae (Fytizas, 1976), Ceratitis capitata (Albajes and Santiago-Alvarez, 1979; Santiago-Alvarez and Sarasua, 1983) and Anastrepha suspensa (Lawrence, 1983).

Seed treatment of pulses with diflubenzuron had given adequate protection of seedlings against Hylemya cilicrura (Vande et al., 1975) and Delia platura (Vea et al., 1976).

Saxena and Kaushik (1986) described larvicidal and pupicidal action of penfluron and furyl triazine against Anopheles stephensi. At lower doses, penfluron was more active than furyltriazine.

Order: Hemiptera

Diflubenzuron was ineffective against the aphid Manellia costalis, the diaspidids - Chrysomphalus aonidum and Aonidiella auranti and the coccids Saissetia oleae,

Ceroplastes floridensis (Pelag and Gothilf, 1981), Planococcus citri and Quadraspidiotus perniciosus (Darvas and Szabo, 1987). But chlorfluazuron and XRD-473 were effective against the mustard aphid Brevicoryne brassicae at concentrations as low as 0.1 ppm (Ammar et al., 1986).

Penfluron disrupted ecdysis of the nymphs of Dysdercus cingulatus (Reena et al., 1984).

Order: Orthoptera

Mariy et al. (1981) have reported various abnormalities in the nymphs of Schistocerca gregaria treated with diflubenzuron.

3. Sterilant action

Many workers have noted and described the sterilant action of chitin synthesis inhibitors in insects. Diflubenzuron was reported as a disrupting chemical of oogenesis and embryonic development in insects (Schmutterer, 1976).

Order: Lepidoptera

In lepidoptera, many workers have reported reduction in adult life span, fecundity and hatchability of eggs when treated with moult inhibitors.

Diflubenzuron produced sterility in Spodoptera mauritia (Beevi, 1979) and Psila rosae (Overbeck, 1979). The compound when topically applied to adults of Laspeyresia pomonella caused no mortality nor did it affect normal oviposition, behaviour or vitality of the offsprings (Hoying and Riedl, 1980). But Velcheva (1982) has reported sterility in both sexes of Cydia (Laspeyresia) pomonella that mated after being in contact with diflubenzuron. TH 6043 and penfluron were more effective sterilants than TH 6045 and diflubenzuron against C. pomonella. None of these compounds affected life span or mating propensity of adults (Moffitt et al., 1983).

Diflubenzuron produced sterility in Spodoptera frugiperda (Segistan and Almeida, 1983) and Ostrinia nubilalis (Faragalla et al., 1984) when treated in the larval stage.

Radwan et al. (1984) have reported that fecundity and life span of Spodoptera littoralis exposed to triflumuron were lower than those exposed to diflubenzuron. BASF LAB 153 959 I reduced fecundity and hatchability of eggs of S. litura (Gujar and Mehrotra, 1986).

Salama et al. (1976) reported no effect with chitin synthesis inhibitors on spermatogenesis, mating or oviposition of the nun moth Lymantria monacha. Flint and Smith (1977) reported similar negative data for the pink boll worm, Pectinophora gossypiella.

Order: Coleoptera

Sterility in Anthonomus grandis treated with diflubenzuron was reported by Taft and Hopkins (1975), Mc Laughlin (1976, 1977) and Bull (1980). But radiation of insects treated with diflubenzuron further enhanced the sterility (Mitchell et al., 1980; Wright et al., 1980; Haynes and Wright, 1981; Haynes et al., 1981; Haynes and Wright, 1982; Villavaso, 1982; Mitchell et al., 1983; Wright and Villavaso, 1985). Taft and Hopkins (1975), Ganyard et al. (1977) and Lloyd et al. (1977) showed that field populations of boll weevils could be controlled by sterilising adults by the application of diflubenzuron. Other coleopteran insects reported to be sterilised by diflubenzuron include Diapreps abbreviatus (Schroeder et al., 1976), Conotrachelus nenuphar (Calkins et al., 1977), Curculio caryae (Tedders, 1977), Graphognathous peregrinus and G. leucoloma (Ottens and Todd, 1979), Otiorhynchus sulcatus (Zepp et al., 1979; Sol, 1985), Dendroctonus frontalis (Sambeek and Van, 1982), Myllocerus undcimpustulatus var. maculosus (Thangavelu, 1982), Melolontha melolontha (Buchi, 1983), Chilocorus pustulatus (Pelag, 1983) and Lissorhoptrus oryzophilus (Tsuzuki and Asayama, 1983). Beavers and Schroeder (1981) have reported that 0.15 to 0.3 g/l of triflumuron reduced the egg hatch to 2% when adults of Diapreps abbreviatus were fed with the compound.

Kolbe and Hartwig (1982) have reported that females of Hylobitelus abietis fed on triflumuron laid about 30% fewer eggs of 5-7% hatchability, whereas those fed on diflubenzuron had no reduction in fecundity, but the hatch rate was 4.6% as compared with 75-80% for eggs laid by females fed on untreated shoots.

Retnakaran and Smith (1982) have observed sterilant effect on both sexes of Pissodes strobi applied with triflumuron 10 ng/weevil.

Topical application of diflubenzuron or penfluron at of 20 µg/insect produced complete sterility in both sexes of Trogoderma granarium (Saxena and Kumar, 1982).

Persistence of sterilisation induced in Carpophilus dimidiatus by feeding on 5 ppm of four benzoyl phenyl ureas were in the order of chlorfluazuron (12 days), XRD-473 (10 days), diflubenzuron (6 days) and teflubenzuron (4 days) (Ascher et al., 1986).

Order: Diptera

Contact as well as oral administration of benzoyl phenyl ureas induced sterility in dipteran insects.

Topical application of a 0.1% solution of diflubenzuron in acetone at 1 µg/insect on the thorax of females of the

cabbage root fly Hylemya brassicae reduced the hatch rate of eggs to 35% (Vande and Delcour, 1976).

Arambourg et al. (1977) have reported that oral administration of diflubenzuron was less effective in reducing egg viability of Ceratitis capitata. But Santiago-Alvarez and Sarasua (1983) have found reduction in fecundity and hatchability of eggs of fruit flies treated with diflubenzuron in the larval as well as adult stages.

Lawrence (1983) observed reduction in fecundity in adults of Anastrepha suspensa fed on a diet containing diflubenzuron. Effects of the diflubenzuron treatment persisted into the first generation causing reduced egg viability. But the sterility was reversed when fed on a normal diet for six days.

Topical application of diflubenzuron and penfluron produced sterility in both sexes of Dacus dorsalis. As a sterilant, penfluron was more effective than diflubenzuron (Thakur and Kumar, 1984). Rup and Chopra (1985) have observed a reduction in the life span, fecundity and hatchability of eggs of the banana fruit fly Zaprionus paravittiger when fed on a diet containing diflubenzuron. Teflubenzuron was a highly effective sterilant on Drosophila melanogaster, while chlorfluazuron and diflubenzuron were less effective (Baum et al., 1988).

Order: Orthoptera

Diflubenzuron when treated to adult females of Schistocerca gregaria, reduced egg hatch and survival to the adult stage of the nymphs to which the eggs gave rise, whereas the number of pods as well as eggs per pod remained unaffected (Mariy et al., 1981). But females of Oxya yezoensis when treated with diflubenzuron, both fecundity and hatchability of the eggs were reduced (Lim and Lee, 1982).

4. Persistence

Among pesticides, benzoyl phenyl ureas are comparatively persistent on plants. Metcalf et al. (1975), El-Tantawi et al. (1976) and Lara et al. (1977) have reported that diflubenzuron was moderately (up to one month) persistent. But Beevi (1979) has reported persistence of diflubenzuron up to 50 days when sprayed on potted rice.

Three insect growth regulators viz. diflubenzuron, triflumuron and Lilly-7063 were found to be much more stable than the organophosphates, diazinon, ethoprofos and chlorpyrifos (Argauer and Cantelo, 1980).

Diflubenzuron residues on foliage were highly resistant to photodegradation. The chemical was stable in soil if associated with plant litter and if it did not leach properly (Bull, 1980).

Residues of diflubenzuron active against Laspeyresia (Cydia) pomonella on pear for six weeks (Hoying and Riedl, 1980) and on peach against Cydia molesta for 10-14 days (Broadbent and Pree, 1984a) were found. Further, Moffit et al. (1984) have reported residues of diflubenzuron, TH 6043 and TH 6044 active against Cydia pomonella on apple and pear for a period of 19 weeks.

Mohamad et al. (1980) have reported that the residual effect of diflubenzuron applied at 0.027% against Plutella xylostella on turnip leaves 8 days after treatment was inferior to that of acephate, bendiocarb, methamidophos and Bacillus thuringiensis var. kurstaki, all at a dose of 0.1%.

Schroeder et al. (1980) could detect residues of diflubenzuron in citrus fruits harvested 27 days after the sixth application of 350 g/ha. But no residue of diflubenzuron was found in the honey from colonies of Apis mellifera after eight aerial sprays.

Residual efficacy of diflubenzuron in the field lasted up to 17 days against the larvae of Mamestra brassicae (Velcheva, 1983) whereas it remained up to 28 days against Spodoptera littoralis larvae (Moustafa et al., 1984).

Residual action of diflubenzuron and triflumuron against stored product pests of wheat, maize and barley grains

persisted the whole of a study period of 12 months (Mian and Mulla, 1982).

Diflubenzuran impregnated in timber at the rate of 0.5 kg/$m^3$ was effective against the larvae of the old house borer Hylotrupes bajulus even after 24 weeks (Dopplereiter, 1983).

Lauren et al. (1984) have reported that the first, second and third half lives of diflubenzuron sprayed on leucerne were 3, 4 and over 15 days respectively.

Highest persistence of diflubenzuron was reported in the pine needles for at least two years after application to control Thaumetopoea pityocampa (Soria et al., 1986).

Mutanen and his coworkers (1988) have reported residues of diflubenzuron in water, humus, litter, mushrooms, bilberries and cowberries for varying periods of up to one month to one year after a spraying in the forest against the pests of pine.

## 5. Effects on non-target organisms

Chitin synthesis inhibitors are in general much less harmful to populations of beneficial fauna than most of the conventional insecticides.

Diflubenzuron was non-toxic or slightly toxic to parasites Apanteles marginiventris, Trichogramma pretiosum (Ables et al., 1980), Ooencyrtus kuvanae on Lymantria dispar (Brown and Respico, 1981), Trichogramma spp. (Hassan, 1983), chalcidoids (Ferrari and Tiberi, 1979) and egg parasites (Tsankov and Mirchev, 1983) of Thaumetopoea pityocampa, Pediobius foveolatus on Epilachna varivestis (Zungoli et al., 1983), Doryphorophaga doryphorae on Leptinotarsa decemlineata (Tamaki et al., 1984), Trichogramma cacoeciae on Laspeyresia pomonella (Niemczyk et al., 1985), Carcelia rasella and Casinaria nigripes on Dendrolimus spp. (Song et al., 1985) and Aleochara bilineata on Delia radicum (Gordon and Cornect, 1986). Besides diflubenzuron, triflumuron and chlorfluazuron were selective to the braconid Trioxya pallidus on Chromophis juglandicola (Purcell and Granett, 1985).

However, diflubenzuron was toxic to parasites such as Apanteles melanoscelus on Lymantria dispar (Granett and Weseloh, 1975; Granett et al., 1976; Madrid and Stewart, 1981), Aphidius matricarinae and Encarsia formosa on green house pests (Iacob et al., 1981), Biosternes longicaudatus on Anastrepha suspensa (Lawrence, 1981), tachnids on L. dispar (Madrid and Stewart, 1981), Macrocentrus ancylivorus on Cydia molesta (Broadbent and Pree, 1984b), Microplitis rufiventris on Spodoptera littoralis (Heynen, 1985) and Trichogramma evanescens (Zaki and Gresraha, 1987).

Toxicity of diflubenzuron on the predator Geocoris punctipes (Ables et al., 1980), Scolothrips longicornis (Iacob et al., 1981), Chilocorus pustulatus (Pelag, 1983). Acholla multispinosa (Broadbent and Pree, 1984b) and Scymnus spp. (Matrangolo et al., 1987) was negligible. Eggs and later instar larvae of Anthocoris nemorum and Episyrphus balteatus were tolerant to diflubenzuron, but early instar larvae suffered heavy mortality (Niemczyk et al., 1985). High toxicity of diflubenzuron was reported against Chilocorus pustulatus (Pelag, 1983), Chrysopa oculata (Broadbent and Pree, 1984b) and Chrysoperla carnea (Niemczyk et al., 1985).

Diflubenzuron was relatively harmless to the predatory mites Phytoseiulus persimilis (Iacob et al., 1981). Typhlodromus occidentalis, Zetzellia mali (Anderson and Elliott, 1982) and T. pyri (Gemini et al., 1983). Flufenoxuron was safe to Amblyseius endersoni and A. stipulatus (Perugia et al., 1986). But Kolchenkov (1983) has reported high mortality of Typhlodromus soleiger and Amblysieus spp. with diflubenzuron.

Besides, effects of diflubenzuron on the beneficial fauna of cotton fields were insignificant (Keever et al., 1977: Rummel et al., 1979). Hassan (1984) has reported diflubenzuron among the least harmful insecticides to the beneficial arthropods. But all the reports were not

uniformly favourable. Zgomba et al. (1983) have reported that application of diflubenzuron against mosquito larvae caused complete mortality of collembola. The widespread use of diflubenzuron to control Thaumetopoea pityocampa on Pinus spp. constituted a threat to populations of the saturnid Grallsia isabellae in Spain (Soria et al., 1986).

Barker and Waller (1978) have found that diflubenzuron prevented production of brood in honey bees. But Johnson (1979) and Schroeder et al. (1980) with diflubenzuron and Hamman and Sirrenberg (1980) and Zoebelein et al. (1980) with triflumuron have reported that chitin synthesis inhibitors did not significantly reduce the bee population.

Diflubenzuron acted as a synergist to Bacillus thuringiensis (Carnivet et al., 1978) and Metarrhizium anisopliae (Hassan and Charnley, 1983). Retnakaran and Ennis (1985) have established non-mutagenecity of chlorfluazuron using five histidine auxotrophs of Salmonella typhimurium.

Stribling and Smith (1987) have reported that diflubenzuron had no effect on breeding bird populations. Martinet et al. (1987) showed that diflubenzuron did not bioaccumulate at higher trophic levels. Sundaram and Nott (1989) have showed that diflubenzuron was unlikely to be leached to ground water from the source of application.

## 6. Field studies

Field studies have established that chitin synthesis inhibitors can be effectively used for the control of insect and mite pests of crops. Elings and Dieperink (1974) evaluated diflubenzuron against various insect pests under field conditions in Netherlands and found toxic to diptera and lepidoptera. Van Busschbach (1975) has presented a review of tests of diflubenzuron against pests of agriculture and forestry and he described it as a persistent, slow-acting stomach insecticide with no contact or systemic action.

### Order: Lepidoptera

Extensive work has been done on the control of lepidopterous pests using moult inhibitors. Diflubenzuron at 75 g ai/ha (Turnipseed *et al.*, 1974) and 150 g/ha (Lorenzato and Corseuil, 1982) was effective against *Anticarsia gemmatalis* and *Plusia* spp. on soyabean. Even doses as low as 15 g/ha could afford more than 80% control of *A. gammatilis* and 60% control of *Pseudoplusia includens* (Winder, 1984). CME-134 at doses of 16.5, 33.0, 66.0, 132.0 and 264.0 g ai/ha offered complete protection for atleast 55 days against noctuid pests of soyabean including *Pseudoplusia includens*, *Heliothis zea*, *Platypena scabra* and *A. gemmatalis*.

Application of diflubenzuron at doses of 0.0039 to 0.125 lb ai/10 gallon water (Granett and Dunbar, 1975), 75 g/ha (Cameron and Waldvogel, 1980) and 4.68 kg 25% WP/ha (Jobin and Carson, 1982) were effective against Lymantria (Porthetria) dispar. But Donaubauer (1976) has reported that 150-500 g/ha was effective against L. dispar and L. monacha. Application at 0.16-0.17 1/2-2.5 l oil controlled L. monacha (Slima, 1984).

Flint et al. (1977) have reported that diflubenzuron at 0.22 and 2 kg ai/ha, controlled Baculatrix thurberiella at both rates of application and Trichoplusia ni at the highest rate, but there was no control of Pectinophora gossypiella. Schmidt and Dorntlein (1980) evaluated triflumuron against pests of cotton. A dose of 250 g/ha caused 83-100% mortality of Spodoptera littoralis. Baculatrix thurberiella, Pseduplusia includens and Alabama aigillacea were controlled by application at 31 g ai/ha. Foliar sprays containing CGA-112913 at 0.14 kg ai/ha gave better control of Heliothis spp., Trichoplusia ni and Pseudoplusia includens than did sprays containing a mixture of triflumuron at 0.34 kg ai/ha and azinphosmethyl at 0.28 kg ai/ha (Hopkins et al., 1984).

Field application of diflubenzuron at 0.28, 0.56 and 1.12 kg ai/ha was effective against Ostrinia nubilalis on maize (Berry et al., 1980). But Khasan and D'Yanchenko (1984)

found the chemical less effective against the pest. Triflumuron at doses of 50 to 150 g ai/ha was effective against O. nubilalis, Busscola fusca, Sesamia cretia, Chilo agamemnon and Spodoptera frugiperda (Schmidt and Dorntlein, 1980). Diflubenzuron reduced damage by Sesamia nonagrioides on maize (Larue, 1984), but was ineffective against the pest on the ornamental plant Sterilitzia reginae (Oliveira and Tavares, 1983).

Mori and Vianello (1980) reported that protection of apple trees with diflubenzuron was as effective as that with organophosphorus insecticides. The compound at 0.05% was toxic to Leucoptera malifoliella, Phyllonorycter blancardella and P. corylifoliella (Dulic and Injac, 1981). At 94-375 ppm, it controlled Choristoneura rosaceana, Pandemis tenulata, Archips argirospilus and A. rosanus, but was ineffective against Cydia pomonella (Elliott and Anderson, 1982). Workers such as Kholchenkov (1983), and Audemard and Marcon (1984) found diflubenzuron effective against C. pomonella also. At a dose of 0.1% it was effective against Yponomeuta sp. (Ivanov, 1984). TH 6043 and TH 6044 were as effective as diflubenzuron against C. pomonella. But TH 6045 exhibited little activity against the tortricid (Moffitt et al., 1984). Triflumuron suppressed damage by Operophtera brumata, Tortrix spp. and Cydia pomonella, whereas diflubenzuron had no significant

effect against Tortrix spp. (Glen et al., 1982). Effective control of Stigmella malella was obtained with triflumuron at 0.9 mg/10 l, diflubenzuron at 1.24 mg/10 l or CME-134 at 0.75 mg/10 l (Maciesiak, 1985). Perugia et al. (1986) could control the lyonetiid Leucoptera scitella using flufenoxuron.

Non-toxicity to majority of non-target organisms makes moult inhibitors suitable for use even in complex ecosystem of forests. In field trials conducted in British Columbia against Orgyia pseudotsugata, diflubenzuron was found effective in reducing the population of the pest (Canadian Forestry Service, 1980). Retnakaran (1981) has reported that UC-62644 and triflumuron were effective against Choristoneura fumiferana, but diflubenzuron was ineffective. Horstmann (1982) conducted field trials with diflubenzuron in oak forests. Complete mortality of Tortrix viridana and Zeiraphera isertana was obtained, but did not affect the larvae of six other species of Tortricidae. Triflumuron and diflubenzuron as foliar sprays offered excellent protection of red oak trees against the leaf shredder Croesia semipurpurana (Retnakaran and Tomkins, 1982) and diflubenzuron against Thaumetopoea pityocampa (Robredo, 1982; Tsankov and Mirchev, 1983). Guzeev and Mansurov (1983) observed that diflubenzuron at 0.05 kg ai/ha was effective against the saturniid Neoris huttoni. Application of diflubenzuron and

triflumuron reduced the population of Operophtera brumata on Acer plantanoides (Albert, 1984) and Ichthyra anstomosis on poplar (Chaudhry and Hanif Gul, 1985).

Diflubenzuron at 1.0 kg/ha (Ramzan and Darshan Singh, 1980) and 0.0035% with 2% neem seed kernal (Sitaramaiah et al., 1986) controlled the attack of Spodoptera litura on tobacco.

Triflumuron was effective against Homona magnanima and Gracillaria theivora on tea and Leucoptera coffedla on coffee (Schmidt and Dorntlein, 1980).

Diflubenzuron at doses ranging from 2.5 to 20 g ai/10 l water produced 77.4 to 100% control of the coconut caterpillar Opisina arenosella (Sundaramurthy, 1980).

Nimbalkar and Ajri (1981) have found synthetic pyrethroids superior to diflubenzuron when applied against the brinjal shoot and fruit borer Leucinodes orbonalis.

As a soil surface treatment, diflubenzuron was found effective against the larvae and pupae of Spodoptera littoralis (Abo-Elghar et al. 1982).

Diflubenzuron at 250 and 750 ppm was effective against Mamestra brassicae (Velcheva, 1983). But Hommes (1984) found that CME 130406 was more effective than triflumuron against

lepidopterous pests of crucifers, while diflubenzuron was ineffective.

Application of triflumuron at 87.5 or 127 g/ha was superior to permethrin (200 ml/ha) or methamidophos (400 ml/ha) + cyfluthrin (200 ml/ha) against the tomato leaf miner Scrobipalpa absoluta (Jeske et al., 1985).

Chlorfluazuron at 12.5 to 50 ppm showed superior activity over diflubenzuron at 250 ppm and triflumuron at 350 ppm against a multiple insecticide resistant strain of Plutella xylostella (Lim and Khoo, 1985).

Triflumuron (0.065 and 0.13%) and diflubenzuron (0.025%) were inferior to cypermethrin (0.01%) but superior to monocrotophos (0.05%) and BPMC (0.05%) against Earias vitella on okra (Prasad et al., 1986).

Sinha and Mehrotra (1988) found diflubenzuron effective against Heliothis armigera on chick pea.

Order: Coleoptera

Neal (1974) conducted experiments with diflubenzuron in small pots against the alfalfa weevil Hypera postica. Treated larvae turned black and showed ropiness when touched with a needle.

In field trials conducted in Florida, diflubenzuron applied by air craft at a rate of 283 g ai/acre was effective against Diapreps abbreviatus on citrus (Schroeder et al., 1976).

A great deal of work has been done on the control of Anthonomus grandis using chitin synthesis inhibitors, especially diflubenzuron. Field doses of 141 g/ha (Ganyard et al., 1977), 0.25 kg ai/acre (Lloyd et al., 1977) 0.14 kg ai/ha (Ganyard et al., 1978), 30, 70 and 140 g ai/ha (House et al., 1978), 141.8 g ai/ha (Johnson et al., 1978), 52.5 g ai/ha (Rummel, 1980) and 0.067 kg/ha (Shadbolt, 1983), diflubenzuron was effective in reducing the populations of the pest. Hopkins et al. (1984) have reported that at a dose of 0.07 kg ai/ha diflubenzuron, penfluron and triflumuron were effective against A. grandis. But CGA-112913 at 0.14 kg ai/ha was ineffective.

Diflubenzuron at 0.15 and 0.30 ai/l of water against Cucurlio caryae (Tedders, 1977), 0.1% against Leptinotarsa decemlineata (Krasnovskaya and Chipischuk, 1978), 0.18, 0.33 and 0.088 kg/ha against Epilachna varivestris, were all effective. Diflubenzuron or triflumuron at a dose of 280 g/ha was effective in reducing the population of the white pine weevil Pissodes strobi (Retnakaran and Smith, 1982).

Order: Diptera

Even though chitin synthesis inhibitors were highly active against diptera under laboratory conditions, they could be rarely used successfully in the field due to the concealed habitats of many dipteran larvae.

Elings and Dieperink (1974) found diflubenzuron effective against diptera under field conditions. But it failed to protect sprouting lima bean from the attack of Delia platura, though it afforded protection to seeds of certain legumes under laboratory conditions (Vea et al., 1976). Diflubenzuron at 120 ppm and triflumuron at 5 ppm afforded protection against Lycoriella mali infesting mushrooms (Cantelo, 1983).

Other insect pests

Diflubenzuron at rates of 150-500 g/ha gave promising results against the sawflies, Pristiphora abictina and Neodeprion sertifer (Donabauer, 1976).

Diflubenzuron effectively controlled Psylla piri on apple and pear (Picco, 1981). But neither diflubenzuron nor triflumuron suppressed the population of P. mali on apple (Glen et al., 1982).

Efficacy of triflumuron was comparable with that of bendiocarb against the tea scale Florina theae (Cooper and Oetting, 1985).

Diflubenzuron or triflumuron at 0.04% or above controlled the shisham defoliator Plecoptera reflexa (Chaudhry and Hanif Gul, 1985). The same compounds reduced damage by the leucerne flea Sminthurus viridis (Wrenn and Mc Ghie, 1986).

Order: Acarina

Chitin synthesis inhibitors posses acaricidal properties too. Diflubenzuron was reported by Reinert (1981) as a potent acaricide against Paracalacarus podocarpi on Podocarpus macrophylla. It was highly effective against Eutetranychus pruni (Kolchenkov, 1983) and Panonychus ulmi (Audemard and Marcon, 1984). Perugia et al. (1986) evaluated flufenoxuron in the field and obtained good control of Pononychus ulmi on apple and P. citri on citrus.

7. Mode of action

Chitin synthesis inhibitors have the unique mode of action that they interfere with the production and deposition of chitin in the cuticle of insects.

Post and Vincent (1973) working with TH 6040 were the first to report the interference of the compound in

chitin synthesis. Later workers like Bitloo (1975), Salama et al. (1976), Clarke et al. (1977), Fogal (1977), Grosscurt (1977), Ker (1977), Duel et al. (1978), Ker (1978), Bene and Porcinai (1979 and 1980), and Vincent and Clarke (1985) have reported that after administration of diflubenzuron, the endocuticle was defectively formed and poorly attached to the epidermis due to the inhibition of chitin synthesis, hence the treated larvae failed to moult or form new cuticle. Bene et al. (1983) have observed degeneration of cytoplasm besides abnormalities in the epidermis and cuticle. Extrusion of cytoplasm from the epidermal cells of post-ecdysial cuticle of treated larvae was reported by Hassan and Charnley (1987).

Baumler and Salama (1976) studied the biochemical changes induced by diflubenzuron in Porthetria dispar. Glucose content of haemolymph and glycogen content in the cuticle increased amino sugars, amino acids and peptides remained unchanged; haemolymph protein appeared normal but proteins were quantitatively lower after treatment. A number of enzymes investigated remained unaffected whereas Ishaaya and Ascher (1977) found that diflubenzuron suppressed the activity of trehalase, invertase and amylase - in vivo in Tribolium castaneum. They concluded that suppression of trehalase activity might hamper the supply of glucose needed for chitin synthesis and those of invertase and amylase activity might affect feeding. But no in vitro inhibition of these enzymes

were found. Chitin synthatase of Trichoplusia ni and Hyalophora cercopiae was insensitive to diflubenzuron and triflumuron in cell-free enzyme preparations (Cohen and Casida, 1982). - ecdysone titre in pharate pupae of Stomoxys calcitrans, exposed to dimilin as larvae remained unchanged (O'Niell et al., 1977).

Relatively high susceptibility of Orgyia pseudotsugata than Choristoneura occidentalis to diflubenzuron was shown to be related to high retention of the compound due to low rate of metabolism (Granett et al., 1980). Denneulin and Lamy (1982) have reported stimulation of cholesterol synthesis by diflubenzuron. This explains why ecdysteroids accumulate in some treated insects and why the effects of the insecticide are far more varied than is generally expected.

Mitsui et al. (1981) have shown that the inhibition of chitin synthesis occurred at the polymerisation of acetyl glucosamine to form chitin. But Saxena and Kumar (1981) found partial blockage of chitin synthesis at the initial stage of conversion of glucose-6-phosphate to fructose-6-phosphate. Mitsui et al. (1984) have postulated that diflubenzuron may be acting as an inhibitor of the transport system of UDP-N-acetyle glucosamine across biomembranes, since an accumulation of UDP-N-acetyl glucosamine occurs in insects treated with the compound.

# Materials and Methods

# MATERIALS AND METHODS

## 1. Test insects

Rice swarming caterpillar Spodoptera mauritia (Boisduval), rice moth Corcyra cephalonica (Stainton) and Bracon brevicornis (Wesmael), a larval parasite of C. cephalonica were used for assessing the various effects of chitin synthesis inhibitors.

## 2. Chitin synthesis inhibitors used for the study

Three benzoyl phenyl urea analogues viz. chlorfluazuron (pp. 145, 5% EC of Indian Explosives Ltd., Bangalore), PH 70-23 (25% LIQ of Duphar BV) and BASF LAB 153 959 I (50% EC of BASF India Ltd., New Delhi) were compared with diflubenzuron (Dimilin 25 WP of Duphar BV, supplied by Coromandal Indag Products India Pvt. Ltd., Madras) for their biological activities on the test insects.

## 3. Assessment of the effects of chitin synthesis inhibitors on Spodoptera mauritia

### 3.1. Laboratory rearing of S. mauritia

Eggs obtained from gravid female moths collected at light were used for starting a culture of the insect in the laboratory. Egg masses were sterilized in 10% formaldehyde for an hour and dried under fan. The caterpillars were

reared on the grass Brachiaria sp. which is the most suitable host plant of the test insect. The grass was periodically collected from the bunds of rice fields.

Newly hatched first instar larvae have the peculiar habit of climbing for long time through any vertical surface in their vicinity, which takes them away from the feed and ultimately kills them. In order to overcome this, first instar larvae were reared in specimen tubes by the following method:

One or two sterilized egg masses were placed in a specimen tube. A pinhole was made on the centre of a piece of cloth. A piece of grass 7.5 - 10 cm in length was taken and its cut basal end was drawn through the pin hole. The grass piece was introduced into the specimen tube which was closed with the cloth held in position by a rubber band. Cut basal end of the grass that protruded out through the pin hole was kept immersed in water contained in a small bottle by placing the specimen tube upside down over the rim of the bottle. On the second day larvae were transferred using a fine camel hair brush on to bundles of grass, cut ends of which were wrapped with wet cotton and kept in cylindrical glass jars. The jars were closed with cloth held in position by rubber bands. As the larvae finished feeding they were transferred to fresh grass daily. Full grown larvae were offered loose soil at the bottom of the

jar for pupation. Pupae were collected from the soil and kept in clean glass jars for adult emergence and covered with cloth towels. Adult moths were allowed to feed on a solution of 10% sucrose from absorbent cotton placed on the sides of the glass jar. Gravid females oviposited on the cloth covering the jars. Egg masses were cut out from the cloth and used for raising subsequent generations.

Eggs as well as pupae could be stored successfully up to a period of 2 - 3 weeks in a desiccator kept in a cooled incubator set at a temperature of $5 \pm 2^{o}C$. This helped to obtain the different stages of the insect required throughout the period of study.

Considerable variation in duration of instars and size of larvae was observed even though they were raised from the same egg mass. So care was taken for selecting larvae of the same instar and uniform size for bioassay experiments.

3.2. Assessment of ovicidal action

In two separate sets of experiments one day-old and two day-old eggs were treated with three concentrations viz. $2x10^{-1}$, $2x10^{-2}$ and $2x10^{-3}$% of aqueous and methanolic solutions of the chemicals. For each treatment 20 eggs were used and all the treatments were replicated thrice. Eggs were individually separated from the egg mass using a fine camel

hair brush. For treatment with aqueous solutions, they were then taken in a piece of cloth and suspended in treatment solutions kept in cavity blocks for 2 minutes. The treated eggs were dried under fan. Eggs similarly treated in distilled water served as control. Dried eggs were transferred to specimen tubes and observations on mortality were taken. For treatment with methanolic solutions, eggs in batches of twenty were placed in a petri dish and a drop of the treatment solution was topically applied on the eggs using a microsyringe. Eggs similarly treated with methanol alone served as control. Observed mortalities were corrected using the Abbot's formula (Abbot, 1925).

## 3.3. Assessing the effect of chitin synthesis inhibitors on larval-larval transformations

### 3.3.1. Stomach action by direct feeding

Stomach action of the chemicals on larval-larval transformations was assessed on the 2nd and 5th instar larvae separately. Larvae within one day after moulting were chosen for the experiment. The concentrations tested were $2x10^{-1}$, $2x10^{-2}$, $2x10^{-3}$, $2x10^{-4}$ and $2x10^{-5}$% in case of all chemicals except chlorfluazuron. As chlorfluazuron $2x10^{-1}$% caused instant mortality of the test larvae, only the lower doses were tried.

Bouquets of grass were dipped in the dilutions prepared in distilled water. Care was taken to ensure complete wetting of the leaves. Grass thus treated was dried under fan. In order to keep the grass fresh its cut basal ends were kept wrapped in wet cotton and placed inside glass chimneys into which larvae were released. Leaves dipped in distilled water and dried under fan were used as control. Second instar and fifth instar larvae were allowed to feed on the treated grass for 36 and 48 hours respectively. Thereafter the treated grass was removed and fresh untreated grass was provided till pupation. Daily observations were taken on the morphological changes and mortality of the larvae.

3.3.2. Contact action by topical application

Fifth instar larvae were used to assess the contact action on the last larval-larval transformation. The concentrations tested were as described under para 3.3.1. Methanolic solutions of the chitin synthesis inhibitors were prepared and 10 µl of the solutions were topically applied on the dorsum of the larvae using a Hamilton microsyringe. BASF LAB 153 959 I is insoluble in methanol; so it was first dissolved in a little quantity of acetone and further dilutions made using methanol. After evaporation

of the solvent, the treated larvae were transferred to glass chimneys containing grass kept over petri dishes and covered with moistened cloth. Larvae treated with methanol alone served as control. Daily observations were taken on mortality.

### 3.3.3. Comparison of contact and stomach actions

Contact and stomach actions of the chitin synthesis inhibitors were compared as follows: A group of 5th instar larvae was topically applied with 10 µl of methanolic solutions of diflubenzuron, PH 70-23 and BASF LAB 153 959 I at $2x10^{-1}$% and chlorfluazuron at $2x10^{-2}$%. Same quantity of the solutions was spotted and dried on grass leaves. Treated leaves were fed to individual larvae of both groups which were then allowed to feed on untreated grass. Survival period was noted.

## 3.4. Testing the effect of chitin synthesis inhibitors on larval-pupal transformation of S. mauritia

### 3.4.1. Stomach action by direct feeding

Two day-old 6th instar larvae were used for this study. Concentrations tested were $2x10^{-1}$, $2x10^{-2}$, $2x10^{-3}$, $2x10^{-4}$ and $2x10^{-5}$% except in the case of chlorfluazuron, which was tested at doses of $2x10^{-2}$, $2x10^{-3}$, $2x10^{-4}$, $2x10^{-5}$ and $2x10^{-6}$%.

0 - Adult without any deformity

1 - Adult with slightly twisted wings

2 - Adult with moderately twisted wings

3 - Adult with severely twisted wings

4 - Adult with highly reduced shrunken wings

5 - Adult partially emerged from the pupae

## 3.6. Assessment of the sterilant action of chitin synthesis inhibitors

### 3.6.1. Sterilant action on females

Moths were sexed and separated soon after emergence. Three dilutions (diflubenzuron, PH 70-23 and BASF LAB 153 959 I at $2x10^{-2}$, $2x10^{-3}$ and $2x10^{-4}$% and chlorfluazuron at $2x10^{-3}$, $2x10^{-4}$ and $2x10^{-5}$%) of the chemicals were prepared in distilled water and 10% sucrose was added. Female moths were kept in glass chimneys singly and allowed to feed from the absorbent cotton soaked in different treatment solutions. After 24 hours, cotton soaked in the treatment solutions was removed. Then cotton soaked in 10% sucrose solution alone was provided for further feeding and a male moth was introduced in each chimney for mating. Observations on the fecundity, egg hatchability and longevity of female moths were taken. Moths fed throughout with 10% sucrose solution alone were kept as control.

Larvae were fed on treated grass for a period of 12 hours and thereafter on untreated fresh grass till pupation. Loose soil was provided for pupation at the bottom of the chimneys. Observations on the number of larvae died above soil, entered the soil but died as prepupae, which had transformed into larval-pupal intermediates and those successfully transformed into pupae were taken after five days. Normal pupae were collected and kept inside chimneys for observing the emerging adults for deformities, if any.

3.4.2. Contact action by topical application

Different treatments listed under para 3.4.1 were applied on 6th instar larvae within 2 days after final moulting as described under para 3.3.2 and observations were taken as described under para 3.4.1.

3.5. Testing the effect of chitin synthesis inhibitors on the pupal-adult transformation of S. mauritia

Five dilutions viz. $2x10^{-1}$, $2x10^{-2}$, $2x10^{-3}$, $2x10^{-4}$ and $2x10^{-5}$% of the chemicals were tried on pupae.

Two day-old pupae were dipped in aqueous solutions of the chemicals for 2 minutes and dried under fan. They were then kept in chimneys and the abnormal adults were scored over a 0 - 5 point scale for deformities as given below and mean score was calculated.

0 - Adult without any deformity

1 - Adult with slightly twisted wings

2 - Adult with moderately twisted wings

3 - Adult with severely twisted wings

4 - Adult with highly reduced shrunken wings

5 - Adult partially emerged from the pupae

## 3.6. Assessment of the sterilant action of chitin synthesis inhibitors

### 3.6.1. Sterilant action on females

Moths were sexed and separated soon after emergence. Three dilutions (diflubenzuron, PH 70-23 and BASF LAB 153 959 I at $2x10^{-2}$, $2x10^{-3}$ and $2x10^{-4}$% and chlorfluazuron at $2x10^{-3}$, $2x10^{-4}$ and $2x10^{-5}$%) of the chemicals were prepared in distilled water and 10% sucrose was added. Female moths were kept in glass chimneys singly and allowed to feed from the absorbent cotton soaked in different treatment solutions. After 24 hours, cotton soaked in the treatment solutions was removed. Then cotton soaked in 10% sucrose solution alone was provided for further feeding and a male moth was introduced in each chimney for mating. Observations on the fecundity, egg hatchability and longevity of female moths were taken. Moths fed throughout with 10% sucrose solution alone were kept as control.

3.6.2. Sterilant action on males

Male moths were treated as described under para 3.6.1 and virgin females were introduced into each chimney after 24 hours. Observations on fecundity and hatchability of eggs laid by the females and the longevity of male moths were recorded.

3.6.3. Sterilant action by application on male and female moths

Male and female moths were simultaneously treated as described under para 3.6.1. Fecundity and hatchability of the eggs laid and longevity of both male and female moths were recorded.

3.7. Assessment of antifeedant action

Treatment solutions of diflubenzuron, PH 70-23 and BASF LAB 153 959 I were prepared in distilled water at dilutions of $2x10^{-1}$, $1x10^{-1}$, $5x10^{-2}$, $2.5x10^{-2}$ and $1.25x10^{-2}$%. Chlorfluazuron was prepared at doses of $2x10^{-2}$, $1x10^{-2}$, $5x10^{-3}$, $2.5x10^{-3}$ and $1.25x10^{-3}$%. Grass was dipped in the treatment solutions and dried under fan. Grass dipped in distilled water alone and dried under fan was used as control. Actively feeding 5th instar larvae were used for the study after starving for 2 hours. Lots of treated grass were

weighed and placed in petri dishes. Five larvae pre-starved for two hours were weighed together and allowed to feed on the grass for 2 hours. Each treatment was replicated thrice. A set of petri dishes with grass alone was kept for assessing the loss of weight due to evaporation. Observations on the weight of leaves eaten and the increase in larval weight were recorded. All weighings were done in an electronic balance with an accuracy of 0.001 g.

### 3.8. Persistence of chitin synthesis inhibitors

Aqueous solutions of diflubenzuron, BASF LAB 153 959 I and PH 70-23 at $2x10^{-2}$% and chlorfluazuron at $2x10^{-3}$% were sprayed using a hand sprayer on tillering rice plants raised in flower pots. A batch of plants was kept indoors, protected from direct sunlight and rain while another batch was exposed to rain and sun. Leaves were collected from both sets of the treated plants at various intervals and fed continuously to 4th instar larvae of *S. mauritia* and mortality was observed for the presence of biologically active residues.

## 4. Assessment of the effects of chitin synthesis inhibitors on Corcyra cephalonica

### 4.1. Laboratory rearing of C. cephalonica

A laboratory culture of the insect was started from moths obtained from the Parasite Breeding Station, Trivandrum. A mixture of flours of wheat and black gram at a ratio of 4 : 1 into which yeast powder was added was used as the medium for rearing.

Eggs were obtained by the following method to raise insects of uniform age: The bottom of a glass chimney was covered with nylon net and the top with a piece of cloth. Both were pasted in position using gum. A 4 mm long cut was made on the cloth covering and 20 - 30 pairs of moths were introduced into the chimney using a suction aspirator. After introducing the moths, the opening was closed using cotton. The chimney was then kept over a petri dish, whose diameter was slightly larger than the basal diameter of the chimney, so that when the chimney was placed in the petri dish, the base remained slightly above the bottom of the petri dish. Eggs laid by the moths were collected in the petri dish which were used for bioassays and raising subsequent generations.

Uniform-sized larvae of the desired instars, identified by the size of the head capsule and prothoracic shield, were collected from the media and used for bioassays.

Naked pupae and prepupae used for the experiments were obtained by the following method: Fully developed larvae that had started construction of cocoons were collected from the medium and placed in a petri dish containing transparent plastic tubes. The inner dimensions of the tubes were slightly larger than that of a larva. In the absence of flour and frass, they pupated inside the tubes making a very thin silken cocoon. Larvae that had turned to pupae were identified by holding the tubes against light and they were taken out of the tubes using forceps. The cocoons were carefully opened using forceps and pupae were taken out of them. Prepupae were also obtained similarly, but before pupation.

4.2. Assessment of ovicidal action

In two separate set of experiments one day-old and five day-old eggs were treated with three concentrations viz. $2x10^{-1}$, $2x10^{-2}$ and $2x10^{-3}$% of methanolic and aqueous solutions of the chemicals. Mode of treatment and observations were same as under para 3.2.

## 4.3. Assessing the effect of chitin synthesis inhibitors on larval-larval transformations of C. cephalonica

### 4.3.1. Stomach action by direct feeding

Stomach action of the chitin synthesis inhibitors on larval-larval transformations was assessed on the 2nd, 4th and 7th instar larvae as three separate sets of experiments. The concentrations tested were $2x10^{-1}$, $2x10^{-2}$, $2x10^{-3}$ and $2x10^{-4}$% in the case of diflubenzuron, PH 70-23 and BASF LAB 153 959 I. Chlorfluazuron was tested at doses of $2x10^{-2}$, $2x10^{-3}$, $2x10^{-4}$ and $2x10^{-5}$%. For one treatment 10 larvae were used and each treatment was replicated twice. Acetonic solutions of the chitin synthesis inhibitors were prepared and mixed with flour. Acetone was evaporated to get diets containing different concentrations of the test chemicals. Flour mixed with equal quantity of acetone alone was used as control after evaporating the solvent. Second instar larvae were allowed to feed on diets containing different concentrations of the chemicals for a period of 6 days and thereafter mortality was recorded. In a set of experiments, 4th and 7th instar larvae were fed on treated flour for two days and thereafter fresh untreated flour was supplied. In another set, the larvae were allowed to feed continuously on treated flour till death or pupation. Observations on bodily deformities and mortality were recorded every day.

4.3.2. Contact action by topical application

This was studied on the 7th instar larvae alone. Treatments were the same as described under para 4.3.1. Methanolic solutions (3 µl) of the chitin synthesis inhibitors were applied to the dorsum of the larvae using a Hamilton microsyringe. Treated larvae were transferred to petri dishes and allowed to feed on untreated flour till pupation. Observations on bodily deformities and mortality were taken on a daily basis.

4.4. Assessing the effect of chitin synthesis inhibitors on larval-pupal transformation of C. cephalonica

4.4.1. Stomach action by direct feeding

Final instar larvae were allowed to feed on treated diet for a period of 24 hours, and thereafter they were transferred to petri dishes containing small quantities of untreated flour. Treatments were same as under para 4.3.1. Larvae were then transferred to transparent polythene tubes for inducing pupation without the production of thick cocoons. This made observations easy. Soon after completion of pupation, pupae were taken out of the tube using forceps. Observations on the number of larvae dead as larva, larvae those constructed pupal cocoons but dead as prepupa,

larval-pupal intermediates and healthy pupae were taken. Adults emerging from normal pupae were observed for deformities, if any.

4.4.2. Contact action by topical application

This was done on final instar larvae and prepupae. Treatments were the same as described under para 4.3.1. Methanolic solutions (5 µl) were applied on to the dorsum using a microsyringe. Final instar larvae were allowed to feed on flour till pupation. Both larvae and prepupae were provided with transparent polythene tubes for pupation. Prepupae were observed for the number of insects dead as prepupae, larval-pupal intermediates and normal pupae. Larval mortality was also recorded. Normal pupae were kept till emergence of adults which were observed for morphological abnormalities. Number of dead pupae was also observed.

4.5. Testing the effect of chitin synthesis inhibitors on pupal-adult transformation of C. cephalonica

Naked pupae were obtained as described under 4.1. Treatments and observations were the same as in the case of S. mauritia (Para 3.5).

## 4.6. Assessment of sterilant action

### 4.6.1. Sterilant action on females

Three dilutions viz. $2x10^{-1}$, $2x10^{-2}$ and $2x10^{-3}$% of the chitin synthesis inhibitors except chlorfluazuron - which was tested at doses of $2x10^{-2}$, $2x10^{-3}$ and $2x10^{-4}$% - were prepared in methanol. Female moths (0 - 12 h old) were anaesthetised with carbon dioxide and they were topically applied with 2.5 µl of the solutions on the ventral side of abdomen with a microsyringe. They were kept inside glass chimneys along with male moths. Observations on fecundity, egg hatchability and longevity of female moths were recorded. Female moths applied with 2.5 µl of methanol along were kept along with male moths as control.

### 4.6.2. Sterilant action on males

Male moths (0 - 12 h old) were topically applied with 2.5 µl of the methanolic solutions as described under para 4.6.1. They were allowed to mate with virgin females. Longevity of the male moths and hatchability of the eggs were recorded.

### 4.6.3. Sterilant action by application on male and female moths

Male and female moths were treated as described under para 4.6.1. Fecundity and hatchability of the eggs laid and longevity of the moths were recorded.

## 5. Evaluation of the toxic effect and statistical analysis

The assessment of toxic effect of the chitin synthesis inhibitors to different larval-larval transformations of S. mauritia and C. cephalonica has been done by the method of Pradhan (1949).

Data were analysed statistically. The 'F' test was done by the analysis of variance (Panse and Sukhatme, 1978). Significant results were compared on the basis of critical difference.

## 6. Assessment of the effects of chitin synthesis inhibitors on Bracon brevicornis

### 6.1. Laboratory rearing of B. brevicornis

The parasite was reared in the laboratory on the final instar larvae of Corcyra cephalonica. Specimen tubes disinfected with methanol were used for rearing. For mass rearing, ten host larvae were taken in a specimen tube and four or five pairs of adult parasites were allowed to parasitise on them. Tubes containing host insects and parasites were exposed to diffused sunlight for enhancing mating, oviposition and development of the parasite. On cloudy days, a 100 watts bulb was used for providing adequate temperature and light. A suction aspirator was used for easy handling of the parasites.

6.2. Effect on the development of the parasite when applied through the host

Host larvae were topically applied with 5 µl of methanolic solutions of the moult inhibitors at three doses (diflubenzuron, BASF LAB 153 959 I and PH 70-23 at $2x10^{-1}$, $2x10^{-2}$ and $2x10^{-3}$% and chlorfluazuron at $2x10^{-2}$, $2x10^{-3}$ and $2x10^{-4}$%). In another experiment, hosts were fed on diets containing the compounds at the above doses for a day. Two larvae each were taken in a specimen tube. A female parasite along with a male was admitted into the specimen tube using a suction aspirator and was allowed to parasitise. Number of parasites pupated, adults emerged and dead pupae were counted.

6.3. Assessment of the effect on the pupae

Effect of direct application on the pupae was studied as follows: Parasitised hosts were placed on a sheet of paper prior to emergence of larvae. Emerging larvae of the parasites pupated on the paper and it was cut into pieces containing ten pupae each. Each pupa was applied topically with 0.5 µl of the methanolic solutions of the compounds at the doses given under para 5.2. The pieces of paper containing pupae were kept inside specimen tubes and adult emergence was observed.

## 6.4. Assessment of the effect on progeny production

Adults emerged from the treated pupae were used for studying the effect of the compounds on the progeny production of the parasite. A pair of adults were allowed to parasitise on two hosts and emergence of the progeny was noted. Each treatment was replicated thrice.

# RESULTS

## 1. Effects of chitin synthesis inhibitors on Spodoptera mauritia

### (a) Ovicidal action of chitin synthesis inhibitors against Spodoptera mauritia

Results relating to this study are given in Table 1. One-day old eggs of S. mauritia when treated with aqueous solutions of chitin synthesis inhibitors, chlorfluazuron $2x10^{-1}$% recorded the highest mortality of 95.2%, followed by PH 70-23 $2x10^{-1}$% (40.1%). The above two treatments were significantly different from other treatments and each other. BASF LAB 153 959 I, at all the test doses did not produce mortality. Other treatments caused mortalities ranging from 0.2 to 7.8% and were on par.

Among treatments of two day old eggs in aqueous medium, chlorfluazuron $2x10^{-1}$% (87.7%) and PH 70-23 $2x10^{-1}$% (72.4%) were on par. Chlorfluazuron $2x10^{-2}$% (40.3%) was inferior to the above treatments, but was superior to all other treatments which produced lower mortalities ranging from 1.4 to 12.3%.

Maximum mortality of one-day old eggs in methanolic medium was produced by chlorfluazuron $2x10^{-1}$% (99.5%),

Table 1. Ovicidal action of chitin synthesis inhibitors against Spodoptera mauritia

| Treatments | Aqueous medium | | Methanolic medium | | Mean | Insecticidal dose x age of eggs | | Insecticidal dose x medium of application | |
|---|---|---|---|---|---|---|---|---|---|
| | 1-day old | 2-day old | 1-day old | 2-day old | | 1-day old | 2-day old | Aqueous medium | Methanolic medium |
| Diflubenzuron | | | | | | | | | |
| $2x10^{-1}$% | 7.8(16.2) | 3.0(10.0) | 98.6(83.3) | 84.2(66.6) | (44.0) | (49.7) | (38.3) | (13.1) | (74.9) |
| $2x10^{-2}$% | 2.7 (9.5) | 3.5(10.7) | 99.3(85.3) | 57.2(49.1) | (38.7) | (47.4) | (29.9) | (10.1) | (67.2) |
| $2x10^{-3}$% | 4.1(11.6) | 2.4 (8.9) | 56.2(48.5) | 40.4(39.5) | (27.1) | (30.1) | (24.2) | (10.3) | (44.0) |
| Chlorfluazuron | | | | | | | | | |
| $2x10^{-1}$% | 95.2(77.2) | 87.7(69.5) | 99.5(85.9) | 94.6(76.5) | (77.3) | (81.6) | (73.0) | (73.4) | (81.2) |
| $2x10^{-2}$% | 6.5(14.8) | 40.3(39.4) | 5.4(13.4) | 0.0(0.0) | (16.9) | (14.1) | (19.7) | (27.1) | (6.7) |
| $2x10^{-3}$% | 0.2 (2.5) | 1.7 (7.4) | 0.3 (3.2) | 0.3 (3.4) | (4.1) | (2.9) | (5.4) | (5.0) | (3.3) |
| PH 70-23 | | | | | | | | | |
| $2x10^{-1}$% | 40.1(39.3) | 72.4(58.3) | 99.4(85.5) | 70.3(57.0) | (60.0) | (62.4) | (57.6) | (48.8) | (71.2) |
| $2x10^{-2}$% | 5.0(13.0) | 12.3(20.5) | 2.3 (8.7) | 0.0 (0.0) | (10.5) | (10.8) | (10.2) | (16.7) | (4.3) |
| $2x10^{-3}$% | 5.0(12.9) | 6.7(15.0) | 1.2 (6.2) | 10.3(18.7) | (13.2) | (9.5) | (16.9) | (14.0) | (12.4) |
| BASF LAB 153 959 I | | | | | | | | | |
| $2x10^{-1}$ | 0.0 (0.0) | 2.8 (9.7) | 89.6(71.2) | 30.6(33.6) | (28.6) | (35.6) | (21.6) | (4.8) | (52.4) |
| $2x10^{-2}$ | 0.0 (0.0) | 3.5(10.8) | 4.0(11.6) | 2.8 (9.6) | (8.0) | (5.8) | (10.2) | (5.4) | (10.6) |
| $2x10^{-3}$ | 0.0 (0.0) | 1.4 (6.7) | 0.8 (5.0) | 1.4 (6.7) | (4.6) | (2.5) | ( 6.7) | (3.4) | (5.9) |
| | (16.4) | (22.2) | (42.3) | (30.3) | -- | (29.4) | (26.1) | (19.3) | (36.2) |

C.D. (1) Medium of treatment : 3.58
(2) Insecticidal dose : 8.77
(3) Medium of Treatment x Age of eggs : 5.06
(4) Medium of treatment x insecticidal dose : 12.40
(5) Medium of treatment x insecticidal dose x Age of eggs : 12.40

(Values of angular transformation are given in brackets)

PH 70-23 $2x10^{-1}$% (99.4%), diflubenzuron $2x10^{-2}$% (99.3%) and $2x10^{-1}$% (98.6%) and BASF LAB 153 959 I $2x10^{-1}$% (89.6%). Diflubenzuron $2x10^{-3}$% (56.2%) was inferior to the above treatments, but was superior to other less effective doses those produced mortalities ranging from 0.3 to 5.4%. Two-day old eggs when treated in methanolic medium, chlorfluazuron $2x10^{-1}$% (94.6%) and diflubenzuron $2x10^{-1}$% (84.2%) produced the highest mortalities. PH 70-23 ($2x10^{-1}$%) with 70.3% mortality and diflubenzuron ($2x10^{-2}$%) having 57.2% mortality followed the above treatments. Other treatments produced mortalities only below 40.4%.

Mortalities of one and two-day old eggs, in aqueous medium, were on par in the case of diflubenzuron and BASF LAB 153 959 I at all the test doses, and in the cases of chlorfluazuron $2x10^{-1}$% and $2x10^{-3}$% and PH 70-23 $2x10^{-2}$% and $2x10^{-3}$%. Mortality of 2-day old egg was significantly higher in the case of chlorfluazuron $2x10^{-2}$% and PH 70-23 $2x10^{-1}$%.

In methanolic medium mortalities of one and two-day old eggs treated with diflubenzuron $2x10^{-3}$%, chlorfluazuron $2x10^{-1}$% and $2x10^{-3}$%, PH 70-23 $2x10^{-2}$% and BASF LAB 153 959 I $2x10^{-2}$% and $2x10^{-3}$% were on par. But in the case of diflubenzuron $2x10^{-1}$% and $2x10^{-2}$%, chlorfluazuron $2x10^{-2}$%, PH 70-23 $2x10^{-1}$% and BASF LAB 153 959 I $2x10^{-1}$%, mortality of one-day old egg was superior. PH 70-23 $2x10^{-3}$% produced significantly higher mortality of two-day old eggs.

Diflubenzuron $2x10^{-1}$%, $2x10^{-2}$% and $2x10^{-3}$% and BASF LAB 153 959 I $2x10^{-1}$% against both one and two-day old eggs, produced significantly higher mortality in methanolic medium. But chlorfluazuron $2x10^{-1}$% and $2x10^{-3}$%, PH 70-23 $2x10^{-3}$% and BASF LAB 153 959 I $2x10^{-2}$% and $2x10^{-3}$% produced no significant difference in the mortalities of one and two-day old eggs in aqueous and methanolic media. Chlorfluazuron $2x10^{-2}$% and PH 70-23 $2x10^{-2}$% produced significantly high mortality of two-day old eggs in aqueous medium, while PH 70-23 $2x10^{-1}$% produced less mortality of one-day old eggs in aqueous medium than in methanolic medium.

(b) Effect of chitin synthesis inhibitors on the larval-larval changes of Spodoptera mauritia

Larvae of S. mauritia when treated with chitin synthesis inhibitors, various deformities and malformations were caused before death. Higher doses caused death of the treated larvae during or before ecdysis, while lower doses retarded development and induced deformities during the course of development similar to those produced by juvenile hormone analogues. In this case death occurred during larval-pupal or pupal-adult transformations resulting in the formation of larval-pupal mosaics or deformed adults. Death in the larval stage was preceded by one or more of the following symptoms:

(a) non-formation of moult and development of a dark colour (Fig. 1), (b) partial moulting of cuticle over the head or/and thoracic region which appears swollen exposing the unsclerotised cuticle below (Fig. 2) and (c) rupture of the unsclerotised cuticle. Symptoms caused by different compounds were more or less similar. Results of the effect of chitin synthesis inhibitors on larval-larval changes of S. mauritia are given in Tables 2 and 3.

Second instar larvae of S. mauritia were treated with various concentrations of the chitin synthesis inhibitors. Diflubenzuron and chlorfluazuron at all the test doses produced complete mortality. PH 70-23 at $2x10^{-1}$, $2x10^{-2}$, $2x10^{-3}$ and $2x10^{-4}$% and BASF LAB 153 959 I at $2x10^{-1}$, $2x10^{-2}$ and $2x10^{-3}$% produced total mortality. BASF LAB 153 959 I $2x10^{-5}$% produced mortality of 97.5% and was on par with the above treatments and the mortality (90.4%) at the next higher dose of the same compound. PH 70-23 at the lowest dose of $2x10^{-5}$% produced the least mortality of 87.0%, which was also on par with BASF LAB 153 959 I $2x10^{-4}$%, but was inferior to all other treatments.

Fifth instar larvae of S. mauritia when fed on a treated diet, chlorfluazuron at all doses ranging from $2x10^{-2}$ to $2x10^{-5}$%, diflubenzuron $2x10^{-1}$, $2x10^{-2}$ and $2x10^{-3}$%, PH 70-23 $2x10^{-1}$, $2x10^{-2}$ and $2x10^{-4}$% and BASF LAB 153 959 I

Table 2. Effect of chitin synthesis inhibitors on the larval-larval changes of Spodoptera mauritia

| Treatments | Corrected mortality of second instar larvae when fed on treated diet | Corrected mortality of fifth instar larvae | |
|---|---|---|---|
| | | when fed on treated diet | when applied topically |
| Diflubenzuron | | | |
| $2x10^{-1}$% | 100.0(90.0) | 100.0(90.0) | 100.0(90.0) |
| $2x10^{-2}$% | 100.0(90.0) | 100.0(90.0) | 100.0(90.0) |
| $2x10^{-3}$% | 100.0(90.0) | 100.0(90.0) | 72.5(58.4) |
| $2x10^{-4}$% | 100.0(90.0) | 93.2(74.8) | 6.4(14.6) |
| $2x10^{-5}$% | 100.0(90.0) | 71.8(57.9) | 4.4(12.1) |
| Chlorfluazuron | | | |
| $2x10^{-2}$% | 100.0(90.0) | 100.0(90.0) | 100.0(90.0) |
| $2x10^{-3}$% | 100.0(90.0) | 100.0(90.0) | 100.0(90.0) |
| $2x10^{-4}$% | 100.0(90.0) | 100.0(90.0) | 100.0(90.0) |
| $2x10^{-5}$% | 100.0(90.0) | 100.0(90.0) | 100.0(90.0) |
| PH 70-23 | | | |
| $2x10^{-1}$% | 100.0(90.0) | 100.0(90.0) | 100.0(90.0) |
| $2x10^{-2}$% | 100.0(90.0) | 100.0(90.0) | 100.0(90.0) |
| $2x10^{-3}$% | 100.0(90.0) | 97.3(80.4) | 97.3(80.4) |
| $2x10^{-4}$% | 100.0(90.0) | 100.0(90.0) | 100.0(90.0) |
| $2x10^{-5}$% | 87.0(68.9) | 93.9(75.7) | 93.9(76.7) |
| BASF LAB 153 959 I | | | |
| $2x10^{-1}$% | 100.0(90.0) | 100.0(90.0) | 100.0(90.0) |
| $2x10^{-2}$% | 100.0(90.0) | 100.0(90.0) | 98.8(83.7) |
| $2x10^{-3}$% | 100.0(90.0) | 100.0(90.0) | 52.4(46.4) |
| $2x10^{-4}$% | 90.4(71.9) | 45.5(42.4) | 48.7(44.2) |
| $2x10^{-5}$% | 97.9(81.7) | 72.1(58.1) | 51.0(45.3) |
| C.D. | (11.41) | (17.35) | |

(Values of angular transformation are given in brackets)

Table 3. Effect of chitin synthesis inhibitors on the larval-larval changes of Spodoptera mauritia in terms of values of speed indices

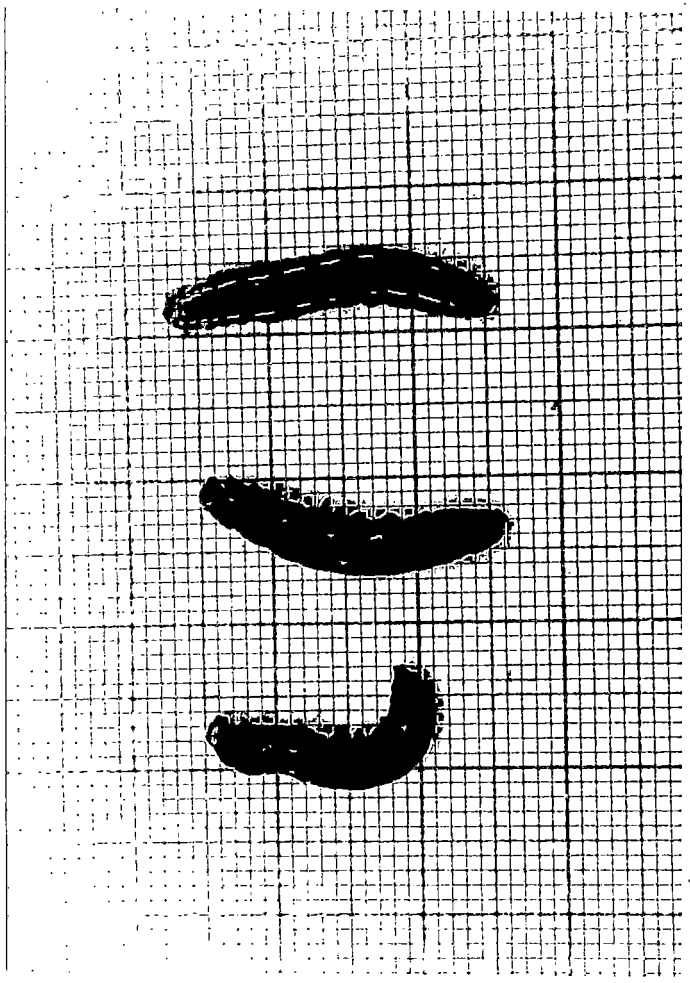
| Treatments | Second instar larvae when fed on treated diet | Fifth instar larvae when fed on treated diet | Fifth instar larvae when applied topically |
|---|---|---|---|
| Diflubenzuron | | | |
| $2x10^{-1}$% | 42.0 (6.6) | 29.9 (5.6) | 27.2 (5.3) |
| $2x10^{-2}$% | 68.2 (8.3) | 28.9 (5.5) | 27.4 (5.3) |
| $2x10^{-3}$% | 48.4 (7.0) | 22.5 (4.8) | 14.9 (4.0) |
| $2x10^{-4}$% | 51.1 (7.2) | 22.5 (4.8) | 30.0 (5.7) |
| $2x10^{-5}$% | 52.6 (7.3) | 23.7 (5.0) | 11.0 (3.5) |
| Chlorfluazuron | | | |
| $2x10^{-2}$% | 64.4 (8.1) | 46.9 (6.9) | 38.9 (6.3) |
| $2x10^{-3}$% | 65.3 (8.1) | 44.3 (6.7) | 35.0 (6.0) |
| $2x10^{-4}$% | 43.1 (6.6) | 35.6 (6.1) | 38.8 (6.3) |
| $2x10^{-5}$% | 35.1 (6.0) | 32.2 (5.8) | 44.1 (6.7) |
| PH 70-23 | | | |
| $2x10^{-1}$% | 58.1 (7.7) | 29.4 (5.5) | 29.4 (5.5) |
| $2x10^{-2}$% | 83.7 (9.2) | 43.7 (6.7) | 43.7 (6.7) |
| $2x10^{-3}$% | 52.2 (7.3) | 25.0 (5.1) | 25.0 (5.1) |
| $2x10^{-4}$% | 41.1 (6.5) | 20.7 (4.7) | 20.7 (4.7) |
| $2x10^{-5}$% | 26.0 (5.2) | 18.9 (4.5) | 18.9 (4.5) |
| BASF LAB 153 959 I | | | |
| $2x10^{-1}$% | 55.8 (7.5) | 49.8 (7.1) | 28.9 (5.5) |
| $2x10^{-2}$% | 63.7 (8.0) | 57.1 (7.6) | 28.5 (5.4) |
| $2x10^{-3}$% | 45.0 (6.8) | 37.4 (6.2) | 27.3 (5.3) |
| $2x10^{-4}$% | 18.9 (4.5) | 22.4 (4.8) | 21.1 (4.7) |
| $2x10^{-5}$% | 10.3 (3.4) | 20.8 (4.7) | 19.4 (4.5) |
| C.D. | | (1.36) | |

(Values of $\sqrt{x + 1}$ transformation are given in brackets)

Fig. 1. Larvae of Spodoptera mauritia died without moulting

Right: Normal larva

Fig. 2. Partially moulted larvae of Spodoptera mauritia with swollen head



$2x10^{-1}$ to $2x10^{-3}$% produced complete larval mortality. PH 70-23 $2x10^{-3}$% (97.3%) and $2x10^{-5}$% (93.7%) and diflubenzuron $2x10^{-4}$% (93.2%) were on par with the above treatments. Diflubenzuron $2x10^{-4}$% was also on par with BASF LAB 153 959 I $2x10^{-5}$% (72.1%) and diflubenzuron $2x10^{-5}$% (71.8%). The latter two treatments were on par with BASF LAB 153 959 I $2x10^{-4}$% (45.5%).

Topical application with all the test doses of chlorfluazuron, diflubenzuron $2x10^{-1}$ and $2x10^{-2}$%, PH 70-23 $2x10^{-1}$, $2x10^{-2}$ and $2x10^{-4}$% and BASF LAB 153 959 I $2x10^{-1}$ resulted in total mortality of the larvae. BASF LAB 153 959 I $2x10^{-2}$% (98.8%), PH 70-23 $2x10^{-3}$% (97.3%) and $2x10^{-5}$% (93.9%) were on par with the above treatments. PH 70-23 $2x10^{-5}$% was on par with diflubenzuron $2x10^{-3}$% (72.5%). Diflubenzuran $2x10^{-3}$% and BASF LAB 153 959 I $2x10^{-3}$% (52.4%), $2x10^{-5}$% (51.0%) and $2x10^{-4}$% (48.7%) were on par. Diflubenzuron $2x10^{-4}$% produced the least mortality (6.4%) and found inferior to all other treatments.

In general, feeding was superior to topical application. But, feeding as well as topical application was found equally effective in the case of PH 70-23 $2x10^{-3}$ and $2x10^{-5}$%, BASF LAB 153 959 I $2x10^{-2}$, $2x10^{-4}$ and $2x10^{-5}$% doses that produced total mortality.

A perusal of the speed indices (Table 3) would show that medium doses produced rapid mortality than higher and lower doses.

Second instar larvae when fed with various doses of the chitin synthesis inhibitors, PH 70-23 $2x10^{-2}$% (83.7), diflubenzuron $2x10^{-2}$% (68.2), chlorfluazuron $2x10^{-3}$% (65.3) and BASF LAB 153 959 I $2x10^{-2}$% (63.7) were on par. PH 70-23 $2x10^{-1}$% (58.1), BASF LAB 153 959 I $2x10^{-1}$% (55.8), diflubenzuron $2x10^{-5}$% (52.6), PH 70-23 $2x10^{-3}$% (52.2), diflubenzuron $2x10^{-4}$% (51.1) and $2x10^{-3}$% (48.4) were also on par with the above treatments except PH 70-23 $2x10^{-2}$%. BASF LAB 153 959 I $2x10^{-3}$% (45.0) was on par with all the above treatments except PH 70-23 $2x10^{-2}$% and diflubenzuron $2x10^{-2}$%. Speed indices of other treatments ranged from 10.3 to 43.1.

Fifth instar larvae when fed on treated diet, the quickest mortality was produced by BASF LAB 153 959 I $2x10^{-2}$% (57.1), $2x10^{-1}$% (49.8), chlorfluazuron $2x10^{-2}$% (46.9), $2x10^{-3}$% (44.3) and PH 70-23 $2x10^{-2}$% (46.7). BASF LAB 153 959 I $2x10^{-3}$% (37.4), chlorfluazuron $2x10^{-4}$% (35.6) and $2x10^{-5}$% (32.2) were on par with the above treatments except BASF LAB 153 959 I $2x10^{-2}$%. Diflubenzuron $2x10^{-1}$% (29.9), PH 70-23 $2x10^{-1}$% (29.4) and diflubenzuron $2x10^{-2}$% (28.9) were on par with all the above treatments except BASF LAB 153 959 I $2x10^{-2}$% and $2x10^{-1}$%. Speed indices in other treatments ranged from 18.9 to 25.0.

Fifth instar larvae, when applied topically, chlorfluazuron $2x10^{-5}$% (44.1), PH 70-23 $2x10^{-2}$% (43.7), diflubenzuron $2x10^{-2}$% (38.9), $2x10^{-4}$% (38.8), chlorfluazuron $2x10^{-3}$% (35.0), diflubenzuron $2x10^{-4}$% (32.0), PH 70-23 $2x10^{-1}$% (29.4), BASF LAB 153 959 I $2x10^{-1}$% (28.9) and $2x10^{-2}$% (28.5) were on par. The above treatments except chlorfluazuron $2x10^{-5}$% and PH 70-23 $2x10^{-2}$% were on par with diflubenzuron $2x10^{-2}$% (27.4), BASF LAB 153 959 I $2x10^{-3}$% (27.3), diflubenzuron $2x10^{-1}$% (27.2) and PH 70-23 $2x10^{-3}$% (25.0). Other treatments were still slower with speed indices ranging only from 11.0 to 21.1.

Speed indices of diflubenzuron $2x10^{-5}$%, BASF LAB 153 959 I $2x10^{-1}$ and $2x10^{-2}$% were significantly higher when fifth instar larvae were fed on a treated diet. In the case of other treatments there was no significant difference between the two modes of treatment - feeding and topical application.

(c) Comparison of contact and stomach actions of chitin synthesis inhibitors against Spodoptera mauritia

Results are given in Table 4. Survival period of larvae fed on chlorfluazuron was minimum (2.8 days) followed by PH 70-23 (3.1 days). On feeding, diflubenzuron and BASF LAB 153 959 I recorded the highest survival period of

Table 4. Comparison of contact and stomach actions of chitin synthesis inhibitors against *Spodoptera mauritia*

| Treatments | Mean survival period (days) | |
|---|---|---|
| | Stomach action | Contact action |
| Diflubenzuron $2x10^{-1}$% | 4.3 | 5.8 |
| Chlorfluazuron $2x10^{-2}$% | 2.8 | 3.5 |
| PH 70-23 $2x10^{-1}$% | 3.1 | 4.7 |
| BASF LAB 153 959 I $2x10^{-1}$% | 4.3 | 3.5 |
| C.D. | NS | NS |

NS: Not significant

4.3 days. BASF LAB 153 959 I and chlorfluazuron recorded the minimum survival period of 3.5 days when topically applied. PH 70-23 recorded 4.7 days and diflubenzuron 5.8 days. Survival periods of larvae treated with diflubenzuron, chlorfluazuron and PH 70-23 were less when fed, compared to that of topical application. But BASF LAB 153 959 I recorded a high survival period when fed. Effects of contact and stomach actions of all the compounds on the survival period of fifth instar larvae of S. mauritia were statistically on par.

(d) Effect of chitin synthesis inhibitors on the larval-pupal transformation of Spodoptera mauritia

The present study has shown that Spodoptera mauritia is highly susceptible to chitin synthesis inhibitors during larval-pupal transformation (Table 5). Treatment of last instar larvae resulted in various morphological abnormalities and heavy mortality. A few larvae died at the last larval stadium itself, but majority succumbed to death after entering inside soil for pupation. Higher doses resulted in proportionate higher early mortality as pre-pupae or as larval-pupal intermediates (Fig. 3), as the dose decreased, mortality occurred in a more advanced stage of the test insect like pupae or adults which mostly emerged as malformed ones. The dose-effect relationship was positive and linear.

Table 5. Effect of chitin synthesis inhibitors on larval-pupal transformation of Spodoptera mauritia (SA: Stomach action, CA: Contact action)

| Treatments | Larval mortality | | Pre-pupal mortality | | Larval-pupal mosaics | | Pupal mortality | | Abnormal adults | | Normal adults | | Score for abnormality (•) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SA | CA | SA | CA | SA | CA | SA | CA | SA | CA | SA | CA | SA | CA |
| Diflubenzuron | | | | | | | | | | | | | | |
| $2x10^{-1}$% | 6.7(15.0) | 0.0 (0.0) | 93.3(75.0) | 83.3(65.8) | 0.0 (0.0) | 14.0(21.9) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 1.1 (6.1) | 0.0 (0.0) | 0.0 (0.0) | 0.0(1.0) | 1.6(1.6) |
| $2x10^{-2}$% | 1.1 (6.1) | 0.0 (0.0) | 98.9(83.8) | 25.0(30.0) | 0.0 (0.0) | 45.7(42.5) | 0.0 (0.0) | 14.5(22.4) | 0.0 (0.0) | 1.1 (6.1) | 0.0 (0.0) | 1.1 (6.1) | 0.0(1.0) | 1.2(1.5) |
| $2x10^{-3}$% | 9.3(17.7) | 32.8(34.9) | 53.5(47.0) | 36.1(36.9) | 16.4(23.8) | 2.4 (8.9) | 4.5(12.3) | 6.7(15.0) | 2.4 (8.9) | 4.5(12.3) | 1.1 (6.1) | 2.4 (8.9) | 1.0(1.4) | 1.6(1.6) |
| $2x10^{-4}$% | 1.1 (6.1) | 11.6(19.9) | 36.1(36.9) | 29.2(32.7) | 29.7(33.0) | 11.6(19.9) | 1.1 (6.1) | 2.4 (8.9) | 15.7(23.4) | 4.5(12.3) | 6.7(15.0) | 16.7(24.1) | 2.2(1.8) | 2.3(1.8) |
| $2x10^{-5}$% | 4.5(12.3) | 26.2(30.8) | 22.2(28.1) | 36.6(37.2) | 40.0(39.2) | 0.0 (0.0) | 8.8(17.2) | 4.5(12.3) | 16.4(23.8) | 1.1 (6.1) | 0.0 (0.0) | 26.2(30.8) | 3.0(2.0) | 0.8(1.3) |
| Chlorfluazuron | | | | | | | | | | | | | | |
| $2x10^{-2}$% | 25.4(30.3) | 56.8(48.9) | 74.6(60.0) | 2.4 (8.9) | 0.0 (0.0) | 34.8(36.1) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0(1.0) | 0.0(1.0) |
| $2x10^{-3}$% | 1.1 (6.1) | 46.0(42.7) | 98.9(83.8) | 31.2(33.9) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 1.1 (6.1) | 0.0 (0.0) | 16.4(23.8) | 0.0(1.0) | 0.3(1.1) |
| $2x10^{-4}$% | 0.0 (0.0) | 14.2(22.1) | 25.0(30.0) | 56.8(48.9) | 60.4(51.1) | 0.0 (0.0) | 1.1 (6.1) | 1.1 (6.1) | 1.1 (6.1) | 4.5(12.3) | 0.0 (0.0) | 9.3(17.7) | 1.2(1.5) | 0.6(1.3) |
| $2x10^{-5}$% | 0.0 (0.0) | 39.9(39.1) | 8.5(16.9) | 11.6(19.9) | 84.7(66.9) | 0.0 (0.0) | 0.0 (0.0) | 11.6(19.9) | 1.1 (6.1) | 0.0 (0.0) | 0.0 (0.0) | 26.2(30.8) | 1.2(1.5) | 0.0(1.0) |
| $2x10^{-6}$% | 0.0 (0.0) | 0.0 (0.0) | 10.0(18.4) | 1.1 (6.1) | 41.3(40.0) | 0.0 (0.0) | 1.1 (6.1) | 0.0 (0.0) | 36.5(37.1) | 9.1(17.6) | 2.4 (8.9) | 88.8(70.4) | 4.0(2.2) | 1.2(1.5) |
| FF 70-23 | | | | | | | | | | | | | | |
| $2x10^{-1}$% | 6.7(15.0) | 13.5(21.6) | 93.3(75.0) | 72.6(58.4) | 0.0 (0.0) | 9.7(18.1) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0(1.0) | 0.0(1.0) |
| $2x10^{-2}$% | 4.5(12.3) | 26.5(31.0) | 95.5(77.7) | 21.7(27.8) | 0.0 (0.0) | 31.2(33.9) | 0.0 (0.0) | 1.1 (6.1) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0(1.0) | 0.0(1.0) |
| $2x10^{-3}$% | 0.0 (0.0) | 0.0 (0.0) | 35.6(36.6) | 3.7(11.1) | 64.4(53.3) | 25.0(30.0) | 0.0 (0.0) | 3.7(11.1) | 0.0 (0.0) | 8.8(17.2) | 0.0 (0.0) | 36.0(36.8) | 0.0(1.0) | 2.7(1.9) |
| $2x10^{-4}$% | 0.0 (0.0) | 1.1 (6.1) | 2.4 (8.9) | 4.5(12.3) | 26.2(30.8) | 2.4 (8.9) | 1.1 (6.1) | 26.9(31.2) | 46.6(43.1) | 8.8(17.2) | 9.3(17.7) | 39.4(38.8) | 3.1(2.0) | 2.2(1.8) |
| $2x10^{-5}$% | 0.0 (0.0) | 0.0 (0.0) | 4.5(12.3) | 2.4 (8.9) | 16.4(23.8) | 33.3(35.2) | 0.0 (0.0) | 1.1 (6.1) | 50.1(45.1) | 0.0 (0.0) | 23.2(28.8) | 56.8(48.9) | 2.5(1.9) | 0.0(1.0) |
| BASF LAB 153 959 I | | | | | | | | | | | | | | |
| $2x10^{-1}$% | 0.0 (0.0) | 6.7(15.0) | 100.0(90.0) | 46.5(43.0) | 0.0 (0.0) | 43.2(41.1) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0(1.0) | 0.0(1.0) |
| $2x10^{-2}$% | 0.0 (0.0) | 4.5(12.3) | 100.0(90.0) | 9.3(17.7) | 0.0 (0.0) | 80.7(63.9) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0(1.0) | 0.0(1.0) |
| $2x10^{-3}$% | 0.0 (0.0) | 2.4 (8.9) | 100.0(90.0) | 6.7(15.0) | 0.0 (0.0) | 22.7(28.4) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 41.7(40.2) | 0.0 (0.0) | 16.6(24.0) | 0.0(1.0) | 2.3(1.8) |
| $2x10^{-4}$% | 0.0 (0.0) | 10.0(18.4) | 97.6(81.1) | 1.1 (6.1) | 2.4 (8.9) | 1.1 (6.1) | 0.0 (0.0) | 1.1 (6.1) | 0.0 (0.0) | 4.5(12.3) | 0.0 (0.0) | 73.5(59.0) | 0.0(1.0) | 1.2(1.5) |
| $2x10^{-5}$% | 2.4 (8.9) | 0.0 (0.0) | 9.3(17.7) | 0.0 (0.0) | 70.0(56.8) | 16.4(23.8) | 4.5(12.3) | 1.1 (6.1) | 0.0 (0.0) | 0.0 (0.0) | 1.1 (6.1) | 80.7(63.9) | 0.0(1.0) | 0.0(1.0) |
| Control | 0.0 (0.0) | 4.5(12.3) | 0.0 (0.0) | 0.0 (0.0) | 6.7(15.0) | 6.7(15.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 93.3(75.0) | 85.6(66.1) | 0.0(1.0) | 0.0(1.0) |
| C.D. (0.05) | (14.04) | (16.95) | (24.07) | (24.89) | (18.67) | (22.80) | NS | (17.20) | (9.86) | (15.25) | (11.84) | (16.28) | (0.57) | NS |

Values of angular transformation are given in brackets

(•) Values of $\sqrt{x+1}$ transformation are given in brackets

NS: Not significant

Fig. 3. Larval-pupal intermediates of *Spodoptera mauritia*

When allowed to feed on foliage treated with various doses of the compounds, total mortality of last instar larvae at larval and pre-pupal stages was produced by diflubenzuron $2x10^{-1}$%, $2x10^{-2}$%, chlorfluazuron $2x10^{-2}$%, $2x10^{-3}$%, PH 70-23 $2x10^{-1}$%, $2x10^{-2}$%, BASF LAB 153 959 I $2x10^{-1}$%, $2x10^{-2}$% and $2x10^{-3}$%. In the case of PH 70-23 $2x10^{-3}$% and BASF LAB 153 959 I $2x10^{-4}$%, development ceased at larval-pupal intermediates. All adults emerged were abnormal from last instar larvae fed with diflubenzuron $2x10^{-5}$% (16.4%), chlorfluazuron $2x10^{-4}$% (1.1%) and $2x10^{-5}$% (1.1%). Mean score for abnormality ranged from 1 to 4, irrespective of strength of the doses. A few normal adults emerged from diflubenzuron $2x10^{-3}$% (1.1%), $2x10^{-4}$% (6.7%), chlorfluazuron $2x10^{-5}$% (2.4%), PH 70-23 $2x10^{-4}$% (9.3%), $2x10^{-5}$% (23.2%) and BASF LAB 153 959 I $2x10^{-5}$% (1.1%). Diflubenzuron $2x10^{-4}$%, PH 70-23 $2x10^{-4}$% and $2x10^{-5}$% were inferior to other treatments by allowing the emergence of more adults, still they were highly effective when compared to control.

Chitin synthesis inhibitors when topically treated, complete mortality occurred after the pre-pupal stage only. Last instar larvae when topically treated with chlorfluazuron $2x10^{-2}$%, PH 70-23 $2x10^{-1}$%, BASF LAB 153 959 I $2x10^{-1}$% and $2x10^{-2}$%, there was no successful transformation of

Fig. 4. Deformed adults of Spodoptera mauritia

Fig. 5. Adults of Spodoptera mauritia partially emerged from pupae

pre-pupa to pupa. In PH 70-23 $2x10^{-2}$%, a small percentage (1.1%) transformed to pupae, but died as such. In diflubenzuron ($2x10^{-1}$%), 1.6% successfully completed pupation, but the adults emerged from these pupae were all abnormal. Diflubenzuron $2x10^{-3}$% allowed the emergence of 2.4% normal adults, but was on par with the above treatments that completely inhibited the emergence of adults. Normal adults also emerged from treatments such as chlorfluazuron $2x10^{-4}$% (9.3%), $2x10^{-3}$% (16.4%), $2x10^{-5}$% (26.2), BASF LAB 153 959 I $2x10^{-3}$% (16.6%), diflubenzuron $2x10^{-4}$% (16.7%), $2x10^{-5}$% (26.2%), PH 70-23 $2x10^{-3}$% (36.0%), $2x10^{-4}$% (39.4%) and $2x10^{-5}$% (56.8%), but was inferior to those totally inhibited adult emergence, and significantly superior to control. Chlorfluazuron $2x10^{-6}$% (88.8%), BASF LAB 153 959 I $2x10^{-5}$% (80.7%) and $2x10^{-4}$% (73.5%) were on par with control. Mean scores for abnormality of the malformed insects ranged from 0.3 to 2.7.

(e) Effect of chitin synthesis inhibitors on the pupae of Spodoptera mauritia

Mortality of pupae and emergence of deformed adults were the major effects when pupae were treated with chitin synthesis inhibitors (Table 6). Abnormalities varied from crumbled wings to partial ecdysis of the pupae (Fig. 4 and 5).

Fig. 4. Deformed adults of Spodoptera mauritia

Fig. 5. Adults of Spodoptera mauritia partially emerged from pupae

Table 6. Effect of chitin synthesis inhibitors on the pupae of Spodoptera mauritia

| Treatments | Mortality of pupae | Abnormal adults | Normal adults | Mean score for abnormality(*) |
|---|---|---|---|---|
| Diflubenzuron | | | | |
| $2x10^{-1}$% | 52.2(46.3) | 32.2(34.6) | 14.9(22.7) | 2.8(1.9) |
| $2x10^{-2}$% | 39.9(39.1) | 31.1(33.9) | 28.6(32.3) | 2.2(1.8) |
| $2x10^{-3}$% | 23.5(29.0) | 35.8(36.7) | 40.0(39.5) | 2.9(2.0) |
| $2x10^{-4}$% | 18.5(25.5) | 26.5(30.1) | 51.9(46.1) | 2.0(1.7) |
| $2x10^{-5}$% | 9.5(18.0) | 13.9(21.9) | 72.0(58.0 | 2.1(1.8) |
| Chlorfluazuron | | | | |
| $2x10^{-1}$% | 30.4(33.4) | 67.2(55.1) | 0.9 (5.4) | 3.9(2.2) |
| $2x10^{-2}$% | 11.2(19.6) | 84.0(66.4) | 2.2 (8.5) | 4.0(2.2) |
| $2x10^{-3}$% | 24.3(29.5) | 57.9(50.0) | 10.5(18.9) | 3.6(2.1) |
| $2x10^{-4}$% | 4.5(12.3) | 34.9(36.2) | 58.4(49.8) | 2.5(1.9) |
| $2x10^{-5}$% | 0.9(10.5) | 29.7(33.0) | 67.8(55.4) | 1.8(1.7) |
| PH 70-23 | | | | |
| $2x10^{-1}$% | 10.2(18.7) | 58.6(49.9) | 25.9(30.6) | 3.5(2.1) |
| $2x10^{-2}$% | 11.6(19.9) | 56.5(48.7) | 27.4(31.5) | 2.4(1.9) |
| $2x10^{-3}$% | 4.7(12.5) | 50.1(45.5) | 41.8(40.3) | 2.5(1.9) |
| $2x10^{-4}$% | 23.2(28.8) | 43.2(41.1) | 31.6(34.2) | 2.6(1.9) |
| $2x10^{-5}$% | 11.4(19.8) | 20.5(26.9) | 60.1(50.8) | 2.2(1.8) |
| BASF LAB 153 959 I | | | | |
| $2x10^{-1}$% | 46.5(43.0) | 32.2(34.9) | 14.0(21.9) | 2.6(1.9) |
| $2x10^{-2}$% | 36.1(36.9) | 21.0(27.3) | 25.0(30.0) | 1.5(1.6) |
| $2x10^{-3}$% | 42.0(40.4) | 11.3(19.6) | 22.2(28.1) | 0.9(1.4) |
| $2x10^{-4}$% | 16.8(24.2) | 1.5 (7.1) | 77.8(61.9) | 0.6(1.3) |
| $2x10^{-5}$% | 9.3(17.7) | 13.0(21.1) | 74.6(59.7) | 1.6(1.6) |
| Control | 10.0(18.4) | 3.0(10.0) | 76.7(80.3) | 12.9(3.7) |
| C.D. (0.05) | (20.38) | (23.44) | (23.55) | NS |

Values of angular transformation are given in brackets

(*) Values of $\sqrt{x + 1}$ transformation are given in brackets

NS : Not significant


9

The symptoms produced by different compounds were mostly common.

Among the various doses of the different chitin synthesis inhibitors, diflubenzuron $2x10^{-1}$% produced the highest pupal mortality (52.2%). BASF LAB 153 959 I $2x10^{-1}$% (46.5%), $2x10^{-3}$% (42.0%), $2x10^{-2}$% (36.1%), diflubenzuron $2x10^{-2}$% (39.9%), $2x10^{-3}$% (23.5%), chlorfluazuron $2x10^{-1}$% (30.4%), $2x10^{-3}$% (24.3%) and PH 70-23 $2x10^{-4}$% (23.2%) were on par with diflubenzuron $2x10^{-1}$%. The other treatments produced a pupal mortality ranging from 0.9 to 18.5% and were on par with control.

Chlorfluazuron $2x10^{-2}$% produced the maximum percentage (84.0) of abnormal adults. Chlorfluazuron $2x10^{-1}$% (67.2%), $2x10^{-3}$% (57.9%), PH 70-23 $2x10^{-1}$% (58.6%), $2x10^{-2}$% (56.5%) and $2x10^{-3}$% (50.1%) were on par with chlorfluazuron $2x10^{-2}$%. The above treatments, except chlorfluazuron $2x10^{-2}$%, were on par with PH 70-23 $2x10^{-4}$% (43.2%), diflubenzuron $2x10^{-3}$% (35.8%), $2x10^{-1}$% (32.2%), $2x10^{-5}$% (29.7%), chlorfluazuron $2x10^{-4}$% (34.9%), $2x10^{-5}$% (29.7%) and BASF LAB 153 959 I $2x10^{-1}$% (32.8%). Excepting chlorfluazuron $2x10^{-2}$% and $2x10^{-1}$%, diflubenzuron $2x10^{-4}$% (26.5%), BASF LAB 153 959 I $2x10^{-2}$% (21.0%) and PH 70-23 $2x10^{-5}$% (20.5%) were also on par with them. Diflubenzuron $2x10^{-5}$% (13.9%), BASF LAB 153 959 I $2x10^{-5}$% (13.0%),

$2x10^{-3}$% (11.6%) and $2x10^{-4}$% (1.5%) were statistically equal to control.

Chlorfluazuron $2x10^{-1}$% was the most toxic treatment to pupae which allowed the emergence of only 0.9% of normal adults. Chlorfluazuron $2x10^{-2}$% (2.2%), $2x10^{-3}$% (10.5%), BASF LAB 153 959 I $2x10^{-1}$% (14.0%), $2x10^{-3}$% (22.2%) and diflubenzuron $2x10^{-1}$% (14.9%), were on par with chlorfluazuron $2x10^{-1}$%. Above treatments except chlorfluazuron $2x10^{-1}$% were on par with BASF LAB 153 959 I $2x10^{-2}$% (25.0%), PH 70-23 $2x10^{-1}$% (25.9%) and $2x10^{-2}$% (27.4%). Diflubenzuron $2x10^{-2}$% (28.6%), $2x10^{-3}$% (40.4%), PH 70-23 $2x10^{-4}$% (31.6%) and $2x10^{-3}$% (41.8%) were on par with the above treatments except chlorfluazuron $2x10^{-1}$% and $2x10^{-2}$%. Emergence of normal adults was comparatively high (51.9 to 77.8%) in the case of other treatments.

Score for abnormality of malformed adults was not significantly different among the treatments.

(f) Sterilant action of chitin synthesis inhibitors on Spodoptera mauritia

Moths of S. mauritia when treated with chitin synthesis inhibitors, there was significant effect on fecundity, hatchability of eggs and longevity of treated male moths. Though the treated and untreated female moths which mated

with treated males, laid less number of eggs with low hatchability, their longevity was not reduced (Table 7).

Treated males when allowed to mate with untreated virgin females, fecundity, hatchability of eggs and longevity of male moths were reduced. Female moths mated with males treated with diflubenzuron $2x10^{-4}$% laid the least number of eggs (123.0), followed by PH 70-23 $2x10^{-3}$% (206.5), diflubenzuron $2x10^{-3}$% (234.5) and chlorfluazuron $2x10^{-3}$% (287.0). Other treatments were on par with control. Hatchability of eggs was significantly less and minimum when males were treated with chlorfluazuron $2x10^{-4}$% (2.6%) followed by diflubenzuron $2x10^{-4}$% (11.1%), PH 70-23 $2x10^{-2}$% (15.4%) and $2x10^{-4}$% (30.3%). Longevity of treated males was significantly less in the case of chlorfluazuron $2x10^{-5}$% (5.3 days), followed by BASF LAB 153 959 I $2x10^{-4}$%, PH 70-23 $2x10^{-3}$%, chlorfluazuron $2x10^{-4}$% (5.7 days each), chlorfluazuron $2x10^{-3}$%, PH 70-23 $2x10^{-2}$% and $2x10^{-4}$% (6 days each).

When females were treated, diflubenzuron $2x10^{-3}$%, chlorfluazuron $2x10^{-3}$% and $2x10^{-4}$% and PH 70-23 $2x10^{-2}$% completely inhibited egg hatching. Chlorfluazuron $2x10^{-5}$% (7.9%), diflubenzuron $2x10^{-2}$% (9.1%), $2x10^{-4}$% (11.8%) and PH 70-23 $2x10^{-4}$% (25.0%) produced a few hatchable eggs, but were statistically on par with the above treatments. Egg

Table 7. Sterilant action of chitin synthesis inhibitors on Spodoptera mauritia

| Treatments | (a) on males | | | (b) on females | | | (c) on males and females | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No.of eggs per female | % hatching | longevity of the treated moth | No.of eggs per female | % hatching | longevity of the treated moth | No.of eggs per female | % hatching | longevity of the treated moths | |
| | | | | | | | | | Male | Female |
| | (*) | (**) | | (*) | (**) | | (*) | (**) | | |
| Diflubenzuron | | | | | | | | | | |
| $2x10^{-2}$% | 731.4(27.1) | 75.0(60.0) | 7.0 | 385.8(19.7) | 9.1(17.6) | 9.0 | 258.9(16.1) | 0.0 (0.0) | 7.0 | 5.3 |
| $2x10^{-3}$% | 234.5(15.3) | 49.9(41.5) | 7.7 | 763.5(27.7) | 0.0 (0.0) | 6.0 | 622.0(25.0) | 18.1(25.2) | 6.3 | 8.7 |
| $2x10^{-4}$% | 123.0(11.1) | 11.1(19.5) | 6.7 | 782.9(28.0) | 11.8(20.1) | 5.7 | 611.9(24.8) | 11.3(19.6) | 11.3 | 9.0 |
| Chlorfluazuron | | | | | | | | | | |
| $2x10^{-3}$% | 287.0(17.0) | 56.1(48.4) | 6.0 | 283.5(16.9) | 0.0 (0.0) | 7.7 | 649.8(25.5) | 0.0 (0.0) | 6.3 | 7.0 |
| $2x10^{-4}$% | 704.6(26.6) | 2.6 (9.2) | 5.7 | 789.2(28.1) | 0.0 (0.0) | 7.7 | 476.1(21.8) | 18.8(25.7) | 7.3 | 7.0 |
| $2x10^{-5}$% | 1056.4(32.5) | 96.6(79.4) | 5.3 | 468.1(21.7) | 7.9(16.3) | 7.3 | 391.5(19.8) | 25.8(30.5) | 6.0 | 6.7 |
| PH 70-23 | | | | | | | | | | |
| $2x10^{-2}$% | 395.4(19.9) | 15.4(23.1) | 6.0 | 419.6(20.5) | 0.0 (0.0) | 9.0 | 1029.6(32.1) | 3.5(10.8) | 6.0 | 7.3 |
| $2x10^{-3}$% | 206.5(14.4) | 59.3(50.4) | 5.7 | 929.6(30.5) | 58.1(49.6) | 8.0 | 799.9(28.3) | 19.9(26.5) | 5.0 | 5.3 |
| $2x10^{-4}$% | 345.6(18.6) | 30.3(33.4) | 6.0 | 685.9(26.2) | 25.0(30.0) | 7.7 | 764.4(31.1) | 12.6(20.7) | 7.3 | 8.0 |
| BASF LAB 153 959 I | | | | | | | | | | |
| $2x10^{-2}$% | 875.8(29.6) | 98.3(82.5) | 9.0 | 759.5(27.6) | 88.6(70.3) | 7.3 | 246.1(15.7) | 9.9(18.4) | 9.0 | 8.3 |
| $2x10^{-3}$% | 808.6(28.5) | 99.7(86.7) | 7.0 | 375.4(19.4) | 61.1(51.4) | 6.7 | 187.5(13.7) | 21.0(27.3) | 5.7 | 6.7 |
| $2x10^{-4}$% | 846.1(29.1) | 85.1(67.3) | 5.7 | 836.7(28.9) | 94.7(76.6) | 6.3 | 51.8 (7.3) | 0.0 (0.0) | 6.7 | 9.0 |
| Control | 1080.8(32.9) | 99.9(88.1) | 9.0 | 1080.8(32.9) | 99.9(88.1) | 8.3 | 1080.8(32.9) | 99.9(88.1) | 9.0 | 8.3 |
| C.D. (0.05) | (13.42) | (51.22) | 2.55 | NS | (44.58) | NS | (16.90) | (54.06) | 3.4 | NS |

(*) Values of $\sqrt{x+1}$ transformation are given in brackets

(**) Values of angular transformation are given in brackets

NS: Not significant

hatchability percentages were 58.1 to 94.7 in other treatments and were on par with control.

Both sexes when treated, longevity of males treated with PH 70-23 $2x10^{-3}$% (5 days) alone was reduced significantly. Longevity of males in other treatments ranged from 5.7 to 11.3 days and were on par with control. Longevity of females ranged from 5.3 to 9 days and were on par with control. Fecundity was significantly less in BASF LAB 153 959 I $2x10^{-4}$% (51.8 eggs), $2x10^{-3}$% (187.5 eggs) and $2x10^{-2}$% (246.1 eggs). Other treatments ranked on par with control. Inhibition of hatching was significant in all treatments. Diflubenzuron $2x10^{-2}$%, chlorfluazuron $2x10^{-3}$% and BASF LAB 153 959 I $2x10^{-4}$% produced no viable eggs. In other treatments egg hatchability ranged from 11.3 to 25.8%.

(g) Antifeedant action of chitin synthesis inhibitors on the fifth instar larvae of Spodoptera mauritia

Chitin synthesis inhibitors exhibited mild to moderate feeding inhibition (Table 8). Chlorfluazuron $5x10^{-3}$% offered highest protection of treated leaf over control (56.0%), followed by chlorfluazuron $2x10^{-2}$% (50.2%), $2.5x10^{-3}$% (45.9%), diflubenzuron $1.25x10^{-2}$% (45.9%), chlorfluazuron $1x10^{-2}$% (42.0%), diflubenzuron $5x10^{-2}$% (41.0%) and $2.5x10^{-2}$% (40.0%). The above treatments were on par. Other treatments gave only a marginal protection of 8.0 to 33.9%.

Table 8. Antifeedant action of chitin synthesis inhibitors against fifth instar larvae of Spodoptera mauritia

| Treatments | Wt.of leaf protected over control | % increase in wt. of larvae |
|---|---|---|
| Diflubenzuron | | |
| $2x10^{-1}$% | 31.2 | 9.1 |
| $1x10^{-1}$% | 15.3 | 9.5 |
| $5x10^{-2}$% | 41.0 | 6.6 |
| $2.5x10^{-2}$% | 40.0 | 4.2 |
| $1.25x10^{-2}$% | 45.9 | 3.9 |
| Chlorfluazuron | | |
| $2x10^{-2}$% | 50.2 | 10.0 |
| $1x10^{-2}$% | 42.0 | 9.0 |
| $5x10^{-3}$% | 56.0 | 5.7 |
| $2.5x10^{-3}$% | 45.9 | 5.3 |
| $1.25x10^{-3}$% | 32.8 | 7.5 |
| PH 70-23 | | |
| $2x10^{-1}$% | 17.2 | 21.7 |
| $1x10^{-1}$% | 10.3 | 20.3 |
| $5x10^{-2}$% | 17.4 | 22.8 |
| $2.5x10^{-2}$% | 11.1 | 19.3 |
| $1.25x10^{-2}$% | 8.0 | 18.5 |
| BASF LAB 153 959 I | | |
| $2x10^{-1}$% | 33.3 | 8.2 |
| $1x10^{-1}$% | 18.0 | 11.5 |
| $5x10^{-2}$% | 34.0 | 15.8 |
| $2.5x10^{-2}$% | 33.8 | 13.0 |
| $1.25x10^{-2}$% | 16.4 | 12.6 |
| Control | | 20.3 |
| C.D. (0.05) | 16.16 | 9.63 |

Increase in weight of larvae feeding on treated grass was low and was significantly different from control in the case of diflubenzuron $1.25 \times 10^{-2}$% (3.9%), followed by diflubenzuron $2.5 \times 10^{-2}$% (4.2%), chlorfluazuron $2.5 \times 10^{-3}$% (5.3%), $5 \times 10^{-3}$% (5.7%), diflubenzuron $5 \times 10^{-2}$% (6.6%), chlorfluazuron $1.25 \times 10^{-3}$% (7.5%), BASF LAB 153 959 I $2 \times 10^{-1}$% (8.2%), chlorfluazuron $1 \times 10^{-2}$% (9.0%), diflubenzuron $2 \times 10^{-1}$% (9.1%), $1 \times 10^{-1}$% (9.5%) and chlorfluazuron $2 \times 10^{-2}$% (10.0%). In other treatments it ranged from 11.5 to 22.8%.

(h) Effect of residues of chitin synthesis inhibitors on rice plants against fourth instar larvae of Spodoptera amuritia

Results relating to the study are given in Table 9. Residual effect of chitin synthesis inhibitors persisted on rice plants for more than a month. Effect of weathering on residues was significant. It was significant at different intervals of observation also. All the four compounds were on par in their effect at different intervals of observation on weathered and unweathered residues. Residues of all compounds caused heavy mortalities of 86.7 to 100% up to the 22nd day. Unweathered residues were equally effective till the last observation on the 36th day. But those exposed to sunlight and rain were less effective and produced a mortality of only 25 to 33.5% on the 36th day. Effect of

Table 9. Residual effect of chitin synthesis inhibitors on rice plants against fourth instar larvae of Spodoptera mauritia

| Treatments | Effect of unweathered residues | | Effect of residues exposed to sun and rain | |
|---|---|---|---|---|
| | Mortality | Speed index | Mortality | Speed index |
| | (**) | (*) | (**) | (*) |
| 12th day | | | | |
| Diflubenzuron | 100.0(90.0) | 56.8 (7.6) | 100.0(90.0) | 95.0 (9.8) |
| Chlorfluazuron | 100.0(90.0) | 107.2(10.4) | 100.0(90.0) | 40.0 (6.4) |
| PH 70-23 | 100.0(90.0) | 97.0 (9.9) | 100.0(90.0) | 41.3 (6.5) |
| BASF LAB 153 959 I | 100.0(90.0) | 83.6 (9.2) | 100.0(90.0) | 52.3 (7.3) |
| 22nd day | | | | |
| Diflubenzuron | 100.0(90.0) | 35.0 (6.0) | 86.7(72.3) | 48.0 (7.0) |
| Chlorfluazuron | 100.0(90.0) | 32.6 (5.8) | 100.0(90.0) | 25.0 (5.1) |
| PH 70-23 | 100.0(90.0) | 38.7 (6.3) | 86.7(72.3) | 25.0 (5.1) |
| BASF LAB 153 959 I | 100.0(90.0) | 37.4 (6.2) | 91.7(80.0) | 31.5 (5.7) |
| 36th day | | | | |
| Diflubenzuron | 100.0(90.0) | 17.5 (4.3) | 25.0(25.0) | 4.3 (2.3) |
| Chlorfluazuron | 100.0(90.0) | 15.8 (4.1) | 25.0(25.0) | 11.3 (3.5) |
| PH 70-23 | 87.5(73.1) | 10.5 (3.4) | 33.3(30.0) | 11.3 (3.5) |
| BASF LAB 153 959 I | 100.0(90.0) | 12.7 (3.7) | 25.0(25.0) | 5.3 (2.5) |
| C.D. (0.05) | (20.53) | (1.94) | (20.53) | (1.94) |

(*) Values of $\sqrt{x + 1}$ transformation are given in brackets

(**) Values of angular transformation are given in brackets

weathering on the persistence of chitin synthesis inhibitors was significant on 22nd and 36th days.

Effect of insecticide as well as weathering was statistically not significant on speed index. But the speed index greatly differed at the three intervals of observation. Observations on the 12th day was significantly superior to that on the 22nd day which was superior to that on the 36th day.

## 2. Effects of chitin synthesis inhibitors on Corcyra cephalonica

### (a) Ovicidal action against Corcyra cephalonica

Results of ovicidal action against C. cephalonica are given in Table 10. One-day old eggs when treated in aqueous medium with various doses of chitin synthesis inhibitors, PH 70-23 $2x10^{-1}$% (38.9%) and chlorfluazuron $2x10^{-1}$% (26.5%) recorded the highest mortality which were on par. All other treatments produced mortalities below 20%. On four-day old eggs, in aqueous medium chlorfluazuron $2x10^{-1}$% produced the maximum mortality of 50.9%. All other treatments produced mortalities below 20%.

One-day old eggs when treated with methanolic solutions of chitin synthesis inhibitors, BASF LAB 153 959 I $2x10^{-1}$% (91.8%) produced the highest mortality. The effect of

Table 10. Ovicidal action of chitin synthesis inhibitors against Corcyra cephalonica

| Treatments | Aqueous medium | | Methanolic medium | | Mean | Insecticidal dose x age of eggs | | Insecticidal dose x medium of application | |
|---|---|---|---|---|---|---|---|---|---|
| | 1-day old eggs | 4-day old eggs | 1-day old eggs | 4-day old eggs | | 1-day old eggs | 4-day old eggs | Aqueous medium | Methanolic medium |
| Diflubenzuron | | | | | | | | | |
| $2x10^{-1}$% | 10.3(18.7) | 12.5(20.7) | 45.3(42.3) | 99.6(86.3) | (42.0) | (30.5) | (53.5) | (19.7) | (64.3) |
| $2x10^{-2}$% | 9.9(18.3) | 6.2(14.4) | 20.2(26.7) | 85.5(66.0) | (31.3) | (22.5) | (40.2) | (16.4) | (46.3) |
| $2x10^{-3}$% | 2.2 (8.6) | 7.7(16.1) | 13.9(21.9) | 78.5(62.5) | (27.3) | (15.2) | (39.3) | (12.3) | (42.2) |
| Chlorfluazuron | | | | | | | | | |
| $2x10^{-1}$% | 26.5(31.0) | 50.9(45.5) | 10.9(19.2) | 7.4(15.8) | (27.9) | (25.1) | (30.7) | (38.2) | (17.5) |
| $2x10^{-2}$% | 19.0(25.9) | 19.5(26.2) | 12.0(20.3) | 4.5(12.3) | (21.2) | (23.1) | (19.2) | (26.0) | (16.3) |
| $2x10^{-3}$% | 13.2(21.3) | 1.2 (6.1) | 0.6 (4.6) | 2.8 (9.6) | (10.4) | (13.0) | (7.8) | (13.7) | (7.1) |
| PH 70-23 | | | | | | | | | |
| $2x10^{-1}$% | 38.9(38.6) | 4.1(11.6) | 86.7(68.6) | 27.3(31.5) | (37.6) | (53.6) | (21.5) | (25.1) | (50.0) |
| $2x10^{-2}$% | 21.1(27.4) | 18.7(25.6) | 5.7(13.8) | 1.1 (6.0) | (18.2) | (20.6) | (15.8) | (26.5) | (9.9) |
| $2x10^{-3}$% | 6.7(14.9) | 10.3(18.7) | 4.6(12.4) | 4.5(12.3) | (14.6) | (13.7) | (15.5) | (18.8) | (12.3) |
| BASF LAB 153 959 I | | | | | | | | | |
| $2x10^{-1}$% | 0.3 (3.3) | 4.1(11.6) | 91.8(73.3) | 60.8(51.2) | (34.9) | (38.3) | (31.4) | (7.5) | (62.3) |
| $2x10^{-2}$% | 1.9 (7.8) | 18.7(25.6) | 13.0(21.1) | 5.8(13.9) | (17.1) | (14.5) | (19.7) | (16.7) | (17.5) |
| $2x10^{-3}$% | 0.5 (4.1) | 17.9(25.0) | 3.5(10.8) | 0.4 (3.7) | (10.9) | (7.4) | (14.4) | (14.6) | (7.2) |
| Mean | | | | | | (23.1) | (25.8) | (19.5) | (29.4) |

C.D. (0.05): 1. Insecticidal doses = (6.13)
2. Age of eggs x insecticidal doses = (8.66)
3. Mode of treatment x insecticidal doses = (8.66)
4. Age of eggs x mode of treatment x insecticidal dose = (8.66)

(Values of angular transformation are given in brackets)

PH 70-23 at a concentration of $2x10^{-1}$% was very close (86.7%) to the former. Diflubenzuron $2x10^{-1}$% (45.3%) was inferior to the above treatments, but was superior to other treatments which produced a maximum mortality of 20.2%. Against four-day old eggs, diflubenzuron $2x10^{-1}$% which caused a mortality of 99.6% was the most superior. Diflubenzuron $2x10^{-2}$% (83.5%) and $2x10^{-3}$% (78.5%) were on par. BASF LAB 153 959 I $2x10^{-1}$% (60.8%) and PH 70-23 $2x10^{-1}$% (27.3%) ranked next to the above treatments and were significant. Other treatments could produce only less than 10% mortality.

In aqueous medium, there was no significant difference in the ovicidal action of one-day old and four-day old eggs treated with diflubenzuron $2x10^{-1}$%, $2x10^{-2}$% and $2x10^{-3}$%. Chlorfluazuron $2x10^{-1}$%, BASF LAB 153 959 I $2x10^{-2}$% and $2x10^{-3}$% caused significantly higher mortality on four-day old eggs over one-day old eggs in aqueous medium. But chlorfluazuron $2x10^{-3}$% and PH 70-23 $2x10^{-1}$% produced higher mortality of one-day old eggs.

In methanolic medium, diflubenzuron $2x10^{-1}$%, $2x10^{-2}$% and $2x10^{-3}$% produced significantly high mortality of four-day old eggs over one-day old eggs. Mortality of one-day old and four-day old eggs treated with chlorfluazuron $2x10^{-1}$%, $2x10^{-2}$% and $2x10^{-3}$%, BASF LAB 153 959 I $2x10^{-2}$% and $2x10^{-3}$%

and PH 70-23 $2x10^{-2}$% and $2x10^{-3}$% were on par. BASF LAB 153 959 I $2x10^{-1}$% and PH 70-23 $2x10^{-1}$% produced higher mortality of one-day old eggs in methanolic medium.

Mortality of one-day old eggs treated with diflubenzuron $2x10^{-2}$%, chlorfluazuron $2x10^{-2}$%, BASF LAB 153 959 I $2x10^{-3}$% and PH 70-23 $2x10^{-3}$% in different media were on par. In the case of chlorfluazuron $2x10^{-1}$% and $2x10^{-3}$% and PH 70-23 $2x10^{-2}$%, mortality percentages of one-day old eggs treated in aqueous medium were higher than those in the methanolic medium. Similarly, methanolic solutions produced high mortality in the case of diflubenzuron $2x10^{-1}$% and $2x10^{-2}$%, BASF LAB 153 959 I $2x10^{-1}$% and $2x10^{-2}$% and PH 70-23 $2x10^{-1}$%.

Four-day old eggs, when treated in different media, chlorfluazuron ($2x10^{-3}$%) and PH 70-23 ($2x10^{-3}$%) produced no significant difference. Chlorfluazuron $2x10^{-1}$% and $2x10^{-2}$%, BASF LAB 153 959 I $2x10^{-2}$% and $2x10^{-3}$% and PH 70-23 $2x10^{-2}$% produced higher mortality in aqueous medium than by the methanolic medium. In methanolic medium, diflubenzuron $2x10^{-1}$%, $2x10^{-2}$% and $2x10^{-3}$%, BASF LAB 153 959 I $2x10^{-1}$% and PH 70-23 $2x10^{-1}$% produced higher mortality compared to aqueous medium.

Fig. 6. Treated larvae of Corcyra cephalonica

(b) Effect of chitin synthesis inhibitors on different instars of larvae of Corcyra cephalonica

Larvae when treated with chitin synthesis inhibitors, no difference was observed in the symptoms produced by the different compounds. Typical symptoms like 'swollen head' produced by partial ecdysis of head capsule exposing the unsclerotised new head capsule and partial moulting of cuticle over the thorax and abdomen were observed. In some larvae, diarrhoea and bursting out of the alimentary canal were seen. Some larvae died without moulting. Such larvae slowly turned dark and died in a few days (Fig. 6). Results are given in Table 11.

Second instar larvae when fed on a treated diet for six days, diflubenzuron $2x10^{-1}$%, chlorfluazuron $2x10^{-2}$%, $2x10^{-3}$%, BASF LAB 153 959 I $2x10^{-1}$%, $2x10^{-2}$% and $2x10^{-3}$% produced total mortality. Chlorfluazuron $2x10^{-4}$% (97.4%) was also on par with the above treatments. Chlorfluazuron $2x10^{-4}$% was on par with $2x10^{-5}$% of the same compound (90.0%) and PH 70-23 $2x10^{-1}$% (87.3%). Latter two treatments were on par with diflubenzuron $2x10^{-3}$% (80.0%) and $2x10^{-2}$% (75.2%). PH 70-23 $2x10^{-2}$% (45.0%), $2x10^{-3}$% (65.8%) and $2x10^{-4}$% (28.8%) were on par. BASF LAB 153 959 I $2x10^{-4}$% (24.8%) and diflubenzuron $2x10^{-4}$% (2.6%) were significantly equal to control.

Table 11. Effect of chitin synthesis inhibitors on different instars of larvae of Corcyra cephalonica

| Treatments | 2nd instar | 4th instar | | | | 7th instar | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feeding for 6 days | Feeding for 2 days | | Feeding till death | | Topical application | | Feeding for 2 days | | Feeding till death | |
| | Mortality | Mortality | Speed index | Mortality | Speed index | Mortality | Speed index | Mortality | Speed index | Mortality | Speed index |
| Diflubenzuron | | | | | | | | | | | |
| $2x10^{-1}$% | 100.0(90.0) | 81.7(64.6) | 15.9(4.1) | 96.3(78.9) | 10.5(3.4) | 0.0 (0.0) | 0.0(1.0) | 41.5(40.1) | 6.9(2.8) | 67.8(55.4) | 8.2(3.0) |
| $2x10^{-2}$% | 75.2(60.0) | 43.5(41.3) | 24.7(5.1) | 40.2(39.3) | 5.6(2.6) | 16.8(24.2) | 49.8(7.1) | 24.7(29.8) | 7.1(2.9) | 50.0(45.0) | 20.5(4.6) |
| $2x10^{-3}$% | 80.0(63.4) | 95.6(77.8) | 12.9(3.7) | 58.6(49.9) | 4.8(2.4) | 43.3(41.1) | 6.5(2.7) | 5.3(13.3) | 20.3(4.6) | 24.8(29.9) | 7.5(2.9) |
| $2x10^{-4}$% | 2.6 (9.2) | 2.6 (9.2) | 1.7(1.7) | 20.4(26.8) | 3.9(2.2) | 11.3(19.6) | 1.8(1.7) | 17.0(24.4) | 28.1(5.4) | 27.6(31.7) | 9.0(3.1) |
| Chlorfluazuron | | | | | | | | | | | |
| $2x10^{-2}$% | 100.0(90.0) | 100.0(90.0) | 24.0(5.0) | 100.0(90.0) | 15.1(4.0) | 100.0(90.0) | 17.5(4.3) | 100.0(90.0) | 16.3(4.2) | 100.0(90.0) | 11.0(3.5) |
| $2x10^{-3}$% | 100.0(90.0) | 100.0(90.0) | 29.3(5.5) | 100.0(90.0) | 16.9(4.2) | 96.8(79.6) | 9.8(3.3) | 100.0(90.0) | 17.3(4.3) | 100.0(90.0) | 11.4(3.5) |
| $2x10^{-4}$% | 97.4(80.8) | 100.0(90.0) | 21.9(4.8) | 100.0(90.0) | 10.6(3.4) | 14.1(22.0) | 9.5(3.2) | 100.0(90.0) | 17.0(4.2) | 94.7(76.7) | 9.4(3.2) |
| $2x10^{-5}$% | 90.0(71.5) | 100.0(90.0) | 18.2(4.4) | 88.7(70.3) | 4.8(2.4) | 13.8(21.8) | 8.8(3.1) | 100.0(90.0) | 12.5(3.7) | 61.2(51.4) | 6.1(2.7) |
| PH 70-23 | | | | | | | | | | | |
| $2x10^{-1}$% | 87.3(69.1) | 32.3(34.6) | 13.1(3.8) | 100.0(90.0) | 18.9(4.5) | 53.5(47.0) | 9.5(3.2) | 39.8(39.1) | 24.9(5.1) | 73.2(58.8) | 11.6(3.5) |
| $2x10^{-2}$% | 45.0(42.1) | 19.1(25.9) | 11.4(3.5) | 89.9(71.4) | 10.3(3.4) | 30.7(33.7) | 9.5(3.2) | 56.3(48.6) | 10.9(3.5) | 75.2(60.1) | 7.6(2.9) |
| $2x10^{-3}$% | 65.8(54.2) | 34.9(36.2) | 4.4(2.3) | 75.0(60.0) | 5.4(2.5) | 10.0(18.4) | 66.7(8.2) | 23.1(28.7) | 8.5(3.1) | 17.5(24.7) | 7.5(2.9) |
| $2x10^{-4}$% | 28.8(32.4) | 2.6 (9.2) | 1.4(1.6) | 16.3(23.8) | 4.4(2.3) | 25.0(30.0) | 5.1(2.5) | 26.4(30.9) | 19.7(4.6) | 53.0(46.7) | 12.7(3.7) |
| BASF LAB 153 959 I | | | | | | | | | | | |
| $2x10^{-1}$% | 100.0(90.0) | 100.0(90.0) | 32.4(5.8) | 100.0(90.0) | 18.8(4.4) | 48.0(43.9) | 8.7(3.1) | 100.0(90.0) | 12.1(3.6) | 100.0(90.0) | 11.5(3.5) |
| $2x10^{-2}$% | 100.0(90.0) | 78.3(62.2) | 25.4(5.1) | 100.0(90.0) | 18.0(4.4) | 10.0(18.4) | 5.6(2.6) | 62.9(52.5) | 19.3(4.5) | 97.4(80.8) | 10.0(3.3) |
| $2x10^{-3}$% | 100.0(90.0) | 94.7(76.7) | 23.8(5.0) | 92.3(73.8) | 9.3(3.2) | 8.2(16.6) | 3.0(2.0) | 22.0(28.0) | 42.7(6.6) | 32.6(29.0) | 9.7(3.3) |
| $2x10^{-4}$% | 24.8(29.9) | 24.5(29.7) | 5.3(2.5) | 23.3(28.8) | 4.3(2.3) | 11.1(19.5) | 5.6(2.6) | 3.2(13.3) | 3.2(2.1) | 0.0 (0.0) | 0.0(1.0) |
| Control | 10.0(18.4) | 10.0(18.4) | 10.0(3.3) | 10.0(18.4) | 10.0(3.3) | 37.7(37.9) | 79.4(9.0) | 20.0(26.6) | 15.4(4.1) | 20.0(26.6) | 15.4(4.1) |
| C.D. (0.05) | (13.29) | (20.73) | (1.64) | (19.58) | (0.80) | (24.33) | (1.86) | (19.65) | (3.83) | (24.20) | (1.01) |

Mortality: Values of angular transformation are given in brackets

Speed index: Values of $\sqrt{x + 1}$ transformation are given in brackets

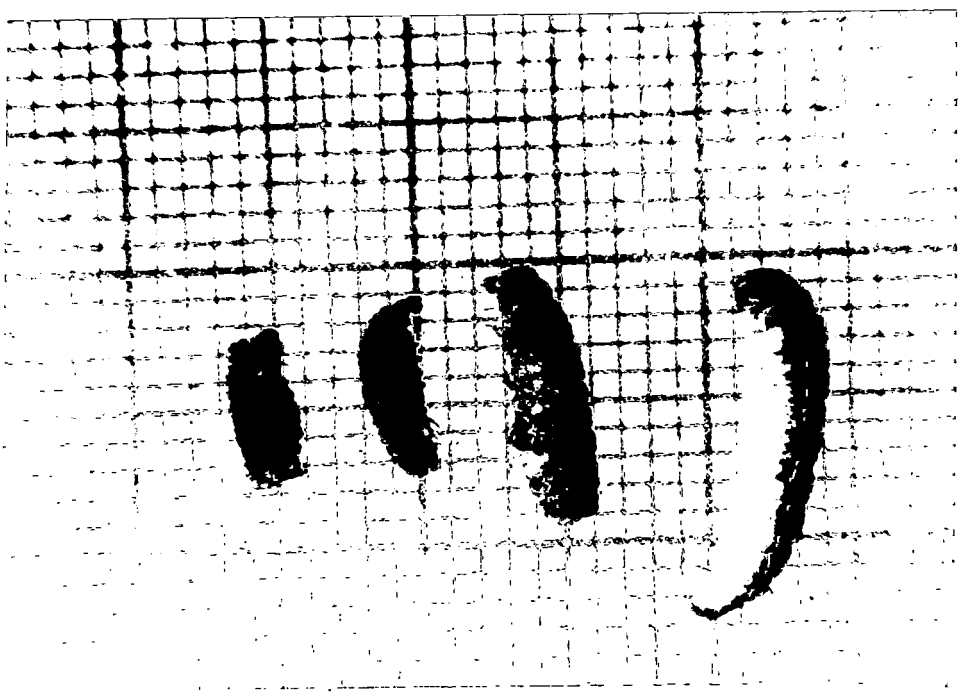


Table 12. Effect of chitin synthesis inhibitors on the last instar larvae of Corcyra cephalonica (SA: Stomach action, CA: Contact action)

| Treatments | Larval mortality | | Pre-pupal mortality | | Larval pupal mosaics | | Pupal mortality | | Abnormal adults | | Normal adults | | Score for abnormality (*) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feeding | Topical | SA | CA | SA | CA | SA | CA | SA | CA | SA | CA | SA | CA |
| Diflubenzuron | | | | | | | | | | | | | | |
| $2x10^{-1}$% | 0.0 | 0.0 | 0.0 (0.0) | 2.6 (9.2) | 61.2(51.4) | 0.0 (0.0) | 11.1(19.5) | 0.0 (0.0) | 2.9 (9.7) | 0.0 (0.0) | 21.1(27.4) | 97.4(80.8) | 0.5(1.2) | 0.0(1.0) |
| $2x10^{-2}$% | 0.0 | 0.0 | 0.0 (0.0) | 2.6 (9.2) | 30.8(33.7) | 0.0 (0.0) | 5.3(13.3) | 0.0 (0.0) | 0.0 (0.0) | 2.6 (9.2) | 58.6(49.9) | 90.0(71.5) | 0.0(1.0) | 0.9(1.4) |
| $2x10^{-3}$% | 0.0 | 0.0 | 0.0 (0.0) | 0.0 (0.0) | 2.9 (9.7) | 0.0 (0.0) | 5.9(14.1) | 2.6 (9.2) | 18.1(25.2) | 0.0 (0.0) | 66.8(54.8) | 97.4(80.8) | 5.0(2.4) | 0.0(1.0) |
| $2x10^{-4}$% | 0.0 | 0.0 | 0.0 (0.0) | 0.0 (0.0) | 16.3(23.8) | 2.9 (9.7) | 0.0 (0.0) | 2.9 (9.7) | 0.0 (0.0) | 0.0 (0.0) | 83.7(66.2) | 94.1(75.9) | 0.0(1.0) | 0.0(1.0) |
| Chlorfluazuron | | | | | | | | | | | | | | |
| $2x10^{-2}$% | 0.0 | 0.0 | 26.1(30.7) | 30.0(33.2) | 65.8(54.2) | 39.8(39.1) | 0.0 (0.0) | 2.6 (9.2) | 0.0 (0.0) | 10.0(18.4) | 3.7(11.1) | 14.6(22.5) | 0.0(1.0) | 1.9(1.7) |
| $2x10^{-3}$% | 5.0 | 0.0 | 27.5(31.6) | 10.0(18.4) | 67.7(55.4) | 0.0 (0.0) | 0.0 (0.0) | 2.6 (9.2) | 0.0 (0.0) | 29.5(32.9) | 0.0 (0.0) | 55.2(48.0) | 0.0(1.0) | 3.5(2.1) |
| $2x10^{-4}$% | 0.0 | 0.0 | 0.0 (0.0) | 0.0 (0.0) | 79.6(63.1) | 29.5(32.9) | 0.0 (0.0) | 2.6 (9.2) | 0.0 (0.0) | 5.3(13.3) | 20.4(26.8) | 55.0(47.9) | 0.0(1.0) | 1.3(1.5) |
| $2x10^{-5}$% | 0.0 | 0.0 | 18.1(25.2) | 0.0 (0.0) | 69.1(56.2) | 2.6 (9.2) | 0.0 (0.0) | 14.6(22.5) | 3.7(11.1) | 0.0 (0.0) | 2.9 (9.7) | 80.0(63.4) | 2.0(1.7) | 0.0(1.0) |
| PH 70-23 | | | | | | | | | | | | | | |
| $2x10^{-1}$% | 0.0 | 0.0 | 0.0 (0.0) | 0.0 (0.0) | 2.6 (9.2) | 14.6(22.5) | 5.3(16.3) | 2.6 (9.2) | 5.3(13.3) | 2.6 (9.2) | 76.7(61.1) | 76.7(61.1) | 1.4(1.6) | 2.0(1.7) |
| $2x10^{-2}$% | 0.0 | 0.0 | 2.6 (9.2) | 0.0 (0.0) | 2.6 (9.2) | 0.0 (0.0) | 2.6 (9.2) | 10.0(18.4) | 0.0 (0.0) | 2.6 (9.2) | 85.4(67.5) | 85.4(67.5) | 0.0(1.0) | 0.5(1.2) |
| $2x10^{-3}$% | 0.0 | 0.0 | 0.0 (0.0) | 2.6 (9.2) | 0.0 (0.0) | 14.6(22.5) | 14.6(22.5) | 14.6(22.5) | 0.0 (0.0) | 19.0(25.8) | 85.4(67.5) | 45.0(42.1) | 0.0(1.0) | 4.5(2.3) |
| $2x10^{-4}$% | 0.0 | 0.0 | 2.6 (9.2) | 0.0 (0.0) | 2.6 (9.2) | 0.0 (0.0) | 10.0(18.4) | 5.3(13.3) | 2.6 (9.2) | 19.0(25.8) | 75.2(60.1) | 72.4(58.3) | 2.0(1.7) | 1.5(1.6) |
| BASF LAB 153 959 I | | | | | | | | | | | | | | |
| $2x10^{-1}$% | 0.0 | 0.0 | 10.5(18.9) | 2.6 (9.2) | 51.8(46.0) | 2.6 (9.2) | 2.6 (9.2) | 10.0(18.4) | 10.5(18.9) | 10.0(18.4) | 12.7(20.9) | 70.0(56.8) | 3.4(2.1) | 5.0(2.4) |
| $2x10^{-2}$% | 0.0 | 0.0 | 19.4(26.1) | 0.0 (0.0) | 30.6(33.6) | 2.6 (9.2) | 3.7(11.1) | 2.6 (9.2) | 0.0 (0.0) | 0.0 (0.0) | 40.5(39.5) | 90.0(71.5) | 0.0(1.0) | 0.0(1.0) |
| $2x10^{-3}$% | 0.0 | 0.0 | 2.6 (9.2) | 0.0 (0.0) | 44.8(42.0) | 0.0 (0.0) | 5.3(13.3) | 0.0 (0.0) | 14.6(22.5) | 0.0 (0.0) | 24.8(29.9) | 100.0(90.0) | 2.6(1.9) | 0.0(1.0) |
| $2x10^{-4}$% | 0.0 | 0.0 | 0.0 (0.0) | 10.0(18.4) | 45.0(42.1) | 2.6 (9.2) | 0.0 (0.0) | 0.0 (0.0) | 14.6(22.5) | 2.6 (9.2) | 39.8(39.1) | 80.0(63.4) | 3.7(2.2) | 0.5(1.2) |
| Control | 0.0 | 0.0 | 0.0 (0.0) | 0.0 (0.0) | 2.6 (9.2) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 97.4(80.8) | 100.0(90.0) | 0.0(1.0) | 0.0(1.0) |
| C.D. (0.05) | — | — | (13.61) | (13.34) | (22.33) | (16.85) | (NS) | (20.64) | (16.52) | (18.66) | (26.59) | (20.21) | (0.95) | (0.77) |

Values of angular transformation are given in brackets

(*) Values of $\sqrt{x + 1}$ transformation are given in brackets

Fig. 7. Larval-pupal intermediates of *Corcyra cephalonica*
Right: Normal pupa

Final instar larvae, when fed on various doses of chitin synthesis inhibitors, there was no mortality in the larval stage except in chlorfluazuron $2x10^{-3}$%, which produced a mortality of 5%. Pupal mortality was also lacking in all test doses of diflubenzuron, chlorfluazuron $2x10^{-4}$%, BASF LAB 153 959 I $2x10^{-4}$%, PH 70-23 $2x10^{-1}$% and $2x10^{-3}$%. Chlorfluazuron $2x10^{-3}$% produced the highest pupal mortality (27.5%), followed by chlorfluazuron $2x10^{-2}$% (26.1%), BASF LAB 153 959 I $2x10^{-2}$% (19.4%), chlorfluazuron $2x10^{-5}$% (18.1%) and BASF LAB 153 959 I $2x10^{-1}$% (10.5%) and were on par. Other treatments produced a marginal mortality of up to 2.6% only and were on par with control. Highest mortality of insects treated at the last larval stadium occurred as larval-pupal intermediates. Chlorfluazuron $2x10^{-4}$% produced the maximum (79.6%) larval-pupal intermediates, followed by chlorfluazuron $2x10^{-5}$% (69.1%), $2x10^{-3}$% (67.7%), $2x10^{-2}$% (65.8%), diflubenzuron $2x10^{-1}$% (61.2%), BASF LAB 153 959 I $2x10^{-1}$% (51.8%), $2x10^{-4}$% (45.0%) and $2x10^{-3}$% (44.8%) and were on par. Diflubenzuron $2x10^{-2}$% (33.7%) and BASF LAB 153 959 I $2x10^{-2}$% (33.6%) were on par with the above treatments except chlorfluazuron $2x10^{-4}$% and $2x10^{-5}$%. Rest of the treatments produced 0 to 16.3% larval-pupal intermediates and were on par with control. Mortality in the pupal stage was not significantly different. No pupal mortality occurred at all test doses of chlorfluazuron, diflubenzuron $2x10^{-4}$% and

BASF LAB 153 959 I $2x10^{-5}$%. Other treatments produced 2.6 to 14.6% mortality. Maximum number of abnormal adults was produced by diflubenzuron $2x10^{-3}$% (18.1%), followed by BASF LAB 153 959 I $2x10^{-4}$% (14.6%), $2x10^{-3}$% (14.6%) and $2x10^{-1}$% (10.5%). Other treatments were statistically equal to control. Abnormal adults with a significantly high degree of malformation were produced by diflubenzuron $2x10^{-3}$% (5.0) and BASF LAB 153 959 I $2x10^{-4}$% (3.7). Other treatments were on par with control and the score ranged from 0 to 2.6.

Final effect of the chitin synthesis inhibitors was reflected in the emergence of normal adults. Chlorfluazuron $2x10^{-3}$% completely inhibited the emergence of adults. Chlorfluazuron $2x10^{-5}$% (2.9%), $2x10^{-2}$% (3.7%) and BASF LAB 153 959 I $2x10^{-1}$% (12.7%) were on par with chlorfluazuron $2x10^{-5}$% as well as chlorfluazuron $2x10^{-4}$% (20.4%), diflubenzuron $2x10^{-1}$% (21.1%) and BASF LAB 153 959 I $2x10^{-3}$% (24.8%). The last treatment was also on par with BASF LAB 153 959 I $2x10^{-4}$% (39.8%), $2x10^{-2}$% (40.5%) and diflubenzuron $2x10^{-2}$% (58.6%), and the above treatments were superior to control. In other treatments 66.8 to 85.4% adults emerged and were on par with control.

Contact action of chitin synthesis inhibitors by topical application on the last instar larvae is described below. No mortality occurred before the construction of

pupal chamber. Pre-pupal mortality was the highest in chlorfluazuron $2x10^{-2}$% (33.2%), followed by chlorfluazuron $2x10^{-3}$% and BASF LAB 153 959 I $2x10^{-4}$% (18.4% each). They were significantly superior to control and chlorfluazuron $2x10^{-2}$% was superior to chlorfluazuron $2x10^{-3}$% and BASF LAB 153 959 I $2x10^{-4}$%. Rest of the treatments were on par with control and produced 0 to 2.6% pre-pupal mortality. Chlorfluazuron $2x10^{-2}$% (39.8%), $2x10^{-4}$% (29.5%), PH 70-23 $2x10^{-1}$% (14.6%) and $2x10^{-3}$% (14.6%) produced significantly higher number of larval-pupal mosaics. But the latter two treatments were inferior to the first treatment. Other treatments produced 0 to 2.7% larval-pupal mosaics and was on par with control. Mortality in the pupal stage ranged from 0 to 14.6% and was not significant. Chlorfluazuron $2x10^{-3}$% (29.5%), PH 70-23 $2x10^{-3}$% (19.0%) and $2x10^{-4}$% (19.0%) produced significantly higher number of deformed adults, while it was up to an insignificant 10% in other treatments. The mean scores for deformities of deformed adults were on par and significantly superior to control in the case of BASF LAB 153 959 I $2x10^{-1}$% (5.0), PH 70-23 $2x10^{-3}$ (4.5) and chlorfluazuron $2x10^{-3}$% (3.5 ).

Finally, minimum number of adults emerged from the last instar larvae treated with chlorfluazuron $2x10^{-2}$% (14.5%), followed by PH 70-23 $2x10^{-3}$% (45.0%). Both the treatments

were on par. PH 70-23 $2x10^{-3}$% was on par with chlorfluazuron $2x10^{-4}$% (55.0%), $2x10^{-3}$% (55.2%), BASF LAB 153 959 I $2x10^{-1}$% (70.0%), PH 70-23 $2x10^{-4}$% (72.4%) and $2x10^{-1}$% (76.7%). Other treatments were less effective, the emergence of normal adults being 80 to 100%.

(d) Effect of chitin synthesis inhibitors on the pre-pupae of Corcyra cephalonica

Treatment of pre-pupae resulted in morphological abnormalities and mortality during the course of development (Table 13). Mortality at the pre-pupal stage was up to 17.0% and was not significant. Highest mortality occurred as larval-pupal intermediates. The highest number of larval-pupal intermediates was produced by chlorfluazuron $2x10^{-2}$% (81.1%), followed by chlorfluazuron $2x10^{-3}$% (41.0%), $2x10^{-4}$% (40.2%), BASF LAB 153 959 I $2x10^{-4}$% (34.9%), $2x10^{-1}$% (32.2%), chlorfluazuron $2x10^{-5}$% (32.2%) and BASF LAB 153 959 I $2x10^{-3}$% (29.4%). Among the above treatments, chlorfluazuron $2x10^{-2}$% was the most significant. Chlorfluazuron $2x10^{-3}$% was on par with $2x10^{-2}$% and rest of the above treatments. Other treatments were on par and produced 9.6 to 26.2% larval-pupal intermediates. Pupal mortality ranged from 0 to 11.2% and was not significant. Emergence of deformed adults was also insignificant and ranged from 0 to 6.7%. Mean score for abnormality of adults was of the order of 0.5 to 2.0 and was

Table 13. Effect of chitin synthesis inhibitors on the pre-pupae of Corcyra cephalonica

| Treatments | Mortality of pre-pupa | Larval-pupal mosaic | Mortality of pupa | Abnormal adults | Normal adults | Score for abnormality (*) |
|---|---|---|---|---|---|---|
| Diflubenzuron | | | | | | |
| $2x10^{-1}$% | 2.6 (9.2) | 2.6 (9.2) | 2.6 (9.2) | 0.0 (0.0) | 85.4(67.5) | 0.0(1.0) |
| $2x10^{-2}$% | 2.6 (9.2) | 14.6(22.5) | 0.0 (0.0) | 0.0 (0.0) | 80.0(63.4) | 0.0(1.0) |
| $2x10^{-3}$% | 2.6 (9.2) | 15.6(23.3) | 0.0 (0.0) | 2.9 (9.7) | 73.6(59.1) | 2.0(1.7) |
| $2x10^{-4}$% | 0.0 (0.0) | 2.6 (9.2) | 0.0 (0.0) | 0.0 (0.0) | 97.4(80.8) | 0.0(1.0) |
| Chlorfluazuron | | | | | | |
| $2x10^{-2}$% | 0.0 (0.0) | 81.1(64.2) | 5.3(13.3) | 2.6 (9.2) | 2.6 (9.2) | 1.3(1.5) |
| $2x10^{-3}$% | 17.0(24.4) | 41.4(40.0) | 0.0 (0.0) | 0.0 (0.0) | 41.4(40.0) | 0.0(1.0) |
| $2x10^{-4}$% | 0.0 (0.0) | 40.2(39.3) | 3.2(10.3) | 3.2(10.3) | 47.3(43.4) | 2.0(1.7) |
| $2x10^{-5}$% | 0.0 (0.0) | 32.2(34.6) | 2.6 (9.2) | 0.0 (0.0) | 62.8(52.4) | 0.0(1.0) |
| PH 70-23 | | | | | | |
| $2x10^{-1}$% | 10.5(18.9) | 26.2(30.8) | 3.2(10.3) | 0.0 (0.0) | 47.3(43.4) | 0.0(1.0) |
| $2x10^{-2}$% | 3.2(10.3) | 11.2(19.6) | 11.2(19.6) | 0.0 (0.0) | 71.7(57.8) | 0.0(1.0) |
| $2x10^{-3}$% | 0.0 (0.0) | 20.0(26.5) | 0.0 (0.0) | 0.0 (0.0) | 80.0(63.4) | 0.0(1.0) |
| $2x10^{-4}$% | 0.0 (0.0) | 18.4(25.4) | 2.6 (9.2) | 0.0 (0.0) | 75.8(60.5) | 0.0(1.0) |
| BASF LAB 153 959 I | | | | | | |
| $2x10^{-1}$% | 0.0 (0.0) | 32.3(34.6) | 0.0 (0.0) | 3.2(10.3) | 61.3(51.5) | 0.5(1.2) |
| $2x10^{-2}$% | 0.0 (0.0) | 2.9 (9.7) | 6.7(15.0) | 0.0 (0.0) | 82.5(65.2) | 0.0(1.0) |
| $2x10^{-3}$% | 0.0 (0.0) | 29.4(32.8) | 6.7(15.0) | 6.7(15.0) | 43.7(41.4) | 1.3(1.5) |
| $2x10^{-4}$% | 0.0 (0.0) | 34.9(36.2) | 8.2(16.6) | 2.6 (9.2) | 44.8(42.0) | 0.0(1.0) |
| Control | 0.0 (0.0) | 2.6 (9.2) | 2.6 (9.2) | 0.0 (0.0) | 89.9(71.5) | 0.0(1.0) |
| C.D. (0.05) | (NS) | (23.30) | (NS) | (NS) | (20.42) | (NS) |

Values of angular transformation are given in brackets NS: Not significant
(*) Values of $\sqrt{x + 1}$ transformation are given in brackets

statistically on par. Normal adults emerged from all of the treatments. Chlorfluazuron $2x10^{-2}$% showed a maximum inhibition of emergence of normal adults (2.6%). Though inferior to chlorfluazuron $2x10^{-2}$%, Chlorfluazuron $2x10^{-3}$% (41.4%), BASF LAB 153 959 I $2x10^{-3}$% (43.7%), $2x10^{-4}$% (44.8%), and chlorfluazuron $2x10^{-4}$% (47.3%) were superior to control. Emergence values of normal adults in other treatments were of the order of 61.3 to 97.4% and they were on par with control.

(e) Effect of chitin synthesis inhibitors on the pupae of Corcyra cephalonica

Pupae when treated with chitin synthesis inhibitors, mortality of pupae and emergence of deformed adults were noticed. Deformations ranged from adults with slightly twisted wings to partially emerged adults (Fig. 8). Some of the adults had poorly-developed wings. Results of the effects of chitin synthesis inhibitors on the pupae are given in Table 14. Pupal mortality was not significant among different treatments. Diflubenzuron $2x10^{-1}$% produced the highest pupal mortality of 57.0%, followed by PH 70-23 $2x10^{-1}$% (43.3%). Other treatments produced pupal mortalities ranging from 0 to 32.2%. Emergence of deformed adults was not significantly different. Maximum number of deformed

Table 14. Effect of chitin synthesis inhibitors on the pupae of Corcyra cephalonica

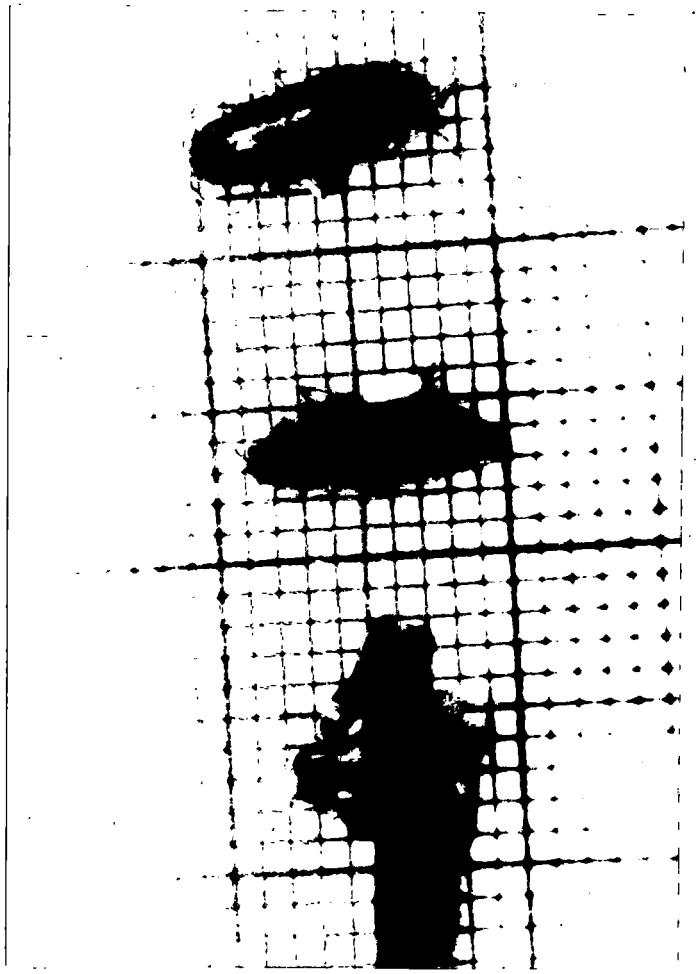
| Treatments | Pupal mortality | Abnormal adults | Normal adults | Score for (*) abnormality |
|---|---|---|---|---|
| Diflubenzuron | | | | |
| $2x10^{-1}$% | 54.0(47.3) | 16.1(23.6) | 27.6(31.7) | 2.7(1.9) |
| $2x10^{-2}$% | 3.2(10.3) | 6.7(15.0) | 81.7(64.6) | 0.5(1.2) |
| $2x10^{-3}$% | 32.2(34.6) | 2.6 (9.2) | 62.8(52.4) | 2.0(1.7) |
| $2x10^{-4}$% | 2.3 (8.8) | 9.5(18.0) | 86.2(68.1) | 1.9(1.7) |
| Chlorfluazuron | | | | |
| $2x10^{-2}$% | 5.3(13.3) | 10.0(18.4) | 81.0(64.2) | 2.3(1.8) |
| $2x10^{-3}$% | 14.6(22.5) | 20.0(26.6) | 65.1(53.8) | 2.3(1.8) |
| $2x10^{-4}$% | 11.2(19.6) | 2.6 (9.2) | 89.9(66.3) | 0.5(1.2) |
| $2x10^{-5}$% | 0.0 (0.0) | 33.3(35.2) | 66.7(54.7) | 4.7(2.4) |
| PH 70-23 | | | | |
| $2x10^{-1}$% | 43.3(41.1) | 28.3(32.1) | 28.3(32.1) | 3.2(2.1) |
| $2x10^{-2}$% | 32.2(34.6) | 29.5(32.9) | 34.2(35.8) | 3.0(2.0) |
| $2x10^{-3}$% | 30.7(33.7) | 5.9(14.1) | 57.9(49.5) | 1.3(1.5) |
| $2x10^{-4}$% | 2.6 (9.2) | 26.4(30.9) | 68.3(55.7) | 1.2(1.5) |
| BASF LAB 153 959 I | | | | |
| $2x10^{-1}$% | 14.6(22.5) | 5.3(13.3) | 75.2(60.1) | 1.3(1.5) |
| $2x10^{-2}$% | 11.3(19.6) | 10.0(18.4) | 72.4(58.3) | 3.4(2.1) |
| $2x10^{-3}$% | 15.6(23.3) | 5.3(13.3) | 74.0(59.3) | 0.7(1.3) |
| $2x10^{-4}$% | 10.0(18.4) | 14.6(22.5) | 75.2(60.1) | 1.0(1.4) |
| Control | 0.0 (0.0) | 2.6 (9.2) | 97.4(80.0) | 0.5(1.2) |
| C.D. (0.05) | (NS) | (NS) | (23.30) | (NS) |

Values of angular transformation are given in brackets

(*) Values of $\sqrt{x + 1}$ transformation are given in brackets

NS: Not significant

Fig. 8. Partially emerged and deformed adults of Corcyra cephalonica
Right: Normal adult



adults emerged from pupae treated with chlorfluazuron $2x10^{-5}$% (33.3%) followed by PH 70-23 $2x10^{-2}$% (29.5%), $2x10^{-1}$% (28.3%) and $2x10^{-4}$% (26.4%). In other treatments it ranged from 2.6 to 20.0%. Mean score for deformity was also not significant. It was highest for chlorfluazuron $2x10^{-5}$% (4.7) followed by BASF LAB 153 959 I $2x10^{-2}$% (3.4), PH 70-23 $2x10^{-1}$% (3.2) and $2x10^{-2}$% (3.0). Other treatments produced deformed adults with a score ranging from 1 to 2.7. Emergence of normal adults from treated pupae was significant. Diflubenzuron $2x10^{-1}$% produced the minimum number of adults (27.6%), followed by PH 70-23 $2x10^{-1}$% (28.3%), $2x10^{-2}$% (34.2%), $2x10^{-3}$% (57.9%), diflubenzuron $2x10^{-3}$% (62.8%), chlorfluazuron $2x10^{-3}$% (65.1%) and $2x10^{-5}$% (66.7%) and they were on par. PH 70-23 $2x10^{-4}$% (68.3%) was on par with the above treatments except diflubenzuron $2x10^{-1}$% and PH 70-23 $2x10^{-1}$%. Rest of the treatments ranked on par with control and produced 72.4 to 86.2% normal adults.

(f) Sterilant action of chitin synthesis inhibitors on Corcyra cephalonica

Adult moths of either or both sexes when treated with chitin synthesis inhibitors, no significant deleterious effect was observed on the fecundity and hatchability of eggs as well as on the longevity of the treated moths (Table 15). When treated males were allowed to mate with freshly-emerged

untreated females, fecundity, hatchability of eggs and longevity of treated moths ranged from 11.9 to 156.2 eggs per female, 63.1 to 99.0% and 8 to 18.7 days respectively. When the females were treated, the above parameters were of the order of 20.1 to 112.1 eggs/female, 43.6 to 99.3% and 6 to 11.7 days respectively. Both sexes when treated, fecundity ranged from 11.2 to 132.2 eggs/female and was not significantly inferior to control. Egg hatchability was of the order of 60.3 to 98.9%. Longevity of males and females ranged from 6.7 to 16 days and 4.3 to 13.3 days respectively.

3. Effect of chitin synthesis inhibitors on Bracon brevicornis

Results are given in Table 16. No significant difference was observed in the number of parasites pupated, when the hosts (final instar larvae of C. cephalonica) were treated topically or by feeding. Though there was no significant difference in the number of parasites pupated, total pupal mortality occurred in the case of chlorfluazuron $2x10^{-2}$% when the hosts were treated through food. When the host was topically treated, there was no significant pupal mortality. Hosts treated with chlorfluazuron $2x10^{-2}$% through food, produced no adults. The effect of the treatment was significantly higher than those of other treatments which were on par with control. In the case of topically-treated hosts, chlorfluazuron $2x10^{-2}$% produced minimum number of adults.

Table 16. Effect of chitin synthesis inhibitors on Bracon bravicornis when reared on Corcyra cephalonica fed on a treated diet and when applied topically

| Treatments | No.of parasites pupated | | No.of dead pupae | | No.of adults | |
|---|---|---|---|---|---|---|
| | Treated diet | Topical application | Treated diet | Topical application | Treated diet | Topical application |
| Diflubenzuron | | | | | | |
| $2x10^{-1}$% | 20.0(4.6) | 9.0(3.1) | 1.0(1.4) | 0.0(1.0) | 19.0(4.5) | 9.0(3.1) |
| $2x10^{-2}$% | 20.5(4.6) | 5.0(2.2) | 0.5(1.2) | 0.5(1.2) | 20.0(4.6) | 4.5(2.1) |
| $2x10^{-3}$% | 17.0(4.2) | 7.0(2.8) | 0.5(1.2) | 1.5(1.6) | 16.5(4.2) | 5.5(2.5) |
| Chlorfluazuron | | | | | | |
| $2x10^{-2}$% | 19.0(4.3) | 0.5(1.2) | 19.0(4.3) | 0.0(1.0) | 0.0(1.0) | 0.5(1.2) |
| $2x10^{-3}$% | 20.5(4.6) | 7.0(2.8) | 1.0(1.4) | 1.0(1.4) | 19.5(4.5) | 6.0(2.6) |
| $2x10^{-4}$% | 20.5(4.6) | 9.5(3.2) | 1.0(1.4) | 0.0(1.0) | 19.5(4.5) | 9.5(3.2) |
| PH 70-23 | | | | | | |
| $2x10^{-1}$% | 26.0(5.2) | 4.5(1.9) | 2.0(1.7) | 0.5(1.2) | 24.0(5.0) | 4.0(1.8) |
| $2x10^{-2}$% | 17.0(4.2) | 11.0(3.4) | 0.5(1.2) | 3.5(2.1) | 16.5(4.2) | 7.5(2.9) |
| $2x10^{-3}$% | 18.0(4.4) | 9.0(3.1) | 0.5(1.2) | 1.0(1.4) | 17.5(4.4) | 8.0(3.0) |
| BASF LAB 153 959 I | | | | | | |
| $2x10^{-1}$% | 24.5(5.0) | 8.0(3.0) | 0.0(1.0) | 0.5(1.2) | 24.5(5.0) | 7.5(2.9) |
| $2x10^{-2}$% | 27.0(5.3) | 10.5(3.4) | 0.0(1.0) | 1.0(1.4) | 27.0(5.3) | 9.5(3.2) |
| $2x10^{-3}$% | 17.0(4.2) | 8.5(2.8) | 0.5(1.2) | 1.0(1.4) | 16.5(4.2) | 7.5(2.6) |
| Control | 21.0(4.7) | 7.0(2.8) | 1.0(1.4) | 0.5(1.2) | 20.0(4.6) | 6.5(2.7) |
| C.D. (0.05) | (NS) | (NS) | (1.27) | (NS) | (0.97) | (NS) |

Values of $\sqrt{x + 1}$ transformation are given in brackets NS: Not significant

Table 17. Effect of chitin synthesis inhibitors on the progeny production of Bracon brevicornis

| Treatments | No.of parasites pupated | No. of dead pupae | No.of adults |
|---|---|---|---|
| Diflubenzuron | | | |
| $2x10^{-1}$% | 23.00(4.8) | 6.67(2.7) | 16.33(4.1) |
| $2x10^{-2}$% | 23.67(5.0) | 0.00(1.0) | 23.67(5.0) |
| Chlorfluazuron | | | |
| $2x10^{-2}$% | 29.33(5.5) | 0.33(1.1) | 29.00(5.4) |
| $2x10^{-3}$% | 4.67(2.3) | 0.00(1.0) | 4.67(2.3) |
| PH 70-23 | | | |
| $2x10^{-1}$% | 20.33(4.6) | 0.00(1.0) | 20.33(4.6) |
| $2x10^{-2}$% | 28.00(5.4) | 0.00(1.0) | 28.00(5.4) |
| BASF LAB 153 959 I | | | |
| $2x10^{-1}$% | 31.33(5.6) | 0.00(1.0) | 31.33(5.7) |
| $2x10^{-2}$% | 23.67(4.9) | 0.33(1.1) | 23.33(4.9) |
| Control | 18.67(4.4) | 0.00(1.0) | 18.67(4.4) |
| C.D. (0.05) | (1.39) | (0.42) | (1.33) |

$\sqrt{x + 1}$ transformed values are given in brackets

Pupae, when treated directly, diflubenzuron $2x10^{-1}$% produced a significantly higher mortality of 25%. All other treatments were on par with control.

Data relating to the effect of chitin synthesis inhibitors on the progeny production are given in Table 17. Adults emerged from pupae treated with chlorfluazuron $2x10^{-3}$% produced the least number of progeny which was significantly less than all other treatments including the higher dose of the same chemical. The number of parasites pupated was significantly less in chlorfluazuron $2x10^{-3}$%. All treatments except chlorfluazuron $2x10^{-3}$% were on par with control. The highest pupal mortality was observed in the case of diflubenzuron $2x10^{-1}$% which was significantly different from other treatments which were on par with control. Chlorfluazuron $2x10^{-3}$% produced minimum number of adults which was significantly lower than all other treatments, including the higher dose of the same chemical, which were on par with control. BASF LAB 153 959 I $2x10^{-1}$% produced significantly higher number of adults than chlorfluazuron $2x10^{-3}$% and diflubenzuron $2x10^{-1}$%.

## DISCUSSION

Two media - water and methanol - were used to assess the ovicidal action of chitin synthesis inhibitors. Eggs of Spodoptera mauritia and Corcyra cephalonica were, in general, less susceptible in aqueous medium. On S. mauritia the highest dose of chlorfluazuron alone produced substantial egg mortality. Beevi (1979) has reported high ovicidal action of diflubenzuron on S. mauritia. This may be due to the difference in the treatment period. In Beevi's study it was 15 minutes as against two minutes in the present experiment. Gujar and Mehrotra (1986) reported opposite results with BASF LAB 153 959 I on eggs of S. litura. In methanolic medium, egg mortality of S. mauritia was increased in the case of diflubenzuron and highest doses of the other three compounds. On C. cephalonica, highest doses of diflubenzuron, PH 70-23 and BASF LAB 153 959 I caused significantly high egg mortality in methanolic medium. This could be due to the enhanced penetration due to low surface tension of the solvent. However, this rule does not act universally. On C. cephalonica, chlorfluazuron $2 \times 10^{-1}$% caused a high mortality in aqueous medium. This can only be considered as an artifact.

In general, there was no significant difference in the susceptibility of one and two-day old eggs of S. mauritia

as well as one and four-day old eggs of C. cephalonica. Results of the present study show that the effect of age of eggs on susceptibility to chitin synthesis inhibitors is inconsistent. Ascher et al. (1978a) conducted experiments with diflubenzuron on the eggs and larvae of Earias insulana. Only moderate levels of mortality were obtained when the eggs were dipped in the compound and more over the results were inconsistent. It is stated that inhibition of eclosion depends on the species of insect, age of the eggs and time of exposure (Schmutterer, 1976). Ammar (1984) reported that susceptibility of the eggs of Leptinotarsa decemlineata decreased with increasing age of the eggs.

Larvae of the test insects differed greatly in their susceptibility to chitin synthesis inhibitors. Second and fifth instar larvae of S. mauritia fed on treated diet for 36 hours and 48 hours respectively, were highly susceptible to doses as low as $2 \times 10^{-5}$% of all the compounds. Chlorfluazuron caused the highest mortality of 100% at all the test doses. All the compounds were highly active by feeding or contact on S. mauritia larvae. Ascher and Nemny (1976) on S. littoralis, Beevi and Dale (1980) on S. mauritia and Granett et al. (1983) on S. exigua reported similar high toxicity of chitin synthesis inhibitors through cuticular application. Speed indices show that mortality of second

instar larvae was more rapid than that of the fifth instar larvae. A rare phenomenon of faster mortality in medium doses than in the highest dose was also observed. This was more evident with second instar larvae giving indications of a non-linear dose-effect relationship. Corcyra cephalonica larvae were less susceptible to chitin synthesis inhibitors. Among the test chemicals, chlorfluazuron was the most toxic compound, followed by BASF LAB 153 959 I. Diflubenzuron and PH 70-23 were less active against larval C. cephalonica. Chlorfluazuron at all the test doses produced either total or very high mortality when different instar larvae were fed. Contact action of chlorfluazuron by topical application was also high so that $2x10^{-2}$% and $2x10^{-3}$% produced 100% and 96.8% mortalities respectively. BASF LAB 153 959 I at $2x10^{-1}$% caused cent per cent mortality of different instar larvae when fed. But contact action was less causing only 48.0% mortality. Though chitin synthesis inhibitors are known to exhibit a high degree of contact action in a few insects like Spodoptera spp. they are generally considered as stomach acting chemicals. Larvae of the cabbage butterfly Pieris brassicae were not susceptible to topical treatment with diflubenzuron or PH 6038 (Mulder and Gijswijt, 1973). Similar evidence of lack of cuticular absorption was presented by Retnakaran and Smith (1975) on Eastern spruce bud worm, Choristoneura fumiferana. Topical application

of diflubenzuron resulted in no mortality, whereas dietary treatments did.

The present study to compare the contact and stomach actions by administering equal quantities of the chemicals orally and topically shows that chitin synthesis inhibitors are active on S. mauritia equally by contact and ingestion though no data of this type of an experiment are available. Information given by Ascher and Nemny (1970), Beevi and Dale (1980) and Granett and co-workers (1983) have already established a high degree of contact action of chitin synthesis inhibitors - which is not exhibited on most of the insects, even on members of the genus Spodoptera. Contact action coupled with stomach action is an added advantage in any pest control programme at the field level.

Application of chitin synthesis inhibitors prior to larval-pupal transformation inhibited successful transformation of the larvae to pupae and pupae to adult and also produced various morphogenetic changes. On S. mauritia, all the compounds were highly active. Contact action was also high. Sundaramurthy (1977) with diflubenzuron and Gujar and Mehrotra (1986) with BASF LAB 153 959 I on S.litura and Beevi (1979) on S. mauritia with diflubenzuron have reported similar effects. On C. cephalonica, chlorfluazuron was the most toxic compound, followed by BASF LAB 153 959 I,

diflubenzuron and PH 70-23. Contact effect of treatments other than chlorfluazuron $2x10^{-2}$% was very low. When pre-pupae were topically treated, the result was similar, with chlorfluazuron $2x10^{-2}$% producing the minimum number of normal adults (2.6%) and other treatments causing the emergence of 41.4 to 97.4% emergence of normal adults. Sudhakara Reddy and Kameswara Rao (1987) have reported low susceptibility of pre-pupae of Henosepilachna vigintioctopunctata to diflubenzuron by contact treatment. No extra larval moult as reported by Roychoudhry and Chakrovorty (1985) was observed in this study with C. cephalonica.

Pupal-adult transformation was interrupted when the chemicals were applied on pupae. But pupal stage was less susceptible to chitin synthesis inhibitors than larval stage and considerable number of normal adults emerged from various treatments. Chlorfluazuron was the most disruptive compound on S. mauritia development. It allowed the emergence of only 0.9% and 2.2% normal adults at doses of $2x10^{-1}$% and $2x10^{-2}$% respectively. Other treatments were less effective as insect growth regulators. The pupae of C. cephalonica were more refractive to the action of chitin synthesis inhibitors. Chlorfluazuron and BASF LAB 153 959 I caused emergence of more adults than PH 70-23 and diflubenzuron. Low susceptibility of pupae to moult inhibitors may be due to

low penetration of the chemicals through pupal case. Low pupal susceptibility has been reported by Gujar and Mehrotra (1986) with BASF LAB 153 959 I, Gujar (1987) with chlorfluazuron on S. litura and Sudhakara Reddy and Kameswara Rao (1987) on H. vigintioctopunctata with diflubenzuron.

When fed to moths of S. mauritia, fecundity, hatchability of eggs and longevity of male moths were reduced. Longevity of female moths remained unaffected. Sterilant action of chitin synthesis inhibitors was reported on S. mauritia (Beevi, 1979), S. frugiperda (Segistan and Almeida, 1983), S. littoralis (Radwan et al., 1984) and many other insects. Topical application of chitin synthesis inhibitors on moths of C. cephalonica had no adverse effect on the fecundity, hatchability of eggs or on the longevity of the treated moths. Salama and co-workers (1976) reported lack of effect on spermatogenesis, mating or oviposition of the nun moth Lymantria monacha. Flint and Smith (1977) reported similar negative observations for the pink boll worm Pectinophora gossypiella. Difference in the modes of treatments may be one of the reasons for the difference in susceptibility of S. mauritia and C. cephalonica. Mc Laughlin (1977) showed that topical treatment of boll weevils did not produce unviable eggs, until several days after treatment, but oral treatments were effective almost immediately.

The present study to assess the antifeedant action has shown that chitin synthesis inhibitors were poor antifeedants against S. mauritia. For antifeedant action, a perfect fit between the chemical and the microsensillae of the maxillae is essential. It has to be presumed from our studies that chitin synthesis inhibitors which are benzoyl-phenyl urea molecules, have a poor association with the maxillary sensillae to effect antifeedant action. Beevi (1979) observed reduction in feeding by treated larvae. Since they are poor antifeedants, target organisms feed on the treated surface without any inhibition and thereafter the damage is reduced eventhough the death is delayed.

Active residues of chitin synthesis inhibitors persisted on the treated rice foliage throughout the study period of 36 days. But the efficacy of residues subjected to weathering decreased considerably. The present study shows that chitin synthesis inhibitors are capable of protecting the crop in the field for a period of atleast one month. Many workers under various conditions have given the persistence of diflubenzuron for varying periods of 10 - 14 days (Broadbent and Pree, 1984) up to two years (Soria et al., 1986). Beevi (1979) has reported persistence of diflubenzuron on rice plants protected from rain for

up to 50 days. Bull (1980) reported that the residues of diflubenzuron on foliage were highly resistant to photo-degradation. Information given by Argauer and Cantelo (1980), Hoying and Riedl (1980), Mustafa (1984) and Mutanen and his co-workers (1988) showed that dissipation of chitin synthesis inhibitors is moderate or slow under field conditions.

An experiment was also conducted to study the effect of chitin synthesis inhibitors on a biological control agent, Bracon brevicornis. Chlorfluazuron inhibited the emergence of adult parasites from treated hosts and adversely affected the progeny production. Diflubenzuron, PH 70-23 and BASF LAB 153 959 I were non-toxic or only slightly toxic to the parasites. Chlorfluazuron was reported selective to another braconid parasite Trioxys pallidus (Purcell and Granett, 1985). Diflubenzuron was safe to many parasites like Apanteles marginiventris (Ables et al., 1980), Trichogramma spp. (Hassan, 1983), Pediobius foveolatus (Zungoli et al., 1983), Doryphorophaga doryphorae (Tamaki, 1984), Trioxys pallidus (Purcell and Granett,1985), and Carcelia rosae (Song et al., 1985). However, all the reports were not favourable. Diflubenzuron was reported toxic against Apanteles melanoscelus (Granett and Weseloh, 1975; Granett et al., 1976;

Madrid and Stewart, 1981), Aphidius metricarinae, Encarsia formosa (Iacob et al., 1981), Biosternes longicaudatus (Laurence, 1981), tachnids (Madrid and Stewart, 1981), Macrocentrus ancylivorus (Broadbent and Pree, 1984), Microplitis rufiventris (Heynen, 1985) and Trichogramma evanescens (Zaki and Gresraha, 1987).

Results of the present investigation show that all the four chitin synthesis inhibitors viz. chlorfluazuron, diflubenzuron, PH 70-23 and BASF LAB 153 959 I are highly effective pesticides against Spodoptera mauritia and can be considered as candidate insecticides for controlling the pest. But for Corcyra cephalonica, it was only chlorfluazuron that showed substantial activity. The former species is more susceptible to chitin synthesis inhibitors than the latter one. Studies using Bracon brevicornis have shown that chlorfluazuron is detrimental to the survival of the parasite while the other three compounds are safe. Though chlorfluazuron emerged as the most effective against both S. mauritia and C. cephalonica, its toxicity towards B. brevicornis is a serious disadvantage to the chemical for using in integrated pest management programmes.

# Summary

SUMMARY

Effects of four chitin synthesis inhibitors - diflubenzuron, chlorfluazuron, PH 70-23 and BASF LAB 153 959 I - were assessed on two insect pests and on a parasitoid.

1. Chitin synthesis inhibitors and Spodoptera mauritia

Ovicidal action of chitin synthesis inhibitors was assessed on one and two-day old eggs of Spodoptera mauritia in aqueous and methanolic media. Excepting the highest dose of $2x10^{-1}$% of chlorfluazuron and PH 70-23, ovicidal action was low in aqueous medium. In methanolic medium, diflubenzuron and the highest doses of the other three compounds showed enhanced action. BASF LAB 153 959 I was the least effective as an ovicide. Considering the age of treated eggs there was no significant difference in the susceptibility of one and two-day old eggs while in methanolic medium, ovicidal action was significantly higher.

Second and fifth instar larvae of S. mauritia when treated with various doses of the compounds, chlorfluazuron was the most active compound, causing cent per cent kill at doses as low as $2x10^{-5}$%. Diflubenzuron, PH 70-23 and BASF LAB 153 959 I were also highly active. Second instar larvae were more susceptible than fifth instar ones. Speed indices

of second instar larvae were higher than those of fifth instar larvae. On topical application with methanolic solutions, a high degree of contact action was observed. Administration of equal quantities of the compounds orally and topically showed that contact and stomach actions were more or less equal.

Final instar larvae of S. mauritia when treated orally and topically, larval-pupal intermediates, pupal mortality and emergence of deformed adults were caused. Toxicity of all the test chemicals to the last instar larvae was very high.

Treatment of pupae caused pupal mortality and emergence of deformed adults. Pupal stadium was a less susceptible period compared to larvae. Chlorfluazuron was the most toxic compound to pupae.

Treatment of moths of S. mauritia resulted in reduction in fecundity, hatchability of eggs and longevity of treated male moths. When males alone were treated, fecundity of female moths was low in diflubenzuron $2x10^{-4}\%$ (123.0), PH 70-23 $2x10^{-3}\%$ (206.5), diflubenzuron $2x10^{-3}\%$ (234.5) and chlorfluazuron $2x10^{-3}\%$ (287.0). Hatchability was less among treatments viz. chlorfluazuron $2x10^{-4}\%$ (2.6%), diflubenzuron $2x10^{-4}\%$ (11.1%), PH 70-23 $2x10^{-2}\%$ (15.4%) and PH 70-23

$2x10^{-4}$% (30.3%). Longevity of treated males was minimum in chlorfluazuron $2x10^{-5}$% (5.3 days). When females were treated, diflubenzuron $2x10^{-3}$%, chlorfluazuron $2x10^{-3}$%, $2x10^{-4}$% and PH 70-23 $2x10^{-2}$% completely inhibited egg hatching. Both sexes when treated, hatching inhibition was significant in all treatments. Diflubenzuron $2x10^{-2}$%, chlorfluazuron $2x10^{-3}$% and BASF LAB 153 959 I $2x10^{-4}$% produced no viable eggs and longevity of males treated with PH 70-23 $2x10^{-3}$% (5 days) was reduced significantly.

Chitin synthesis inhibitors were poor antifeedants. Still, chlorfluazuron at $2x10^{-2}$% inhibited 50.2% feeding over control.

Active residues of all the four compounds persisted on rice foliage against the fourth instar larvae of S. mauritia throughout a study period of 36 days. But their efficacy when subjected to weathering, decreased considerably.

2. Chitin synthesis inhibitors and Corcyra cephalonica

Ovicidal action of chitin synthesis inhibitors was low to medium in aqueous medium. But in methanolic medium, diflubenzuron and highest dose of PH 70-23 and BASF LAB 153 959 I showed enhanced ovicidal action. Other treatments caused low to medium action in methanolic medium also. In

general, there was no significant difference between the susceptibility of one and four-day old eggs.

On treatment of the second, fourth and seventh instar larvae with various doses of the chitin synthesis inhibitors, chlorfluazuron was found to be the most toxic followed by BASF LAB 153 959 I. Diflubenzuron and PH 70-23 were less toxic. Rate of mortality was high in early instars than in the late instars. Contact effect of compounds other than chlorfluazuron was low.

Last instar larvae when treated, larval-pupal mosaics, pupal mortality and emergence of malformed adults were caused. Chlorfluazuron was the most toxic compound. Contact effect of the treatments other than chlorfluazuron $2x10^{-2}$% was low. When prepupae were treated, treatments other than chlorfluazuron $2x10^{-2}$% (2.6% normal adults) allowed the emergence of 41.4 to 97.4% normal adults.

Pupae of C. cephalonica were less susceptible to the action of chitin synthesis inhibitors. Mortality of pupae and emergence of deformed adults from treated pupae was observed. Diflubenzuron $2x10^{-1}$% (27.6%) followed by PH 70-23 $2x10^{-1}$% (28.3%) and $2x10^{-2}$% (34.2%) caused the emergence of minimum number of normal adults. From other treatments 57.9 to 89.9% normal adults emerged.

Moths when topically applied with various doses of the chitin synthesis inhibitors, no adverse effect was observed on fecundity, hatchability of eggs or on the longevity of the treated moths.

3. Chitin synthesis inhibitors and Bracon brevicornis

Chlorfluazuron inhibited the emergence of adult parasites from treated hosts and adversely affected the progeny production of B. brevicornis. Diflubenzuron, PH 70-23 and BASF LAB 153 959 I were non-toxic or only slightly toxic to the parasite.

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* Original not seen

# EFFECT OF CHITIN SYNTHESIS INHIBITORS ON RICE SWARMING CATERPILLAR, *Spodoptera mauritia* (Boisduval) AND RICE MOTH, *Corcyra cephalonica* (Stainton) AND A LARVAL PARASITOID, *Bracon brevicornis* (Wesmael)

By

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ABSTRACT

Effects of four chitin synthesis inhibitors viz. diflubenzuron, chlorfluazuron, PH 70-23 and BASF LAB 153 959 I were assessed on two insect pests, the rice swarming caterpillar Spodoptera mauritia (Boisduval) and rice moth Corcyra cephalonica (Stainton) and on its larval parasitoid Bracon brevicornis (Wesmael).

Ovicidal action was assessed by treating one and two-day old eggs of S. mauritia in aqueous and methanolic media. It was low in aqueous medium. But in methanolic medium diflubenzuron and the highest doses of the other three compounds showed enhanced action. In general, high ovicidal action was observed in methanolic medium. There was no significant difference between one and two-day old eggs in their susceptibility to chitin synthesis inhibitors.

Chlorfluazuron was the most toxic causing cent per cent mortality at doses as low as $2 \times 10^{-5}$% when treated on second and fifth instar larvae of S. mauritia. Diflubenzuron, PH 70-23 and BASF LAB 153 959 I were also highly effective. Second instar larvae were more susceptible than fifth instar ones. Besides stomach action, a high degree of contact action was also observed.

Final instar larvae of S. mauritia when treated with the test chemicals, produced larval-pupal intermediates and caused pupal mortality and emergence of deformed adults. All the four moult inhibitors were highly active during larval-pupal transformation.

Pupae were less susceptible to chitin synthesis inhibitors. Yet, some treatments caused mortality and emergence of deformed adults. Chlorfluazuron was the most toxic to pupae.

Fecundity, hatchability of eggs and longevity were reduced when the male moths of S. mauritia were fed on sugar solution containing the moult inhibitors.

Antifeedant action of the chitin synthesis inhibitors was found to be less pronounced.

Residual effect of all the four compounds persisted on the treated rice foliage throughout a study period of 36 days. But the efficacy of residues exposed to sunlight and rain was very low.

Ovicidal action of the moult inhibitors was low to moderate on one and four-day old eggs of C. cephalonica in aqueous medium. In methanolic medium diflubenzuron at $2x10^{-1}$%, $2x10^{-2}$% and $2x10^{-3}$% and PH 70-23 and BASF LAB 153 959 I at

$2x10^{-1}$% caused enhanced ovicidal action. In general there was no significant difference between the susceptibility of one and four-day old eggs.

Chlorfluazuron was found to be the most toxic compound against larvae of C. cephalonica followed by BASF LAB 153 959 I. Diflubenzuron and PH 70-23 were less effective. Early larval instars were more susceptible. Contact action of compounds other than chlorfluazuron was low. Larval-pupal intermediates, pupal mortality and emergence of deformed adults were resulted when the last instar larvae of C. cephalonica were treated with the chemicals. Chlorfluazuron was found to be the most toxic compound. Prepupal treatment also caused the above juvenomimetic effects. But treatments other than chlorfluazuron $2x10^{-2}$% were less effective.

Treatment of pupae of C. cephalonica resulted in pupal mortality and emergence of deformed adults. But pupae were less susceptible to the moult inhibitors as compared to the larval stages.

External application of chitin synthesis inhibitors to moths of C. cephalonica had no adverse effect on fecundity, hatchability of eggs and longevity of the treated moths.

Chlorfluazuron was found to inhibit the emergence of adult parasites from treated hosts and adversely affect the progeny production of B. brevicornis. Diflubenzuron, PH 70-23 and BASF LAB 153 959 I were non-toxic or only slightly toxic to the parasite.