Effect of Sub-lethal Doses of Decamethrin And Carbaryl on the Orientation, Feeding Reproductive Rate and Survival of Key Pests of Brinjal, *Solanum melongena* L.

By

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THESIS

Submitted in partial fulfilment
of the requirement for the degree of

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Department of Agricultural Entomology
College of Horticulture

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Dedicated to my father
Late JANAKI RAM PADMANABHAN

DECLARATION

I hereby declare that this thesis entitled "Effect of Sub-lethal doses of Decamethrin and Carbaryl on the orientation, feeding, reproductive rate and survival of key pests of brinjal *Solanum melongena* L." 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 any other similar title of any other university or society.

Vellanikkara,
19 - 4 - 1989.

M.K. SHEILA

CERTIFICATE

Certified that this thesis entitled "Effect of sub-lethal doses of Decamethrin and Carbaryl on the orientation, feeding, reproductive rate and survival of key pests of brinjal Solanum melongena L." is a record of research work done independently by Smt. M.K. SHEILA, under my guidance and supervision, and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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We the undersigned, members of the Advisory Committee of Smt. M.K. SHEILA, a candidate for the degree of Doctor of Philosophy in Agriculture with major in Agricultural Entomology, agree that the thesis entitled "Effect of sub-lethal doses of Decamethrin and Carbaryl on the orientation, feeding, reproductive rate and survival of key pests of brinjal *Solanum melongena* L." may be submitted by Smt. M.K. SHEILA in partial fulfilment of the requirements for the degree.

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Introduction

INTRODUCTION

The current level of production of vegetables in the country is only 45 million tonnes as compared to the national requirement of more than 98 million tonnes, computed on the basis of the minimum dietary requirement of 280 g/day/person. The per-capita consumption of vegetables in Kerala is among the lowest in the country (8.395 kg/year) against the minimum requirement of 54.75 kg/year. In the state of Kerala, the shortfall in the production of vegetables is a staggering 1.159 million tonnes/year (Kerala Agrl. University, 1988). Augmenting the production of vegetable crops in the State is, therefore, a matter which should be given top priority. To bridge the shortfall in production, popularisation of vegetable crops with high production potential in relatively shorter periods should receive emphasis. While planning for producing more vegetables for domestic consumption in Kerala and elsewhere, the brinjal crop deserves to be popularised through intensive production drives, in view of its high production potential of up to 80 t/ha in a period of 150-160 days under the warm humid tropical conditions.

In order to realise the production potential of superior varieties of brinjel which are recommended for commercial cultivation, a rational strategy of pest management is indispensable. Among the pest complex associated with the brinjal crop, the fruit and the shoot borer *Leucinodes orbonalis* Guen. (Lepidoptera: pyralidae) is the most destructive one. The extent of damage caused by *L. orbonalis* in India has been estimated to range from 19.49 per cent (Thondadarya and Hiremath, 1983) to 59.10 per cent (Krishnamurthi Rao *et al.*, 1983). The important minor pests recorded on the crop in the peninsular India are the leaf hopper *Amrasca biguttula biguttula* Ishida, the epilachna beetle *Henosepilachna 28 punctata* (Fabr.) and the aphids *Aphis gossypii* Glover. The fruit and shoot borer being an internal feeder, need-based control operations cannot be successfully exercised. Therefore, scheduled applications of synthetic insecticides at intervals of 15 days during the cropping period starting from one month after planting is currently recommended against the fruit and shoot borer (Kerala Agricultural University, 1986). Among the synthetic insecticides which are recommended for scheduled applications, decamethrin at 0.005 per cent and carbaryl at 0.15 per cent have become very popular. Wherever scheduled applications of insecticides have become a routine practice, the tendency to apply sub-lethal concentrations is becoming more widespread in the country.

Resurgence of arthropod pests following pesticide application is a well documented phenomenon (Huffaker and Spitzer, 1950; Bartlett, 1968; Reynolds, 1971; Eveleens et al., 1973 and McClure, 1977). The stimulatory effects of the sub-lethal concentrations of insecticides on insect reproduction is also well documented in literature (Dittrich et al., 1974; El Lakwah and Salam, 1974; and Honek and Novak, 1977). The massive outbreak of the cotton white fly Bemisia tabaci Gen. and the widespread failure of the cotton crop in Andhra Pradesh due to extensive use of synthetic pyrethroids to control the boll worms of cotton and fruit borer in brinjal should be considered as a pointer to the magnitude of the havoc that can be caused due to resurgence of secondary pests. In the brinjal crop also, it is quite likely that on account of the scheduled application of decamethrin and carbaryl, the problem of resurgence of the secondary pests such as the leaf hoppers, the aphids or the epilachna beetles might come up in the near future.

The information available on the insecticide-induced resurgence hazards in several species of minor pests of the brinjal crop is very scanty. Such valuable information would be required to formulate rational pest management strategies to curb the resurgence of the primary and the secondary pests. The mechanism of resurgence needs to be fully understood with a view to counteract any tendencies in crop pests to resurge.

The present studies were taken up in this context to evaluate the effect of sub-lethal doses of decamethrin and carbaryl on the resurgence potential of three important minor pests of brinjal namely, the plant hopper (*A. b. biguttula*), epilachna beetle (*H. 28 punctata*) and the aphid (*A. gossypii*).

Review of Literature

2. REVIEW OF LITERATURE

The post-treatment resurgence of crop pests or secondary pests following the application of insecticides has been recorded for several crops including cotton, rice, citrus, brussels sprouts, corn, soybean, bhindi, mustard and straw berry. Reports on the effect of sub-lethal doses of insecticides on target insects have emerged mainly from studies on chemical control of pests. Reynolds (1971) made a fairly exhaustive general review of the problems of insect population upsets and resurgence of insect pests caused by pesticidal chemicals. Specific reviews on resurgence induced by sub-lethal doses of pesticides are very scanty. The up-to-date literature on the effect of sub-lethal doses of insecticides on insect and mite pests of crops is reviewed in this chapter.

The sub-lethal doses of toxicants are those which do not cause any mortality (Sutherland et al., 1967). However, since effects will generally, but not always be proportional to dosage, it is necessary to further define the sub-lethal level and its units of expression in order that the measurement of an observed effect be meaningful. Since insecticides vary considerably in the levels of their toxicity the sub-lethal dosages are to be expressed with reference to the lethal levels.

The LC_{50} per unit time can be considered as sub-lethal since the mortality expected is only 50 per cent of the test insect population for the time interval in question (Sutherland *et al.*, 1967). Knutson (1955) reported that in the case of *Drosophila melanogaster* exposed to lethal concentrations of dieldrin for a sufficiently longer period of time brought about mortality levels ranging between 66 and 99 per cent. The survivors from such treatments gave rise to 7.6 per cent more eggs, 5.6 per cent more maggots, 5.7 per cent more pupae and 5.8 per cent more of adults than in control flies. The increase in progeny production following treatment with dieldrin, was attributed to a direct reflection of extension of the life span of the survivors and the resultant realisation of better progeny production traits. The increased amount of yolk associated with greater number of eggs developing in the survivors might serve as innocuous storage sites for DDT (Sutherland *et al.*, 1967). Thus eventhough sublethal effects can be expressed in survivors from exposure to levels toxic to a proportion of the population, it will be essential that studies on the effect of sub-lethal dosages are essentially based on levels which are sub-lethal to the entire populations rather than a segment of the population.

Moriarity (1968) stated that the more persistent an insecticide is in an organism, the greater the likelihood of sub-lethal effects. Sub-lethal effects may be manifested, if insecticidal molecules sufficient to cause death do not reach the site of action.

Singh and Lal (1966) indicated that the possible reasons for all insects not uniformly getting lethal doses of insecticides include uneven application of insecticides, insects not coming in contact with the insecticide for sufficiently longer period and the insects getting themselves exposed to the residual effect of weak or partially deteriorated films of insecticides.

Sub-lethal doses of insecticides could influence the populations by affecting the survival pattern and reproductive potential of the individuals and by altering the genetic make-up of future generations (Moriarity, 1969).

2.1. Biological effects of sub-lethal doses of insecticides on insects and mites

2.1.1. Orientation

Perception of any feeding substance by house-flies causes the extension of the proboscis. Smith and Roys (1955) studied the acceptance threshold to sucrose solution for the tarsal chemoreceptors for DDT-susceptible and DDT-resistant strains of _Musca domestica_ and also for a strain of _Phormia regina_ susceptible to the toxicant. They have further reported that the lethal doses of DDT lowered the acceptance threshold of _M. domestica_ nine-fold in each susceptible strain, but the resistant strain remained unaffected. The rejection thresh-old for salt and alcohol in these insects were unaffected. It was further observed that the acceptance thresh-old to sucrose applied to the labellar chemoreceptor was reduced by a topical dose of DDT about 350 times lower than the LD_{50} and this minimum dose was only a quarter of that required to produce visible symptoms of poisoning. However, parathion showed no such apparent effect on chemoreception in _P. regina_ and _M. domestica_ (Solaiman and Cutkomp, 1963).

Titova (1968) conducted laboratory and field studies in the Soviet Union to determine the effects of insecticides on the surviving populations as well as on their progeny. The surviving insect populations after the treatments showed a reduced level of metabolism and were more resistant to many adverse environmental factors including insecticidal treatments. The increase in the number of such hardy individuals in natural insect populations was considered to be one of the reasons for the need to intensify insecticidal treatments to attain adequate levels of control. Titova did not mention the nature of insecticides which were used for testing.

Brady and Finley (1969) tested the disruptive effects of LD_{50} concentrations of dicrotophos on adults of the Indian meal moth *Plodia interpunctella* and found no reduction in male response to female sex pheromone as a result of such treatments. Schricker and Stephen (1970) reported the prevention of communication of information on food sources to the other members of the honey bee colony on oral administration of parathion. The moths of *Corcyra cephalonica* and *Cadra cautella* which had survived after exposure to malathion in storage godowns, were found to show whirling movements and frantic oviposition in nearby sites (Yadav, 1977). A close observation of oviposition under such a situation revealed frequent ejection of eggs and even the formation of a chain of immature eggs. After oviposition, the moths did not undertake much movements and then died.

Volney and Mc Dougell (1979) reported that permethrin acted as a motor stimulent to virgin females of the Eastern spruce bud worm moths *Choristoneura fumiferana*. When males were exposed to sub-lethal doses of permethrin, prostrate and unco-ordinated behaviour was dominant in the first 96 hours of treatment.

The odour emanating from the insecticide residue had no influence on the orientation of hoppers (Chellish and Heinrichs, 1980).

The sub-lethal activity of amidines on *Heliothis armigera*, *Pieris brassicae* and *Spodoptera littoralis* infesting cabbage was assessed by feeding these insects on cabbage leaves previously dipped in a suspension of amitraz at 0.5 g/l. It was found that the larvae spent more time moving around on leaves rather than showing a direct feeding response (Giles and Rothwell, 1983).

2.1.2. Feeding

Georghion (1965) evaluated the effect of sub-lethal doses of Isolan - a carbamate insecticide at 0.3 µg/fly on the house fly M. domestica. It was found that the treated flies consumed as much as 51.8 per cent less ^{32}P labelled milk than the untreated flies even up to eight days after treatment.

The rate of feeding of the ground beetles Harpalus rufipes, a predator of Pieris rapae larvae, was influenced by DDT applied to soil (Dempster, 1968). One-third reduction in feeding was recorded in insects occurring in soils containing 10 or 20 ppm DDT. P. brassicae larvae fed on meridic diet containing 0.75 ppm of DDT showed an overall reduction in food consumption but the digestibility of food and efficiency of conversion of ingested material into tissue biomass were higher than in control (Turunen, 1975). When resurgence-inducing insecticides such as decamethrin, methyl parathion and diazinon were sprayed on rice plants, the feeding rate of the brown plant hopper Nilapervata lugens was increased by 61, 43 and 33 per cent, respectively, as compared to control (Chelliah and Heinrichs, 1980). Sub-lethal doses of DDT and fenitrothion on cotton semilooper Achoea janata lowered the rate of food intake, but this treatment increased the weight gain and the digestibility of the food significantly over control (Ramdev and Rao, 1980). Tan (1981) investigated the antifeedant effect on the first and fifth instar larvae of P. brassicae at sub-lethal levels of cypermethrin and permethrin (1 mg ai/l) using leaf discs of brussels' sprout treated with pyrethroids by dipping in the insecticide. Permethrin was slightly more effective than cypermethrin as an antifeedant against fifth instar larvae of P. brassicae. However, the sub-lethal levels of cypermethrin which induced an antifeedant response of over 50 per cent against the fifth instar larvae were lethal to the first instar larvae. Gajendran et al., (1986) tested the effect of sub-lethal doses of four insecticides namely deltamethrin, methyl parathion, monocrotophos and carbaryl on the last instar nymphs of A. gossypii. Nymphs developing from the survivors were found to feed more than the control population. Nymphs treated with deltamethrin (LD_{10}) fed 21.29 per cent more than the nymphs from untreated check. Though methyl parathion at LD_{10} recorded an increased feeding rate at LD_{35}, carbaryl and monocrotophos at all sub-lethal dosages reduced feeding rate to a greater extent.

.1.3. Sex ratio and Reproduction

Singh and Lal (1966) observed no significant difference in the sex ratio of the first and second generation *Dysdercus koenigii* obtained from adults surviving various doses of DDT and endrin. The female-male ratio in the F_1 generation was shifted in favour of the females in the broads of *Tetranychus urticae* reared on carbaryl and DDT residues (Dittrich *et al.*, 1974). Studies to investigate the role of certain biological factors as possible cause for brown plant hopper resurgence indicated that, although there were more females than males in hoppers cultured on insecticide sprayed plants, the differences among treatments were not significant (Chelliah and Heinrichs, 1980).

Among the different effects of the sub-lethal doses of insecticides reported on insects, the impact on the reproductive potential is most pronounced. Such effects are reported to be either stimulatory or suppressive.

Huffaker and Spitzer (1950) reported stimulatory effect on the reproductive potential of the

European red mite Panonychus ulmi following the application of DDT. Outbreaks of the soft scale Coccus hesperidum (Bartlett and Ewart, 1951) and the frosted scale Lecanium pruinosum (Bartlett and Ortega, 1952) were recorded following application of DDT and lead arsenate. Application of parathion on European red mites occurring as a pest of apples led to rapid increase in the populations of these mites (Hueck et al., 1952).

Roan and Hopkins (1961) suggested that sub-lethal doses of insecticides might positively stimulate neural activity to bring about a favourable neuro-hormonal influence on insect reproduction. Apparent increase in the population of the treated strawberry aphid Caetosiphon fragalfoli, than in the control was detected to be caused by the application of phorate and disulfoton (Shanes, 1961). In experiments with the colarado potato beetle Leptinotarsa decemlineata it was found that sub-lethal doses of DDT or methyl parathion had a stimulatory effect on egg production (Kuipers, 1962). However, Adkinson and Wellso (1962) showed that sub-lethal doses of DDT brought about a decrease in the fecundity of the pink boll worm *Pectinophora gossypiella*. Exposure of grubs and adults of *Calandra oryzae* to sub-lethal doses of pyrethrins (3 ppm) reduced the reproductive potential of adults (Chadwick, 1962).

Aedes aegypti did not lay eggs until after a blood meal and although feeding and egg laying were unaffected by sub-lethal doses of dieldrin causing very little mortality, higher doses of dieldrin decreased egg laying. This has been attributed to lack of feeding (Duncan, 1963).

In studies on the effect of sub-lethal doses of carbaryl, methyl parathion and endrin applied topically to the larvae of *S. littoralis*, Essac *et al*. (1963) recorded an increase in the number of eggs produced by treated larvae as compared to the untreated individuals. According to Bordeaux (1963) increase in the arthropod populations following application of synthetic organic insecticides could not be solely attributed to the relaxation of the biotic stress from natural enemies, but mainly due to stimulatory effects on the populations.

The influence of insecticides on the reproductive potential of target insect species is highly variable. DDT at lower doses produced an unusual response in the viviparous individuals of Glossina palpalis which developed a lower percentage of fertile flies than in the control populations for all dosages tested. However, at higher doses of DDT the percentage of survivors which produced larvae showed an increasing trend. But most of the offspring thus developing did not survive to attain adulthood (Baldry, 1964). Topical application of half the LD_{10} dose, which had virtually no toxicity caused substantial decrease of egg production in M. domestica with four of the five carbamate insecticides tested and such reduction in fecundity could not be attributed to any decrease in feeding activity (Georghion, 1965).

Maximum reduction in the average number of eggs per female occurred in groups of the cotton bugs treated with higher doses. Singh and Lal (1966) applied graded doses of DDT and endrin on D. koenigii and found that the less toxic doses (sub-lethal) sometimes increased the fecundity but always reduced the percentage of ovipositing females. Similar results were obtained for M. domestica treated with γ BHC (Ramade, 1967).

Lucky (1968) developed the "hormoligosis" concept according to which sub-harmful quantities of any stressing agent will be stimulatory to the organism by providing it increased sensitivity to respond to changes in the environment and increased efficiency to develop new or better systems to fit a sub-optimum environment. Moriarity (1969) has reviewed in detail the effect of sub-lethal doses of synthetic insecticides on insects. Campion (1970) made a review of the influence of fifteen compounds applied to adult moths of red boll worm Diparopsis castenea. Sub-lethal doses of carbaryl led to a marked increase in the rate of oviposition.

Increased reproduction of Myzus persicae at sublethal doses of phosphamidon under caged conditions was observed by Parry and Ford (1971) and they suggested that it might be due to neuro-endocrine imbalance. The parental populations of female Tetranychus urticae kept on substrates containing residues of 200 ppm spray of carbaryl and 100 ppm of DDT showed significantly higher fecundity as compared to untreated individuals (Dittrich et al., 1974). Adult females of the F_1 populations also had a significantly higher egg production when kept on substrates containing residues of carbaryl and DDT.

Counterpoise hormoligosis involving the stimulation by small quantities of a stresser is implicated to be responsible for such effects rather than due to improved nutritional status resulting from altered physiology of the food plant. In S. littoralis at sublethal dose of phosfolan and leptophos an increased number of eggs laid per female as well as adult longevity was observed (Lakwah and Salam, 1974). Adults of the black carpet beetle Attagenus megatoma that survived sub-lethal doses of malathion and dichlorvos produced 63 and 74 per cent fewer larvae respectively than did untreated adults (Zettler and Lecato, 1974).

Shepard et al. (1977) reported resurgence of insect pests of soybean as a response to insecticides and field isolation. Treatment of soybean with methyl parathion and methomyl caused resurgence of most of the associated insect pest populations. When monocrotophos was applied, less resurgence occurred. They have further reported that newly established soybean fields in isolated situations were more prone to outbreaks of these pests than the fields which were cultivated every year. Upsurge of the storage pests C. cephalonica and C. cautella was observed in godowns when storage walls were sprayed with sub-lethal doses of malathion and DDVP (Yadav, 1977).

Chelliah and Heinrichs (1978) studied the effect of direct spray of sub-lethal concentration of certain resurgence-inducing insecticides on brown plant hopper. An increase in the fecundity of hoppers, sprayed with sub-lethal concentrations of methyl parathion, WL 43467 and FMC 35001 was recorded in this experiment. While evaluating insecticides against the pea aphid, *Acyrthosiphon pisum* Mueke *et al.* (1978) observed an increase in the population of pea aphid on the resistant varieties namely Dawson and Team when sprayed with leptophos both in laboratory and under field conditions.

When Kwan and Gatehouse (1978) applied permethrin at LD_{15} and LD_{30} dosages, the tsetse fly *Glossina morsitens morsitans* male survivors showed increased activity and a level of mating success equal to the untreated males, but in females fecundity was reduced. Heinrichs *et al.* (1978) suggested that resurgence inducing insecticides like decamethrin and methyl parathion could be utilised to induce heavy population build up of the brown plant hopper *N. lugens* so as to ensure field screening for resistance.

The reproductive rate of BPH was higher when they were confined on plants sprayed with the insecticides-methyl parathion and decamethrin at their late nymphal (fourth and fifth instar) and adult stages than from first instar to adult and second instar to adult stages (Chelliah, 1979). The effects of topically applied sub-lethal doses of carbofuran and carbaryl on the western corn rootworm Diabrotica virgifera have been studied by Ball and Su (1979). The mean number of eggs per female per day for insects treated with 0.0025 μg of carbofuran was significantly higher than for females treated with 0.000025 μg/insect or for the untreated individuals. In the case of carbaryl, the number of eggs deposited per female per day was significantly higher at the doses 0.0005 μg and 0.05 μg/insect.

Patil and Khanvilkar (1979) reported a reduction in the oviposition in the polyphagous pest S. litura when treated with LC_{30} and LC_{50} doses of parathion. Topical application of LD_5, LD_{10}, LD_{25} and LD_{50} of methyl parathion and decamethrin on fifth instar nymphs of the BPH, N. lugens caused increased reproduction in the resulting adults, although the dose for maximum stimulation differed between the two insecticides

(Chelliah et al., 1980). At LD_{50}, decamethrin stimulated reproduction in hoppers significantly. At this dose, there was an increase in the number of nymphs by over 75.0 per cent, followed by LD_5 (45.0 per cent), LD_{25} (30.0 per cent) and LD_{10} (21.0 per cent). In the group treated with methyl parathion, the number of nymphs was highest at LD_{25}, while perthane at all the sub-lethal doses did not cause significant difference in nymphal numbers. Heinrichs et al. (1982) investigated the effect of insecticide applications in low land rice, as influenced by method and timing of insecticide application. Stimulation of reproduction as indicated by the high BPH egg population in the insecticide-treated plots was the most important factor causing resurgence. Kempraj (1982) also recorded that when methyl parathion and cypermethrin were sprayed in rice fields, these caused resurgence of BPH. The sub-lethal effects of demeton -S- methyl on the development and fecundity of M. persicae were determined in laboratory studies in the United Kingdom. Fecundity during the first four days of reproductive life was higher for the progeny of treated aphids than for those of untreated aphids (Coombes, 1983). When tobacco bud worm (Manduca sexta) larvae were subjected to oral doses of fenitrothion ranging from 0.001 to 1.0 mg/kg body weight, the reproductive potential of the resulting adults was slightly higher than control (Steward and Philogine, 1983).

The effect of sub-lethal concentrations (LC_{15} and LC_{50}) of permethrin, fenvalerate, methamidophos and carbaryl on female fecundity of diamond back moth Plutella xylostella was investigated (Kumar and Chapman, 1984). Except permethrin, the other insecticides inhibited female fecundity. Treated females preferred to oviposit on untreated leaf discs rather then on those which were treated with the pyrethroids at concentrations equal to their LC_{50}. Dittrich et al. (1985) found that there was a stimulation in fertility in the white fly Bemisia tabaci developing on cotton plants due to DDT residues.

Balaji et al. (1986) tested the effect of spraying rice plants with synthetic pyrethroids on the population build up of the BPH, over two generations. They found that lower doses of decamethrin caused a stimulatory effect on the progeny production in N. lugens in the second generation. Decamethrin was found to retain the stimulatory effect even on the third generation progeny. Among the mechanisms of resurgence, reproductive stimulation in females receiving sub-lethal doses of insecticides and selective elimination of natural enemies were considered to be of major relevance. The resurgence inducing insecticides develop a favourable environment in the rice ecosystem for the BPH to orient, feed and reproduce, leading to build up of large populations which are injurious to the crop (Chelliah, 1986).

An upsurge of the yellow mite *Polyphagotarsonemus latus* on chillies following foliar application of monocrotophos, methyl demeton, thiometon, phosphamidon, formothion and neem cake extract was reported by David (1986). The stimulation in the reproductive rates due to the sub-lethal doses of these pesticides was implicated in the flare up of their populations. Sub-lethal effects of the four insecticides, deltamethrin, methyl parathion, monocrotophos and carbaryl were studied on the last instar nymphs of cotton aphid *A. gossypii* (Gajendran *et al.*, 1986). Deltamethrin registered the lowest LD_{50} value among these toxicants and at this level the insecticide increased the reproductive rate of the aphid.

2.1.4. Duration of immature stages and adult longevity

The extension of the adult life-span of females has been attributed as a possible reason for the increased rate of reproduction in D. melanogaster (Knutson, 1955).

The life-span of the treated female housefly became longer on exposure to the sub-lethal doses of dieldrin. The progenies from such individuals showed increased weights (Afifi and Knutson, 1956).

Adkinson and Wellso (1962) recorded a contrasting trend of shortening the longevity of the adult pink boll worm which survived treatment with low dosages of DDT. The average duration of the larval development period of the boll worm Heliothis zea surviving egg treatment with the insecticides endrin and a 1:1 mixture of azinphos methyl and azinphos ethyl was approximately two days longer than for the untreated control groups. However, the duration of the development period of the larvae of tobacco bud worm, Heliothis virescens was unaffected by the insecticidal treatment of eggs. The total developmental period of larvae of this insect treated with a mixture of azinphos methyl and azinphos ethyl (1:1) was approximately two days longer for boll worms and four days longer for the bud worm than for the untreated control groups of each species (Chauthari and Adkinson, 1966).

The oviposition period, fecundity and post-oviposition period of the female D. *koenigii* surviving the lower doses of DDT (0.006 to 0.03 per cent) and endrin (0.0015 to 0.004 per cent) were not significantly different from the control in both the adult and in the first generation individuals (Singh and Lal, 1966). There was no significant difference in the nymphal period and sex-ratio of the first and second generation populations emerging from adults surviving various doses of both the insecticides.

Madhavan *et al.* (1970) investigated the effect of sub-lethal doses of DDT, endrin, carbaryl, endosulphan and parathion on growth, developmental period and fecundity of *Tribolium castaneum* by rearing the insect in wheatflour medium containing sub-lethal concentrations of these insecticides. Treatment with sub-lethal doses prolonged the larval period in approximately direct proportion to the concentration of the insecticide while the rate of growth of the larva was supressed.

The longevity of the female western corn root worm D. *virgifera* topically treated with the sub-lethal doses of carbofuran at 0.0025 μg and 0.000025 μg per insect, was significantly greater than for control groups. There was no significant difference in longevity between the two doses (Ball and Su, 1979).

Chelliah (1979) reported decrease in nymphal duration of BPH when lower doses of diazinon (at 0.1 kg ai/ha) was applied to rice plants. There was no significant difference in the sex-ratio of the adult emergents among the treatments. The duration of nymphal stadia of hoppers developing on plants sprayed with methyl parathion or decamethrin did not differ significantly from that of control. However, the total nymphal duration was significantly different among the treatments. The hoppers developing on deltamethrin treated leaf surfaces completed their nymphal stage 1.1 days earlier than on control plants (Chelliah and Heinrichs, 1980).

A shortening of the larval duration in S. *litura* was reported by Patil and Khanvilkar (1979), following application of parathion at its sub-lethal concentration. Lengthening of the larval period of _P. brassica_ was observed when the fifth instar larvae were continuously fed leaves treated with the sub-lethal doses of cypermethrin and permethrin. The larval and pupal weights were also reduced due to this treatment. (Tan, 1981). A significant difference in the longevity and weight of female _Ischiodon scutellaris_ was observed when exposed to sub-lethal doses of malathion (Teh _et al._, 1983).

Ross and Brown (1982) reported the inhibition of larval growth of _Spodoptera frugiperda_ due to sub-lethal dietary concentrations of insecticides. Fenvalerate, permethrin, endosulfan, SD 35651 and cyromazine inhibited growth by more then 39 per cent while chloropyrifos, methyl parathion and piperonyl butoxide were less inhibitory to larval growth. Toxaphene, carbaryl, thiodecarb, methomyl, chlordimeform and imidazole produced only a transitory growth reduction, while methiocarb and the JH analogue methoprene increased growth.

Steward and Philogine (1983) studied the sub-lethal effect of fenitrothion on the development of a parental generation of _M. sexta_. Treated larvae took more time to reach the pupal stage and had greater larval body weights than control.

Sub-lethal effects of permethrin, fenvalerate, methamidophos and carbaryl on the diamond back moth, P. xylostella was investigated. The insecticides tested had a deleterious effect on the number of larvae which pupated, the pupal duration, the number of pupae which survived to adults and cocoon formation in pupae. Prolonged duration of the larval period and deformities in pupae were also detected (Kumar and Chapman, 1984). Significant differences in the nymphal duration and alate production were not recorded on A. gossypii when they were treated with sub-lethal doses of four different insecticides deltamethrin, methyl parathion, monocrotophos and carbaryl (Gajendran et al., 1986).

2.1.5. Survival

Though the longevity of the adult pink boll worm subjected to the low dosages of DDT was shortened (Adkinson and Wellso, 1962) the extent survival of the insect was found to be adversely affected by such treatments. Bariola and Lindquist (1970) investigated the effects of exposing the cotton boll weevil, Anthonomis grandis to sub-lethal doses of systemic insecticides, disulfoton, dicrotophos, monocrotophos and aldicarb. An increase in mortality was observed when the duration of exposure was increased and also when the dose was decreased. Sub-lethal doses of carbaryl (LD_{30}) significantly increased pre-oviposition and oviposition periods as well as male and female longevity in S. litura (Abo- Elghor et al., 1972)

Rudd et al., (1985) reported that sub-lethal doses of three selected insecticides had no influence on the survival of Thyridopteryx ephemeraeformis an important bagworm pest of Juniperus virginiana trees in Texas. B. tabaci assumed serious proportions on cotton and brinjal and several reasons have been attributed for its outbreak. David et al., (1986) ascribed this phenomenon to indiscriminate use of synthetic pyrethroids to suppress the boll worm pests of cotton and the fruit borer of brinjal. Patel et al., (1986) also reported the resurgence of sucking pests on cotton following the use of DDT and carbaryl. Increase in population of aphid and leaf hopper pests of cotton was recorded in plots which received synthetic pyrethroids. This was more pronounced in those plots which received lower doses of permethrin and deltamethrin (Ravindranath and Pillai, 1986).

2.2. Effects on field application

2.2.1. Effects on Plant growth and indirect effects on pest populations

At low levels, some of the organic pesticides provide a supplementary source of nitrogen, phosphorus and other nutritive elements and thus they tend to promote growth and development of the plants. Increase in fecundity of insects developing on such plants might be partly due to improvement of the nutritional status of the plant (Rudd, 1964). The effect of low doses of treatments of seeds of cotton with insecticides phorate, toxaphene and DDT on aphids and thrips was studied by Mistric and Mitchell (1966). Under such treatments fruiting was delayed but there was increase in yield of seed cotton with decrease in concentration.

Reghupathy and Jayaraj (1973) studied the pattern of infestation of the leaf hopper Amrasca devastans on bhindi plants which received soil application of disulfoton granules at 0.5 and 1.0 kg ai/ha at the time of sowing. They have observed that the populations of the test insect showed an increasing trend after loosing the toxic stimulus of the systemic insecticide. Since the involvement of predators was excluded in this experiment, the resurgence of the test insects was attributed to the improved nutritional status of the plants, characterised by the reduction in calcium. Reduction in the content of calcium brings about reduction in the mechanical strength of the cell wall which in turn promotes stylet penetration by the sucking insects. In the treated plants, there was an appreciable increase in the content of ammoniacal nitrogen, a condition which is very favourable for the nutrition of the associated insects.

Sithanantham *et al.* (1973) reported resurgence of *A. gossypii* on cotton plants that had received soil application of phorate and disulfoton granules. Lower carbohydrates, narrow C/N ratio and greater quantities of free amino acids were implicated as factors responsible for such resurgence.

Reghupathy and Jayaraj (1974) observed that the application of phorate through soil resulted in the resurgence of *A. gossypii* and *A. devastans* when the effect of the chemical vanished. They have attributed the pest flare up due to the alteration of the physiology of the plant by enhanced supply of phosphorus from insecticide. This was associated with increase in ammoniacal nitrogen, phosphorus and decrease in carbohydrates and calcium content which seemed to be favourable to the pests.

Lee (1976) reviewed the phytotoxic effects of carbofuran which may render the rice plants more favourable for the associated insects. Stabilization of the IAA content in rice plants due to inhibition of IAA oxidase, increase in the contents of chlorophyll A and B and higher nitrogenase activity in treated plants are indicated as the important factors that confers the phytotoxic effects on treated rice plants.

Relationship between improved growth of rice plants following insecticide application and the changes in the nutritional status of the plant have not been fully established. While studying the causes of resurgence of the blue leaf hopper Zygina maculifrons on the rice plant protected with systemic insecticides, Mani and Jayaraj (1976) reported that low content of calcium in treated plants contributed to resurgence.

On studying the effect of dipping chilli seedlings in three concentrations of different organophosphate insecticides namely phorate, carbofuran, quinalphos and methyl demeton on the growth of the plant, Sinha and Roy (1977) reported an increase in plant height and the fruit characters (length, number and weight) in these plants which were treated at the lowest concentrations. The fecundity of BPH increased when they were fed and allowed to oviposit on plants previously sprayed with NRDC 161, diazinon and methyl parathion at a stage when the toxic stimulus of the toxicants vanished and after the toxicity of the insecticide was lost (Chelliah and Heinrichs, 1978). The increase in fecundity was ascribed to the biochemical changes in host plant which might have indirectly affected the hoppers feeding on it.

Application of granular formulation of carbofuran in paddy fields significantly increased the height of rice plant (Heinrichs _et al_., 1978). Increased plant growth might contribute to resurgence as green healthier plants attracted more macropterous hoppers of _N. lugens_ to alight on luxuriantly growing plants. Increased rate of feeding, enhanced reproduction and extended longevity would also have contributed to the resurgence of the hoppers. Field tests carried out in India on the effectiveness of spray combination of Dipel (a preparation of Bacillus thuringiensis) and various chemical insecticides at their sub-lethal concentrations resulted in increased fruit yield in brinjal (Sekar and Baskaran, 1978).

A field evaluation on the efficacy of five different insecticides, monocrotophos, phosphamidon, dimethoate, carbaryl and aldicarb against aphids and jassids on okra was carried out by Patel et al. (1980). Five randomly selected plants were measured after nine weeks of germination so as to determine its effectiveness on growth of plants. An average increase in the plant height in aldicarb treated plots was reported.

Rice plants sprayed with methyl parathion and decamethrin produced more number of tillers and leaves . This increased growth caused the plants to be more attractive by the hoppers. Methyl parathion when sprayed on rice plants stimulated plant growth by increasing tiller number and leaf number (Heinrichs et al., 1982). Ahamed (1986) studied the relationship between the population of the cicadellid Amrasca biguttula biguttula in brinjal.

The number of individuals of the insects occurring on the crop was negatively correlated with plant height, number of leaves, number of flowers and fruit yield.

2.2.2. Effect on natural enemies associated with crop pests

Selective elimination of natural enemies due to lethal and sub-lethal doses of insecticides has been implicated as an important factor that regulates resurgence of phytophagous insects. Perhaps one of the striking cases was the classical example of biological control i.e., the cottony cushion scale Icerya purchasi and its predator, the vedalia beetle Rodolia cardinalis was upset by the use of DDT for other citrus pests in Central Africa (Debach, 1947). The complete defoliation of citrus plants in 1946 was attributed to the elimination of natural enemies. The elimination of various predatory mites due to pesticides used for the control of mites and insect pests resulted in several of the minor pests becoming major ones (Huffakker and Spitzer, 1950).

Destruction of natural enemy following intensive application of broad spectrum insecticide was suggested as an important factor for BPH resurgence in rice (Kirtani, 1972, 1975).

Correlation studies showed that natural enemy destruction provided a reasonable cause-effect explanation for all pesticide-induced outbreaks of mites and aphids. Newsom (1973) conducted experiments on the direct lethal effects of pesticides on parasites and predators. He suggested that various predatory species may be poisoned by feeding on prey intoxicated by feeding on plants treated with systemic insecticides. Sub-lethal effects of LD_{50} and LD_{90} dosages of carbofuran, methyl parathion and methoxychlor on the alfalfa weevil parasites, Microctonus aethiopoides was studied by Dumbre and Hower (1976). The parasites surviving exposure to LD_{50} doses of the insecticides during the adult or pupal stages showed a 25-50 per cent reduction in the life-span and a reduction in the reproductive potential by 40-60 per cent. Dyck and Orlido (1977) reported that, regular spraying with methyl parathion reduced the populations of the mirid predator Cyrtorhinus lividipennis resulting in substantial increase in BPH populations. Heinrichs (1977) cautioned that the use of insecticides for controlling the insects might not always be effective and this could produce considerable side effects. High toxicity of insecticides like methyl parathion to natural enemies of the BPH was implicated by Stapley et al. (1977) as one of the important factors for resurgence of hoppers. This conclusion was based mainly on the mortality of C. lividipennis an importent predator of hoppers.

Resurgence of the scale Fiorina externa on Hemlock following insecticide application was reported to be due to extinction of the parasites from the half sprayed portions (McClure, 1977). Chu et al. (1978) compared the relative toxicity of nine insecticides against rice pests and their natural enemies. Of these the compounds fenitrothion, methyl parathion and phenthoate were most toxic even at their low concentrations. Resurgence of BPH has been attributed to the destruction of natural enemies. The build up of the aphid and the mite pests of cotton, following the use of pyrethroids, was mainly due to mortality of predators (Sellammal et al., 1979). Syrett and Penman (1980) studied the toxicity of insecticides to lucern aphids and their predators. On the basis of LD_{50} values the insecticides were as toxic to both aphids and predators. A comparative study of the effect of some pesticides on three predaceous mite species Typhlodromus pyri, Amblyseius potentillae and A. bibens revealed that in abandoned orchards these predatory mites were able to keep the spider mites in check. Outbreaks of tetranychids occurred when the orchards were under pesticide treatment in a situation where the predatory mites were virtually absent (Overmeer and Vanzon, 1981).

The parasites Apanteles congregatus emerging from the larvae of M. sexta which were treated with low doses of methoprene (1μ) had pupated but were transformed into non-viable pupal-adult mosaics (Beckage and Riddiford, 1982). Jacobs et al. (1984) could not detect any sub-lethal effects on the number of egg deposited per host egg or on the sex-ratio of the resulting offspring of Trichogramma pretiosum exposed up to the LC_{55} of endosulfan or an LC_{90} of permethrin. Wan and Wen (1984) reported a high mortality of the natural enemies of cotton mites following the deltamethrin application.

Field plot tests carried out in India to determine the selective toxicity of some synthetic pyrethroids and conventional insecticides to the brinjal aphid predator, Menochilus sexmaculatus showed that the conventional insecticides were less toxic to aphids than the synthetic pyrethroids but gave high mortality of the coccinellid (Tewari and Moorthy, 1985).

In field and microplot experiments conducted by Natarajan et al., (1986) it was found that there was a very high increase in the population of aphid, A. gossypii following the treatments with synthetic pyrethroids in situations where the natural parasitism and predator population were less. Field and green house studies conducted to identify resurgence inducing insecticides and their toxicity to the mirid bug C. lividipennis and wolf spider Lycosa pseudoannulata the important natural enemies of BPH, it was revealed that all the insecticides were highly toxic to the predatory bug and the spider. The resurgence of the BPH was stated to be mainly due to a decrease in the natural enemy population (Raman and Uthamasamy, 1986). Rosenheim and Hoy (1988) investigated the impact of sub-lethal effects of insecticides on the parasitoid Aphytis melinus. Survivors from individuals exposed to carbaryl did not exhibit any significant sub-lethal effects, whereas exposure to the organophosphorus toxicants reduced their longevity by 73-85 per cent and also temporarily reduced progeny production. Chlorpyrifos also caused shifts in the sex ratios of the offspring in favour of dominance of the males.

Materials and Methods

3. MATERIALS AND METHODS

Laboratory and field studies were carried out to evaluate the effect of sub-lethal doses of decamethrin and carbaryl on the orientation, feeding, reproductive potential and survival of the following test insects:

a) Henosepilachna 28 punctata (Fabr.)
(Coleoptera; Coccinellidae)

b) Aphis gossypii Glover
(Hemiptera: Aphididae)

c) Amrasca biguttula biguttula Ishida
(Hemiptera: Cicadellidae)

Maintenance of stock cultures of the test insects

Rearing of H. 28 punctata

Grubs collected from field were used to establish nucleus culture of this insect. The grubs were reared on fresh brinjal leaves kept in glass petridishes of 15 cm diameter. Moistened filter paper discs were kept on the bottom of the dishes for keeping the leaves turgid. Fresh leaves were introduced every day to the container after removing leaf debris and excreta.

Immediately on emergence the adults were sexed and pairs were then confined in separate dishes for breeding and oviposition. Cotton swab soaked with diluted honey was kept in the petridishes for the adults to feed on. Eggs deposited on successive days were removed and kept for rearing to ensure availability of stages of the test insect of precisely known age. For hatching, the leaf bits containing the eggs were kept over a moist pad of cotton inside petridishes. The freshly hatched grubs were transferred to tender leaves as already explained before. On attaining the third instar 15 to 20 grubs were transferred to rectangular museum jars of size 13 x 13 x 20 cm and kept covered with muslin cloth held in position by rubber bands. Bouquets of brinjal leaves with their petiole ends dipped in water in glass vials were introduced into the museum jars for feeding. The required number of test insects were drawn from the battery of rearing jars.

All the glasswares used for rearing the test insects were washed thoroughly, rinsed with 80 per cent formaldehyde and then kept in hot air oven at 160°C for one and a half hours before use.

Rearing of A. gossypii

For establishing a stock culture of A. gossypii, a single apterous adult was initially collected from an untreated healthy brinjal plant grown under caged condition and this was then transferred on to another healthy potted 30 day-old brinjal plant of the type SM-6 using a camel hair brush, the bristles of which were slightly moistened. From among the F_1 progeny of this insect, five healthy apterous adults were then transferred individually to the potted plants in cages for further multiplication. The progenies developing from these insects were maintained in separate cages. Additional healthy brinjal plants were introduced into the cages when the host plants developed symptoms of wilting on account of feeding by A. gossypii.

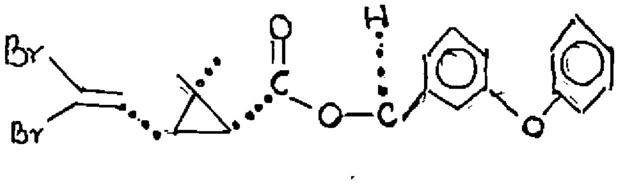
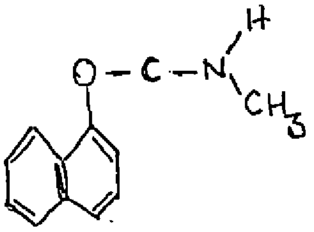
Rearing of A. b. biguttula

The breeding stocks of adult hoppers from untreated brinjal plants in the field were collected and released on young potted plants kept inside field cages. Freshly hatched nymphs on emergence were transferred to fresh seedlings of brinjal and kept inside field cages of the same size. Generations of the test insect were thus reared for experimental purposes.

Insecticides

The two insecticides decamethrin and carbaryl belonging to pyrethroids and carbamates respectively were selected for the study. Details about the test insecticides are as follows:

Table 1. Details of insecticides used in the experiments

Property	Test insecticide	
	Decamethrin (Deltamethrin)	Carbaryl
Trade name	Decis	Sevin
Formulation used	98.5% technical material	85% WP
Chemical name	(S) - -cyano-m-phenoxybenzyl (IR, 3R)-3-(2, 2 dibromovinyl)-2,2-dimethyl cyclopropanecarboxylate	1-Naphthyl N-methyl carbamate
Structural formula		
Empirical formula	$C_{22}H_{19}Br_2NO_3$	$C_{12}H_{11}NO_2$

Molecular weight	505.26	1.232 at 20°C
Melting point	98 to 101°C	142°C
Appearance	Odourless - Crystalline powder	Crystalline solid
Colour	Practically white	White
Solubility	Soluble in acetone, ethanol dioxan and most organic solvents. Practically insoluble in water (< 0.002)	Soluble in polar organic solvents - low solubility in water (40 ppm)
Stability	Very good - No degradation after 6 months at 40°C	Stable in storage
Acute dermal LD_{50} values (Rats)		500 mg/kg
Acute oral LD_{50} values (Rats)	135 mg/kg	400 mg/kg
Tolerance limit	0.05 mg/kg	
Practical application doses in agriculture (in g/ha of active ingredient)	5-17.5 g	750-1500 g
Source	Roussel Uclaf Division Agrovet 163, Avenue, Oambetta 75020, Paris, (France)	Union Carbide India Ltd., Middleton street, Calcutta 700 071

Laboratory studies

Fixing of sub-lethal doses for the test insects

Different concentrations of the test insecticides were prepared in 5 per cent benzene emulsion water (5 ml benzene + 0.5 ml of teepol + 94.5 ml distilled water). Suspensions of the insecticides at graded concentrations were applied at 5 ml of spray fluid per treatment topically to the fourth instar grubs of *H. 28 punctata* kept in petri-dishes of 15 cm diameter using a Potter's tower, keeping the pressure at 10 kg/cm^2. Two series of controls were run in this experiment, one for sprays of distilled water and the other for benzene-emulsion-water.

For determining the LD levels of 5, 10, 25 and 50 values of the insecticides, separate experiments were carried out. In order to fix up the graded concentrations for the different experiments, trials were initially conducted using several graded concentrations well below the recommended concentrations for field application which is expected to cause 95-100% mortality. Based on the mortality rates for such concentrations, the limits within which the required

LC levels would fall were determined. The approximate LC levels were also assessed in such probing trials.

Altogether five concentrations were tested in separate series around the approximate median concentration, two on the higher side and two on the lower side, the median concentration being the other. For each concentration, three replicates were run and there were ten insects per replicate.

After topical application of the insecticides, the petri-dishes along with the insects were dried for 15 min. under a ceiling fan and the grubs were transferred to clean Petri-dishes in which brinjal leaves of the optimum age were introduced for the grubs to feed. The mortality data were recorded after a period of 24 hours and these were corrected using the Abbott's formula. The LC values were computed following the standard procedure (Finney, 1952). Since the quantity of the toxicant used in each treatment was fixed (5 ml of fluid/treatment) the LD_{50} values were the same in the present studies.

The general methodology adopted for determining the sub-lethal concentrations of decamethrin and carbaryl in the case of H. 28 punctata was also followed in the case of A. gossypii and A. b. biguttula.

In the case of these two insects, the fourth instar nymphs were used for these experiments. The nymphs of A. b. biguttula were temporarily immobilised by keeping the stages of the insects in a refrigerator at 5°C for a period of 10 min.

3.1. Testing the effects of sub-lethal doses

3.1.1. Effect of treatment with sub-lethal concentrations on orientation

a) H. 28 punctata

To assess the orientational response of H. 28 punctata towards the plants treated with the sub-lethal concentrations of the LC 5, 10, 25 and 50 the experiments were conducted in field cages (size 180 x 90 x 90 cm) using potted plants (Plate-1). One month old potted plants were arranged in the cages in an oblong manner (Plate 1). Eight of the potted plants were treated each with 25 ml of the four sub-lethal concentrations of decamethrin and carbaryl using an atomizer. There were two controls - one with water spray and another with benzene-emulsion-water. Fifty numbers of one-day-old adults were transferred to a petridish and starved for 3 h. The petridish containing the insects

Plate 1 Field cages used for assessing the orientational response of H. *28 punctata*

Plate 2 Glass trough used to assess the orientational response of *A. gossypii*

Plate 1

Plate 2

Plate 1

Plate 2

was kept open in the centre of the potted plants at a height close to the canopy. The insects alighting in each of the potted plant were counted and collected using an aspirator at the end of 24 h. They were starved for a period of 3 h and kept in petridishes in the centre of the cages for re-determining their orientational response. The plants in the cage were rearranged before reintroduction of these insects. The response of the insects towards both treated and control plants was thus recorded at intervals of 24 h for 7 days.

b) *A. gossypii*

To evaluate the orientational response of *A. gossypii*, fresh healthy leaves were collected and 2 ml of the sub-lethal doses of the insecticides were sprayed on the lower leaf surfaces. Benzene emulsion water and distilled water treated leaves served as controls. Treated leaves were air dried and then placed in a circular manner over a labelled glass trough (diameter 30 cm) (Plate 2).

One hundred last instar nymphs of the test insect were kept in the centre of the trough and they were forced to disperse by allowing the leaf to wither. The number of nymphs reaching the treated and control leaves at the end of 7 h was recorded to determine the orientational preferences of the aphids to treated leaf surfaces.

c) A. b. biguttula

The experiments to determine the orientational response of these insects were carried out in small field cages which were illuminated from above by a fluorescent tube light (light intensity approximately 175 lux). Seedlings aged 25 days were sprayed with the sub-lethal doses of the insecticides and the root systems were immersed in water kept in conical flask of capacity 250 ml (Plate 3). These conical flasks containing the treated seedlings were then arranged in a circular manner inside the cage (60 x 60 x 90 cm) Fifty adults aged 10 days were released in the centre of the cage (Plate 3).

At the end of 1 h, the number of insects actually present on the treated plant and control plants were recorded. At the end of 60 min. the plants were rearranged and similar observations taken once again.

Plate 3

Plate 4

3.1.2. Effect of sub-lethal concentrations of insecticides on the extent of feeding

a) *H. 28 punctata*

Fresh uniform sized leaves of medium development (15-20 days) were taken and the lower surfaces were treated with the sub-lethal doses of the insecticides under the Potter's tower. The lower surface of the leaf was treated because the insects tend to aggregate more on this side. The treated leaves were dried and newly moulted fourth instar grubs were transferred to the leaves and kept in petri-dishes. Ten grubs were allowed to feed on the treated leaves for 8 h. The control sets were treated with BEW and distilled water. The area fed by the ten grubs was measured using a graph paper.

b) *A. gossypii*

To estimate the rate of feeding of *A. gossypii* on exposure to sub-lethal doses, radio active phosphorus (^{32}P) was used. Ten micro curies of ^{32}P were transferred to a conical flask (250 ml) and the volume of the solution in the flask was brought to 200 ml by adding distilled water. After thorough mixing 10 ml of this solution was pipetted out separately into different conical flasks (i.e. each flask contained 0.5 µCu) to each of which 240 ml distilled water was added. Thirty-day-old brinjal plants were placed in conical flasks (one plant/flask) in such a way that the root portion of the plants were fully immersed in the radioactive solution (Plate 4). The plants were allowed to absorb ^{32}P for a period of 36 h. They were then removed from the flasks and after washing the roots in distilled water the plants were introduced into another set of conical flasks containing distilled water. Fifty nymphs which survived the treatment with sub-lethal concentrations were then released to the plants (Plate 5 a). The flasks and plants were kept inside a cylindrical cage and allowed to feed for two days (Plate 5 b). Forty eight hours later, the test insects were removed from the plants and collected in scintillation vials. These vials were kept in an oven at about 50° to 60°C for 2 min. The vials were then taken out from the oven and 1.0 ml Lipo luma solution was added to dissolve this material followed by di-acid digestion (HNO_3-$HClO_4$). After digestion, the volume of the digest was brought to 200 ml with distilled water and radioactivity was determined by Cerenkov counting technique in a microprocesser

Plate 5(a) Nymphs of *A. gossypii* on leaves of ^{32}P labelled brinjal plants

Plate 5(b) Brinjal plant (^{32}P labelled) having *A. gossypii* kept inside cylindrical ges to assess feeding rate of the sect

Plate 5(a)

Plate 5(b)

controlled liquid scintillation system (Rack beta of LKB Wallac). The feeding rate was assessed indirectly from counts for the respective treatments.

c) A. b. *biguttula*

The procedure employed for A. *gossypii* was also followed for A. b. *biguttula*

3.1.3. The influence of topical applications of sub-lethal concentrations on the sex-ratio, reproductive potential, duration of immature stages and adult longevity

a) H. 28 *punctata*

Sex-ratio

The number of adult males and females developing from 50 grubs surviving from sub-lethal treatments were reared till becoming adults and their sex-ratio (female:male) was then worked out.

Reproductive potential

The sub-lethal doses of the insecticides were topically applied on the freshly moulted last instar grubs under potters tower at 10 kg/cm^2 pressure. Grubs treated with BEW and distilled water served as controls.

Twenty five grubs were taken for each treatment so as to get at least five successful mating pairs of survivors from each of the replications. Treated grubs were dried under the ceiling fan for 15 min. and were then carefully transferred on to fresh brinjal leaves. A pair of male and female insects was separated and this was confined in labelled petridishes. Fresh brinjal leaves and cotton swabs with honey were provided as food for the adults (Plate-6). The number of eggs deposited per female in successive days was recorded and the fecundity rates were thus worked out.

The number of days from egg laying to egg hatch was expressed as the incubation period.

For determining the egg hatch percentage leaf bits with egg masses having 100 numbers of eggs from each treatment were cut out with a fine pointed scissors carefully without causing any damage to the eggs. The eggs thus separated were placed over moistened cotton in petridishes and the number of eggs hatching out was recorded.

Ten numbers of freshly hatched grubs were separated out for each of the treatments and were then reared to adulthood. The mean number of days taken by the grubs to reach the pupal stage was expressed as the larval duration.

b) *A. gossypii*

Reproductive potential

To study the effect of topical application of decamethrin and carbaryl at their sub-lethal concentrations on the reproductive potential of *A. gossypii*, the test insecticides were applied topically on the last instar nymphs at 5 ml/replicate/treatment under a Potter's tower. Insects treated under the Potter's tower with BEW and distilled water served as controls. The initial number of insects in each replicate was so fixed at relatively higher levels in such a way as to get at least 10 survivors in each lot. After twenty four hours of treatment 10 survivors from each of the treated groups were drawn out and these were then transferred to 30-day-old potted brinjal plants. These plants were confined in cages with wooden frames

(60 x 60 x 90 cm) and covered with polynet having 25 meshes/cm^2(Plate 7). As the adults started reproducing, the progeny production was counted at intervals of every 24 h to assess the reproductive potential. The young ones after counting were removed from the plants leaving the adults to reproduce on the plants and thereby to realise the full reproductory potential.

The nymphs produced by the adult survivors exposed to sub-lethal concentrations of the test insecticides were removed immediately and reared on young potted plants (25-30 days-old). These plants were enclosed in round nylon film cages. Number of days taken by the nymphs to reach the adult stage in each treatment was recorded and expressed as the nymphal duration.

The number of days taken by the adults from emergence till death was expressed as adult longevity.

c) <u>A</u>. <u>b</u>. <u>biguttula</u>

Sex ratio

For determining sex ratio, nymphs obtained from the adults which had emerged from fourth instar nymphs previously exposed to sub-lethal doses of the insecticides were used. When the nymphs attained adulthood,10 individuals were sexed and the sex-ratio (female: male) was then worked out.

Reproductive potential

Healthy apical shoots of the brinjal plants of uniform growth and development were kept in an upright position inside specimen tubes of size 10 cms using cotton plugs. Small quantities of water were kept inside the specimen tubes to keep the shoots turgid and without fading. These were transferred to eight glass jars (13 x 13 x 20 cms) (Plate 8). Ten females of A. b. biguttula aged 8 days which had been exposed to different sub-lethal concentrations during their last nymphal instar were drawn out and then transferred into the shoots kept under confinement in glass jars covered with muslin held in position by rubber bands. The jars were kept at room temperature under fluorescent tube light continuously for 24 h. After this period, the insects were removed and the plant parts were treated with lacto-phenol reagent, to render the plant tissue transparent and thus to locate the eggs which were deposited into the plant parts

Plate 6 Oviposition cage for *H. 28 punctata*

Plate 7 Cage used to assess the reproductive potential of *A. gossypii*

Plate 8 Oviposition cage for *A. b. biguttula*

Plate 8

Plate 7

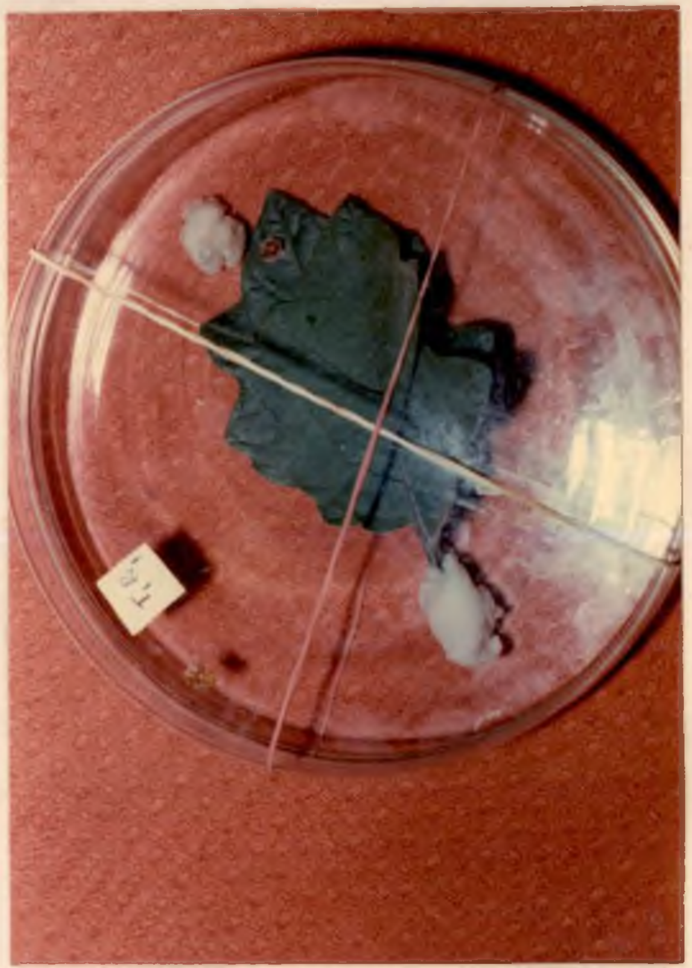


Plate 6

clearly visible. The number of eggs deposited in the shoots belonging to different treatments were thus recorded to assess the influence of the sub-lethal doses of insecticides in the test insects.

The procedure for calculating the nymphal duration was the same as that was described earlier for *A. gossypii*. The procedure for studying adult longevity of *A. b. biguttula* was same as that described for *A. gossypii*.

3.1.4. Effect of sub-lethal concentrations of decamethrin and carbaryl on the reproductive potential on F_1 and F_2 generations.

The aim of these experiments was to assess the effect of treatment of the parental, and the F_1 emergents with decamethrin and carbaryl at their sub-lethal concentrations. The effects of such treatments were studied mainly in terms of progeny production.

a) *H. 28 punctata*

Lots of fourth instar grubs (final instar) drawn from the stock culture were treated topically with sub-lethal concentrations of the two test insecticides (section 3.1. 3. a,) and they were reared on brinjal leaves until pupation in petridishes. On adult emergence five pairs of freshly emerged individuals were collected and these were confined separately in pairs in petri-dishes containing tender leaves of brinjal. The fecundity, egg hatching percentage, larval duration and adult longevity of the treated parental generation as well as the F_1 and F_2 generation were recorded by continuous rearing of the individuals under the same stress conditions from the particular sub-lethal concentrations of the insecticide.

b) *A. gossypii*

The fourth instar nymphs of *A. gossypii* emerging from a parental population exposed to the sub-lethal concentrations of the two test insecticides were again exposed to the same levels of sub-lethal doses by topical applications at its fourth instar stage and were further reared on brinjal plants as already described in section 3.1.3.b. The data on progeny production in the F_1 and F_2 generations were recorded in this experiment to assess the impact of successive treatments with the two test insecticides at their sub-lethal concentrations.

c) *A. b. biguttula*

Procedure followed under section 3.1.3.c. was adopted here too. Fourth instar nymphs emerging out from a parental population exposed to sub-lethal concentrations were again exposed to the same sub-lethal concentrations. The data on progeny production in the F_1 and F_2 generations were recorded in this experiment to assess the impact of successive treatments.

3.1.5. Effect of sub-lethal concentrations of decamethrin and carbaryl on the survival of the adults of insects

In this experiment, the adult survival percentages of the test insects were studied to assess the impact of treatment with sub-lethal concentrations of the insecticides on the pattern of survival of the insects.

a) *H. 28 punctata*

Fifty numbers of last instar grubs of this insect were topically treated with the sub-lethal concentrations of the two test insecticides and on adult emergence, three replications each containing five pairs of adults were run. The adults were confined in petridishes and fed with brinjal leaves of uniform age and texture. The replicates were kept under continuous observation and data on the number of survivors were recorded on every alternate day for upto 20 days after emergence, and expressed as per cent survival.

b) A. gossypii

From among the fourth instar nymphs of A.gossypii treated topically with the two insecticides at their sub-lethal concentrations, three replicates each consisting of 50 individuals were drawn out and these were confined on caged brinjal plants aged 30-35 day. The replicates were kept under continuous observation. The nymphs emerging out in the cages were removed at intervals of 8 h using the wet bristles of camel hair brush to retain only the adults. The data on the survival of adults were recorded at intervals of 24 h for a total period of upto 5 days.

c) A. b. biguttula

The same technique as detailed under A. gossypii was adopted for A. b. biguttula.

3.2. Field studies

The field experiment was conducted during the autumn season in the Instructional Farm of the College of Horticulture, Vellanikkara during 1985, adopting a randomised block design with three replications. Uniform sized 25-30 days-old brinjal seedlings of the type SM-6 were planted at a spacing of 60 cm. The gross plot size was 3.5 x 2.4 m. All the cultural operations except plant protection measures suggested in the Package of Practices of Kerala Agricultural University (1984) were followed.

The treatments were as follows:

T_1	Decamethrin	LC_5
T_2	"	LC_{10}
T_3	"	LC_{25}
T_4	"	LC_{50}
T_5	Carbaryl	LC_5
T_6	"	LC_{10}
T_7	"	LC_{25}
T_8	"	LC_{50}
T_9	Standard field dose (0.005%) for decamethrin	
T_{10}	Standard field dose for carbaryl (0.20%)	
T_{11}	Control with BEW	
T_{12}	Control with distilled water	

The first spraying was applied one month after transplantation. The second and third rounds of sprayings were given at intervals of 21 days. The pre-treatment observations on the incidence of the test insects were collected on the previous day before spraying and the post-treatment data were taken one week after insecticidal application. Six plants at the centre of each plot formed the observational unit.

3.2.1. Assessment of pest distribution

a) *H. 28 punctata*

For recording the occurrence of eggs and incidence of grubs and adults, 10 leaves of medium growth stage were selected at random from each of the six observation plants.

b) *A. gossypii*

One tender leaf from the top, middle and bottom portions of each of the six observation plants was selected at random and the number of aphids occurring on all the three leaves was directly counted to represent the population load. Counts of adults and nymphal stages were recorded from each leaf after gently turning the leaf to expose the ventral aspects of the lamina horizontally.

c) *A. b. biguttula*

The general procedure followed for recording population of *A. b. biguttula* was the same as in the case of A. gossypii. Since the adults and the nymphs, particularly the former were very agile with leaping movements, particular care was taken in taking the observations after turning the leaves in an extremely gentle manner without dislodging the individuals. The adults which tended to fly off from the sampling unit were also counted and recorded.

3.2.2. Plant growth attributes

The possible effects of the insecticides when applied at sub-lethal doses on growth of the plant were also assessed. For this 10 plants were selected at random from each plot. The following parameters were recorded.

a) Height of the plant

Height measurement was taken at the end of 10 days after treatment using a metre scale.

b) Canopy/spread of plant

The full canopy/spread of the plant was measured on the 10th day after applying the insecticide along the outer most circle as its perimeter.

c) Number of branches

The number of fresh branches appeared 10 days after the application of insecticides was recorded.

d) Yield

Number and total weight of fruit harvested at weekly intervals were recorded.

3.2.3. Presence of natural enemies

The pattern of occurrence of natural enemies after application of sub-lethal doses of insecticides was recorded.

3.2.4. Residue analysis

The residues of the insecticides in fruit harvested from plants treated with the sub-lethal doses of the insecticides were assayed chemically.

Detection of carbaryl residues

The simple colorimetric method suggested by Benson and Finneachiaro (1965) was adopted to detect carbaryl residues.

Reagents and chemicals used for the assay were the following:

a) Acetone

b) Methylene chloride

c) Activated charcoal

d) Anhydrous sodium sulphate

e) Coagulating solution: 1 g of ammonium chloride dissolved in 400 ml of distilled water and added 2 ml of orthophosphoric acid

f) Alcoholic potassium hydroxide (56 g of potassium hydroxide in 1 litre distilled ethanol)

g) Chromogenic reagent: saturated a cold mixture of 25 ml of ethanol and 2 ml of glacial acetic acid with para nitrobenzene diazonium fluoborate (about 25 mg) by mixing thoroughly for 2 or 3 min. Filtered through Whatman No.1 filter paper and kept cool.

Preparation of sample solution

Twenty five grams of the fruit sample was weighed and transferred into a conical flask (250 ml). Acetone was added just to soak the material which was kept for 24 hours. To this, methylene chloride was added and the contents were shaken in a shaker for half an hour. To this, a pinch of charcoal was introduced and again it was kept in the shaker. The contents were then filtered through anhydrous sodium sulphate and the volume was made upto 100 ml. This extract was allowed to evaporate in a beaker. The contents were washed with acetone (10 ml) which was transferred to 25 ml volumetric flask. Fifteen ml of the coagulating solution was added to this and the volume was made upto 25 ml with 10% aqueous acetone. Five ml of this was then transferred from the flask to B 19 tubes. It was then placed in ice bath below 4°C. It was then set for 3 min. after adding 2 ml of alcoholic potassium hydroxide by gentle swirling. Then 1 ml of acetic acid was added and was again shook for a while immediately. One ml of cold chromogenic reagent was added to develop colour. The absorbance was determined at 477 nm (wavelength observed to give the maximum absorbance) against a blank prepared from the fruit harvested from control plots.

Statistical analysis:

The data collected in various experiments were statistically analysed by following methods outlined in Panse and Sukhatme (1957). The LD_5, LD_{10}, LD_{25} and LD_{50} values of the insecticides were worked out by the method described by Finney (1952). Values were transferred into corresponding angles (Arc sine transformation) or to square root values on a need based manner and analysis was done. The control obtained due to insecticidal treatments was assessed over the post treatment counts.

Duncans multiple range test (DMRT) was applied for comparing the treatment means. Letter designation was applied for comparing the treatments.

The various laboratory experiments were carried out at ambient temperature and humidity conditions indicated in Appendix I.

Results

4. RESULTS

4.1. Sub-lethal concentrations of insecticides to test insects

The LD_5, LD_{10}, LD_{25} and LD_{50} values of decamethrin and carbaryl to the three test insects, epilachna beetle H. 28 punctata, brinjal aphid A. gossypii and the brinjal hopper A. b. biguttula are presented in Table 2. At LD_5 level decamethrin showed 1,00000, 1,76470 and 1,31250 per cent more toxic stimulus as compared to carbaryl for the insects H. 28 punctata, A. gossypii and A.b. biguttula respectively. At the LD_{10}, LD_{25} and LD_{50} levels also the incremental toxic potency of decamethrin was pronounced.

4.2. Biological effects of sub-lethal concentrations of insecticides on the test insects

4.2.1. Effect of treatment with sub-lethal concentrations on orientation

The influence of sub-lethal concentrations of insecticides on the orientation of the three test insects are presented in Table 3.

Table 2. Sub-lethal doses (LD_5, LD_{10}, LD_{25} and LD_{50}) of decamethrin and carbaryl to test insects

Insect	Insecticide	Dose - mg/10 insects			
		5	10	25	50
H. 28 punctata	Decamethrin	17×10^{-8}	67×10^{-8}	92×10^{-7}	97×10^{-6}
	Carbaryl	17×10^{-5} (1000)	18×10^{-5} (269)	98×10^{-5} (107)	82×10^{-4} (85)
A. gossypii	Decamethrin	17×10^{-8}	13×10^{-7}	18×10^{-6}	60×10^{-6}
	Carbaryl	3×10^{-4} (1765)	17×10^{-4} (1308)	43×10^{-4} (239)	68×10^{-4} (112)
A. b. biguttula	Decamethrin	16×10^{-8}	27×10^{-8}	19×10^{-7}	16×10^{-6}
	Carbaryl	21×10^{-5} (1313)	49×10^{-5} (1815)	45×10^{-4} (2368)	64×10^{-4} (400)

Figures in parentheses denote number of times increase in a given dose of carbaryl over decamethrin.

Table 3. Sub-lethal effects of insecticides on the orientational response of insects

Insecticide	Lethal dose (LD)	Number of insects		
		H. 28 punctata	*A. gossypii*	*A.b. biguttula*
Decamethrin	5	12.90 d	13.67 e	7.80 e
	10	9.62 c	6.67 cd	4.10 bcd
	25	6.86 b	4.33 abc	4.17 bcd
	50	4.86 a	2.00 ab	1.97 ab
Carbaryl	5	13.57 d	13.33 e	4.93 d
	10	8.00 bc	8.00 d	3.27 abcd
	25	4.81 a	3.67 abc	2.10 abc
	50	4.09 a	1.00 a	1.63 a
Check	(DEW)	17.62 e	22.00 f	9.30 ef
Check	(Plain)	16.67 e	22.67 f	10.73 f

The values followed by common letters within a column are not significantly different at 5% level (DMRT)

a) *H. 28 punctata*

The response of insects towards both treated and the untreated check plants recorded at intervals of 24 h upto seven days resulted in adults alighting more on the untreated check plants than on the treated ones. The number of insects alighting on the untreated check plants was significantly higher than with that of any of the insecticidal treatments. Among the different treatments there was a significant difference between the number orientating towards substrates which received lower and higher sub-lethal concentrations. The lowest concentrations of the two insecticides did not show significant differences. In the case of decamethrin, the number of *H. 28 punctata* alighting on plant treated with the LD_{50} concentration was distinctly lower than all the lower doses of LD_{25}, LD_{10} and LD_5. In the case of carbaryl also the trend of orientation was almost similar, the number alighting on the treatment with LD_{50} being significantly lower than in the case of LD_{10} and LD_5 treatments.

b) *A. gossypii*

The orientational response of *A. gossypii* was basically similar to *H. 28 punctata*.

The number of aphids moving towards treated leaves at the end of seven h showed that, the odour from the residues of both insecticides sprayed at their sublethal concentrations on the leaves did not elicit specific positive orientation response of aphids. The number of aphids alighting on treated leaves was significantly lower than in control. The minimum number of aphids settled on leaves treated with carbaryl at LD_{50} dose and this was lower than in the case of all other sub-lethal doses except decamethrin at LD_{50}.

c) A. b. biguttula

In respect of the number of hoppers alighting on treated leaves the variations were significant. The number of hoppers settling on decamethrin treated leaves at LD_5 level was on par with the control with BEW. At LD_{50} concentration of both insecticides, there was least attraction. The number of hoppers collected from leaves treated with the LD_{10} and LD_{25} doses for each of the test chemicals showed no significant difference.

4.2.2. Effect of treatment with sub-lethal concentrations of insecticides on the extent of feeding

The differential rates of feeding of H. 28 punctata on exposure to different sub-lethal concentrations of the two test insecticides are presented in Table 4 and that of A. gossypii and A.b. biguttula in Table 5.

a) H. 28 punctata

The feeding rates by the fourth instar grubs fed on leaves treated with different sub-lethal concentrations of the test insecticides showed significant variations. It was evident that, both insecticides at all four sub-lethal concentrations resulted in a reduction in the rate of feeding as compared to the untreated check. The range of reduction was between 28 and 71 per cent and 26 and 63 per cent for decamethrin and carbaryl respectively (Fig 1). The feeding was minimum in the case of the two insecticides at their LD_{50} levels and these were on par for both insecticides. At LD_5 and LD_{10} levels the feeding rates were on par.

b) A. gossypii

Feeding rates of A. gossypii (Table 5) nymphs surviving treatments with different sub-lethal concentrations

Table 4. Differential feeding rate of *H. 28 punctata* grubs on substrates treated with sub-lethal doses of insecticides

Insecticide	Lethal dose	Area fed (Sq.mm)	Per cent increase or decrease over check
Decamethrin	5	344.99 cd	(-) 40.27
	10	411.94 d	(-) 28.67
	25	232.77 ab	(-) 59.70
	50	164.44 a	(-) 71.53
Carbaryl	5	336.95 cd	(-) 41.65
	10	422.50 d	(-) 26.84
	25	288.61 bc	(-) 50.02
	50	214.03 ab	(-) 62.90
Untreated check	(BEW)	530.28 e	-
"	(Plain)	577.50 e	-

The values followed by a common letter are not significantly different at 5% level (DMRT).

Table 5. Differential feeding rate of *A. gossypii* and *A. b. biguttula* treated with sub-lethal doses of insecticides.

		A. gossypii		*A. b. biguttula*	
Insecticide	Lethal dose	cpm/50 insects	percent increase/ decrease over check	cpm/50 insects	percent increase/ decrease over check
Decamethrin	5	6.46 c (640.33)	- 4.87	9.09 g (8830.79)	+ 2.22
	10	6.96 d (1051.53)	+ 2.58	8.41 e (4509.76)	- 5.34
	25	5.89 b (361.77)	-13.16	7.94 c (2807.36)	-10.68
	50	5.42 a (225.65)	-20.11	7.24 a (1391.31)	-18.57
Carbaryl	5	7.09 d (1207.13)	+ 4.61	8.75 f (6310.69)	- 1.56
	10	6.73 cd (833.81)	- 0.84	8.18 d (3568.85)	- 7.98
	25	5.45 a (233.46)	-19.61	7.75 b (2326.22)	-12.79
	50	5.09 a (162.39)	-24.96	7.14 a (1257.65)	-19.70
Untreated check	BEW	6.75 cd (854.91)	-	8.87 f (7129.53)	-
"	Plain	6.78 cd (882.71)	-	8.89 f (7251.76)	-

Figures in parentheses are the retransformed values. Values followed by common letters within a column are not significantly different at 5% level (DMRT)

Analysis was carried out after square root transformation of the insecticide in terms of the radioactivity counts varied significantly between treatments. Decamethrin at LD_{10} and carbaryl at LD_5 showed a slight increase in feeding rates by 2.5 and 4.6 per cent respectively but it was not significantly different from the untreated checks (Fig.2). A significant reduction in the feeding rates was noticed at the highest sub-lethal level tested in which case the decrease was by 20.11 and 24.96 per cent respectively for decamethrin and carbaryl as compared to the untreated check. At LD_{50} level of decamethrin the feeding rate was distinctly lower than at LD_{25} dose and such a dose dependent reduction in extent of feeding was not manifested in the case of carbaryl.

c) *A. b. biguttula*

Indirect assessment of feeding rates of *A. b. biguttula* as influenced by treatment with sub-lethal concentrations of insecticides recorded as ^{32}P counts showed that decamethrin stimulated feeding in the nymphs at its lowest sub-lethal level of LD_5. Here, the per cent increase in feeding was by 2.22 over the untreated check (Fig 3). Carbaryl at LD_{50} dose showed a slight per cent reduction in feeding rate and at this dose the feeding rate was statistically on par with the untreated checks. All the other treatments

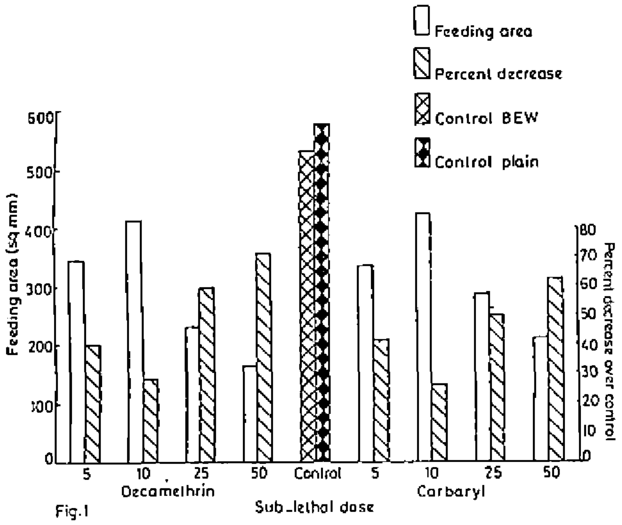


Fig.1

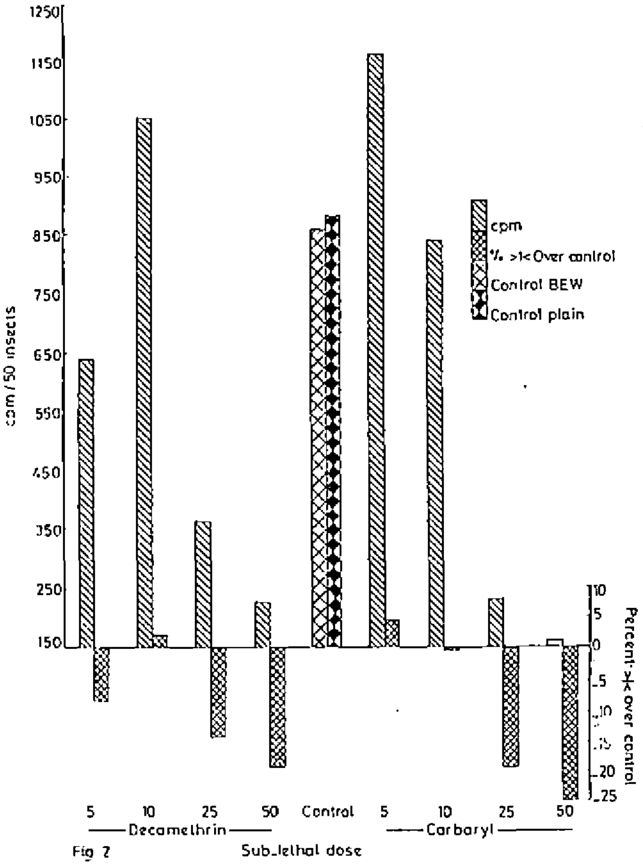


Fig 2

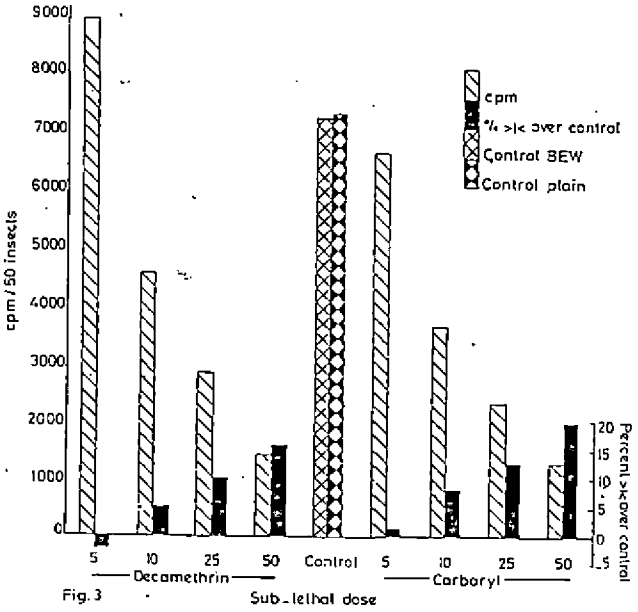


Fig. 3

resulted in reduction of feeding which showed an increasing trend at incremental doses of insecticides. The nymphs exposed to LD_{50} concentrations of both insecticides showed minimum feeding activity with a reduction of 18.57 and 19.10 per cent respectively for decamethrin and carbaryl.

4.2.3. Influence of topical applications of sub-lethal concentrations on the sex ratio, reproductive potential, immature stages and adult longevity

a) *H. 28 punctata*

Sex-ratio

The influence of the two test insecticides at their sub-lethal concentrations on the sex ratio (female: male) of the F_1 population (Table 7) did not show marked fluctuations. At the LD_{50} dose of carbaryl, there was 36.79 per cent reduction in the proportion of females while the corresponding reduction for decamethrin was 20.21 per cent. The increase in the proportion of females (70.94 per cent) at LD_5 level of decamethrin as compared to the proportion at LD_{50} of carbaryl was quite significant.

Reproductive potential

The influence of topical application of sub-lethal concentrations of the two test insecticides on the reproductive potential of H. 28 punctata are presented in Table 6.

The topical application of sub-lethal concentrations of decamethrin and carbaryl on the last instar grubs of H. 28 punctata showed similar effects in the adult emergents in respect of the number of eggs deposited. It led to reproductive stimulation of resulting adults, the dose for maximum stimulation being different for the two insecticides. Adults emerging out from the grubs surviving the treatments with decamethrin at its first three sub-lethal concentrations (LD_5, LD_{10} and LD_{25}) registered a significant increase in the reproductive rate which was higher than any of the corresponding sub-lethal concentrations of carbaryl. Those adults from treatments with decamethrin at LD_{25} produced the highest number of eggs (947.75 eggs/female) the increase in fecundity being 56.76 per cent over the untreated check (Fig 4 a). But, for carbaryl, among the above three sub-lethal levels, the oviposition by the adults from LD_5 remained without any significant change as compared the untreated checks. For both test insecticides, at LD_{50} there was a reduction in the average number of eggs laid. The lowest fecundity recorded was 90.55 eggs/female for the

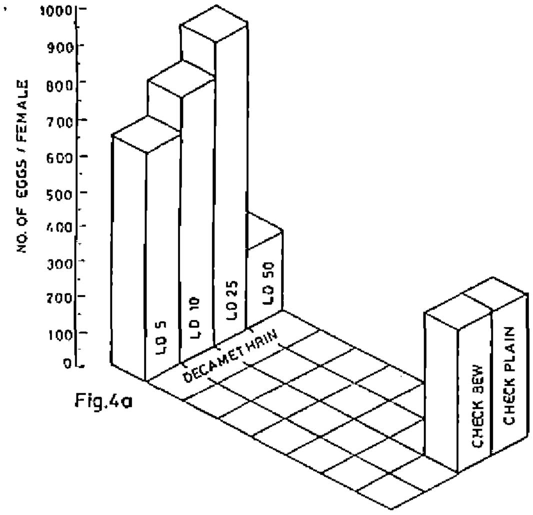


Fig.4a

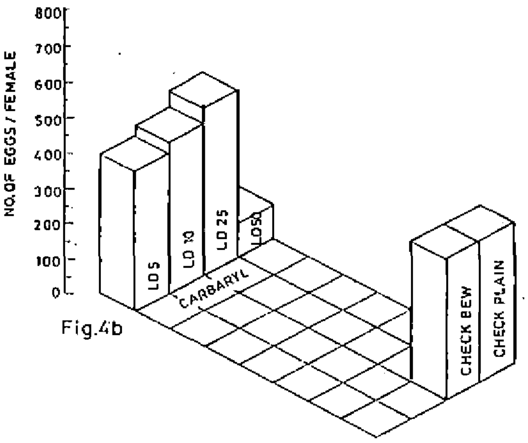


Fig.4b

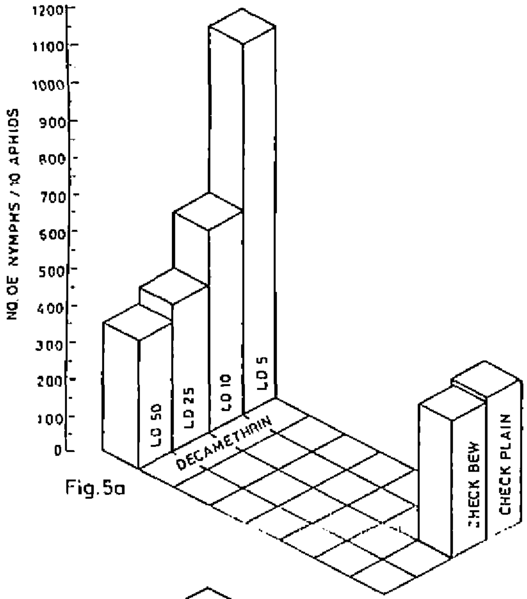


Fig.5a

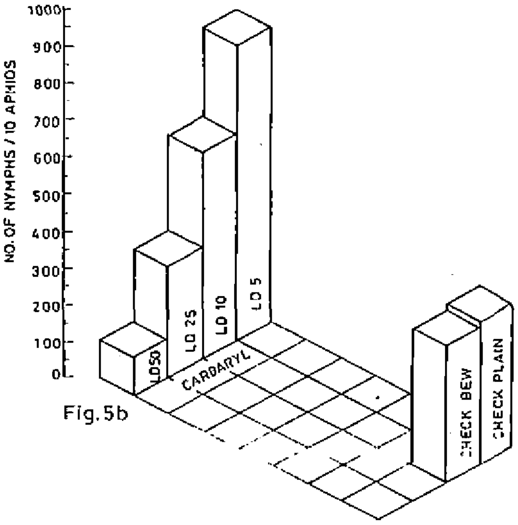


Fig.5b

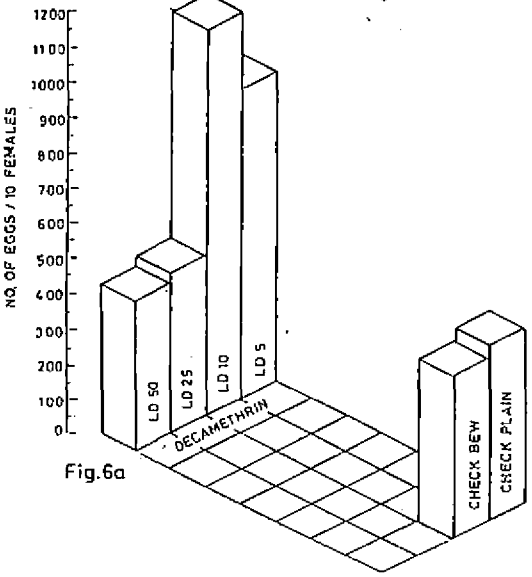


Fig.6a

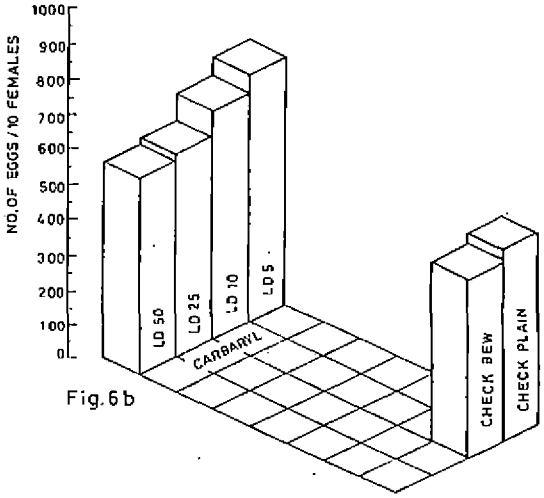


Fig.6b

adults emerging out from grubs subjected to treatments with carbaryl at LD_{50}(Fig 4 b). This was a decrease by 30.23 per cent over the untreated check.

Duration of immature stages

Incubation period

The incubation period of the eggs deposited by females emerging out from those grubs exposed to sub-lethal doses differed significantly. A notable decrease in the incubation period was detected in the eggs deposited by adults surviving the lowest sub-lethal level and with an increase in the concentration, the results were quite contrary (Table 6). Treatments with LD_5 dose of decamethrin resulted in producing eggs with the shortest average incubation period. Here, the grubs emerged out within a period 5.16 per cent earlier than those from untreated check. The incubation period on an average was extended to as long as 116.88 h as compared to 88.16 h over the untreated check (Fig 7) at LD_{50} of decamethrin, the per cent increase being 32.57. Similar reduction in incubation period were also rendered out by treatments with LD_5 and LD_{10} concentrations of carbaryl. The incubation period was still lower here at LD_5 which was only

Table 6. Effect of sub-lethal concentrations of insecticides on the reproductive rate, incubation period and per cent egg hatch of *H. 28 punctata*

Insecticide	Lethal dose	Fecundity		Incubation period (h)	Egg hatch	
		No. of eggs/ female	Transformed values		Per centage *	Transformed values
Decamethrin	5	663.58 (31.17)	25.76 e	83.60 b (-5.17)	71.30 (-17.02)	45.48 b
	10	761.93 (40.55)	27.60 e	96.72 c (9.71)	78.17 (-6.19)	51.41 ab
	25	947.78 (56.76)	30.79 f	98.56 c (11.79)	92.09 (22.36)	67.06 d
	50	223.08 (-23.95)	14.94 b	116.88 d (32.57)	78.80 (-5.21)	52.00 ab
Carbaryl	5	389.98 (0.56)	19.75 c	75.20 a (-14.70)	77.42 (-7.43)	50.74 a
	10	436.60 (6.40)	20.90 cd	85.04 b (-3.53)	86.52 (9.31)	59.91 bcd
	25	473.32 (10.90)	21.78 d	88.56 b (0.45)	87.53 (11.45)	61.08 cd
	50	90.55 (-30.23)	9.52 a	100.80 c (14.34)	72.90 (-16.42)	46.80 a
Untreated check	BEW	384.47	19.61 c	86.64 b	80.10	53.23 abc
"	Plain	385.69	19.64 c	88.16 b	81.72	54.81 abc

Figures in parentheses denote the per cent increase or decrease over untreated check. Analysis was carried out after square root transformation.

* Arc sine transformation was done.

The values followed by common letters within a column are not significantly different at 5% level (DMRT)

Table 7. Effects of sub-lethal concentrations of insecticides on the larval duration and sex-ratio of *H. 28 punctata*

Insecticide	Lethal dose	Larval duration (h)	Sex-ratio (Female: male)
Decamethrin	5	502.67 f (50.95)	3.67 b (70.94)
	10	468.67 a (40.74)	2.58 ab (+20.31)
	25	410.67 c (23.32)	1.88 ab (-14.62)
	50	330.33 a (-0.80)	1.71 ab (-20.21)
Carbaryl	5	470.33 e (41.24)	2.46 ab (14.72)
	10	440.00 d (32.13)	2.81 ab (30.08)
	25	384.33 b (15.41)	2.02 ab (-5.05)
	50	334.00 a (+0.30)	1.36 a (-36.79)
Untreated check	(DEW)	333.33 a	2.26 ab
"	(Plain)	333.00 a	2.15 ab

Figures in parentheses denote the per cent increase/decrease over untreated check

Values followed by a common letter within a column are not significantly different at 5% level (DMRT)

75.2 h. The increase at LD_{50} was 100.8 h which was by 14.34 per cent over the untreated check.

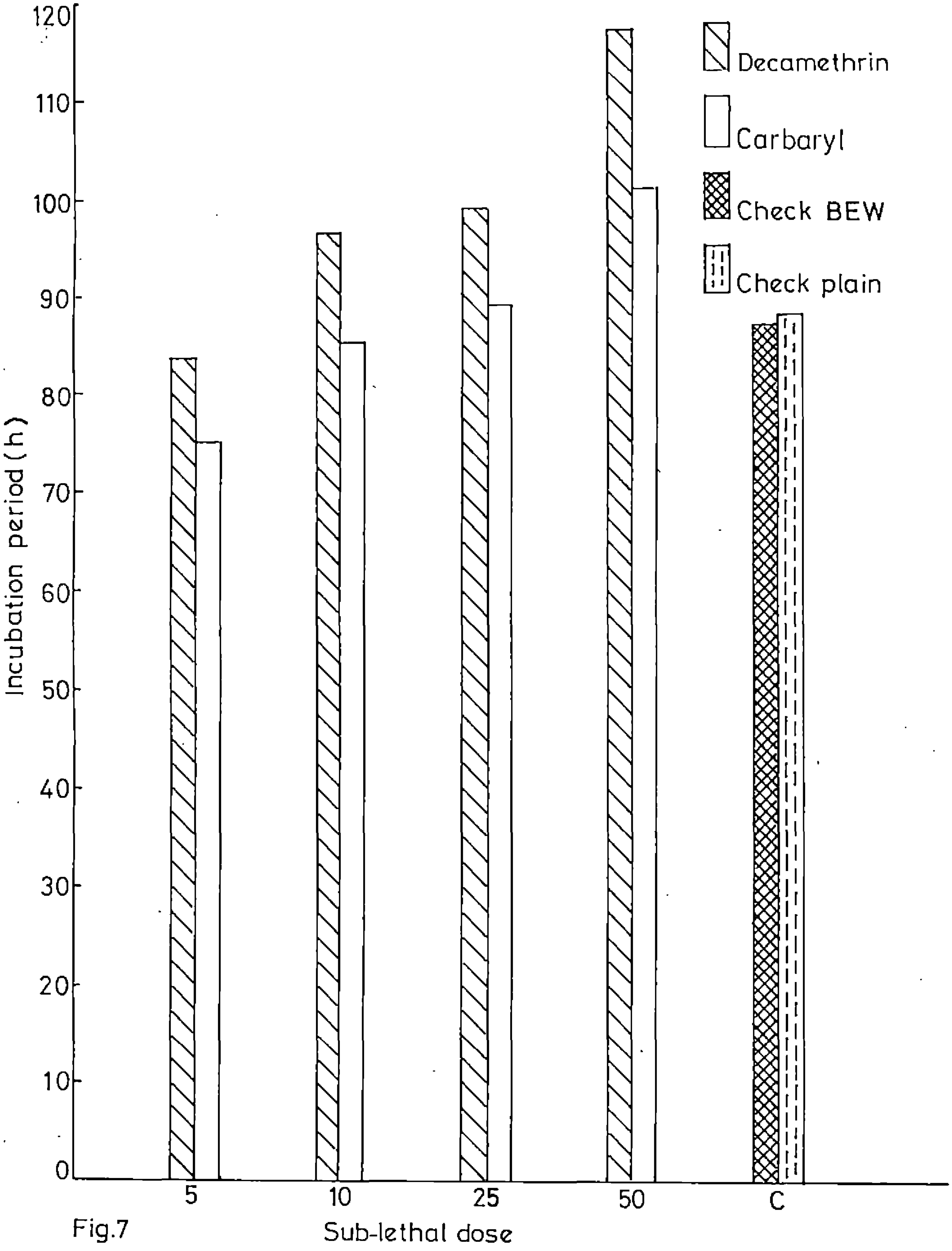
Egg hatch

In respect of the egg hatch, treatment with the two test insecticides showed significant impacts. There was a significant increase in egg hatch at LD_{25} for both the toxicants and also at LD_{10} dose of carbaryl (Table 6). Except for this all treatments showed a reduction in the viability of eggs over the untreated check which was within a range of 5.11 and 17.02 per cent (Fig 8).

Larval duration

The range in the larval duration for the different treatments was between 330.333 to 502.667 h (Fig 9). The maximum larval period was by those exposed to decamethrin at LD_5.

The influence of sub-lethal concentrations of the test insecticides on the larval duration was manifested in the form of a significant increase in the larval duration of the offsprings from different treatments except in those emergents from exposures to LD_{50} of both chemicals (Table 7).



Incubation period (h)
120
110
100
90
80
70
60
50
40
30
20
10
0
Decamethrin
Carbaryl
Check BEW
Check plain
5
10
25
50
C
Sub-lethal dose

Fig.7

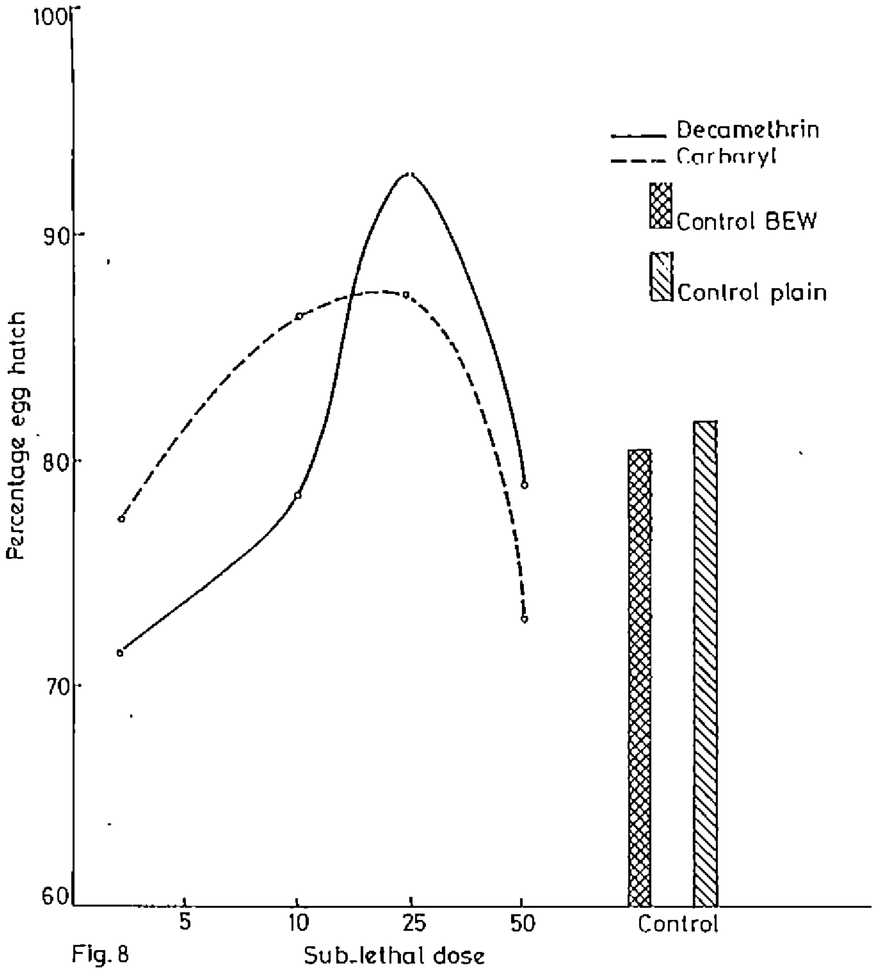

Decamethrin
Carbaryl
Control BEW
Control plain
Percentage egg hatch
100
90
80
70
60
5
10
25
50
Control
Sub_lethal dose

Fig. 8

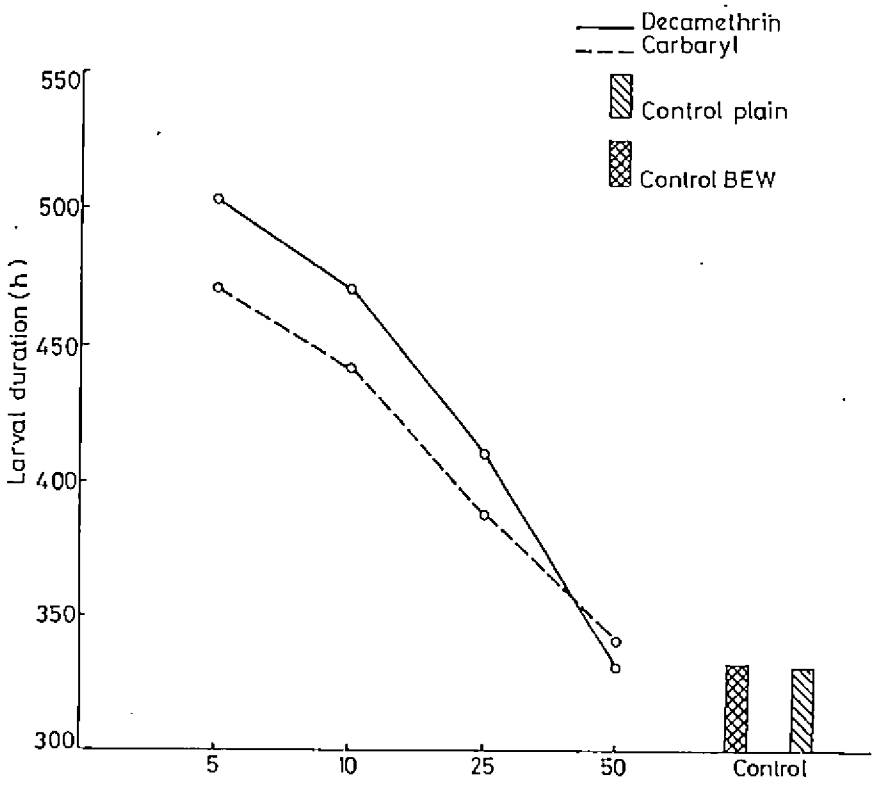

Decamethrin
Carbaryl
Control plain
Control BEW
Larval duration (h)
550
500
450
400
350
300
5
10
25
50
Control
Sub_lethal dose

Fig. 9

b) A. gossypii

Reproductive potential

Attempts to artificially induce oviposition in the apterous adult females of A. gossypii by exposing them to stress situations involving food scarcity under caged conditions were not found to be successful. A series of trials conducted under confinement of A. gossypii have showed that under stress conditions imposed by food shortages as well as under favourable conditions, parthenogenetic vivipary was the dominant mode of reproduction in A. gossypii. Therefore, the progeny production was recorded as a measure of the reproductive potential of the aphid.

Topical application of some of the sub-lethal concentrations of decamethrin and carbaryl on the last instar nymphs of A. gossypii led to reproductive stimulation in the adult emergents. At LD_5 and LD_{10} of both test chemicals, there was a significant increase in aphid reproduction. In control, ten aphids gave rise to 400.84 nymphs, as compared to the corresponding number of 999.38 from those surviving LD_5 decamethrin treatments, the per cent increase being 57.9. At LD_{10} of decamethrin the increase was by 20.41 per cent over the untreated check (Fig 5 a). In the case of carbaryl the improvement in fecundity was not as strikingly manifested as in the case of decamethrin. With carbaryl the number of nymphs was highest at LD_5 - the per cent increase over untreated check being 40.65 and at LD_{10} the increase was by 20.92 (Fig 5 b). However, aphids surviving the treatments with LD_{25} and LD_{50} concentrations of both chemicals resulted in the production of nymphs the total numbers of which were on par with the untreated checks (Table 8).

Nymphal duration

The duration of the nymphs emerging out from the adults subjected to topical applications of sub-lethal doses of the test chemicals in their last instar nymphal stages ranged from 163.6 to 201.366 h (Table 8). The total nymphal duration showed significant treatment differences. Aphids completed their nymphal stage earlier at all the tested sub-lethal doses of decamethrin and the two lower doses LD_5 and LD_{10} of carbaryl. At LD_5, the shortening of the nymphal duration was 16.05 and 14.90 per cent respectively, for decamethrin and carbaryl as compared to checks (Fig 10). However, a prolongation in the duration at the two sub-lethal doses of LD_{25} and LD_{50} of carbaryl was noticed, but this was not significantly different at 5 per cent level from controls.

Table 8. Effect of sub-lethal concentrations of insecticides on the reproductive rate, nymphal duration and adult longevity of *A. gossypii*

Insecticide	Lethal dose	Reproductive rate		Nymphal duration		Adult lon gevity (h
		No. of nymphs/10 aphids	Per cent increase/ decrease over check	Hours	Per cent increase/ decrease over check	
Decamethrin	5	31.61 e (999.38)	57.90	163.60 a	-16.05	374.40 c
	10	24.11 c (581.19)	20.41	173.27 ab	-11.08	341.37 bc
	25	19.95 b (397.92)	-0.36	170.00 ab	-12.76	327.43 b
	50	19.35 b (374.58)	-3.33	181.20 b	- 7.01	280.56 a
Carbaryl	5	28.16 d (792.93)	40.65	165.83 a	-14.90	328.80 b
	10	24.21 c (586.07)	20.92	177.85 b	- 8.73	311.20 ab
	25	17.69 b (313.18)	-11.61	200.23 c	+ 2.75	322.96 ab
	50	10.32 a (106.39)	-48.40	201.37 c	+ 3.34	310.64 ab
Untreated check	DEW	19.88 b (395.17)		194.53 c		319.20 ab
"	Plain	20.04 b (400.84)		194.87 c		329.36 b

Figures in parentheses denote the retransformed values. The values followed by common letters within a column are not significant at 5% level (DMRT)

Adult longevity

The effect of topical application of sub-lethal concentrations of the test insecticides on the longevity of adults of *A. gossypii* is presented in Table 8. The adult aphids in control showed the maximum life-span of 329.36 h. With decamethrin at LD_{50} there was a significant reduction in the adult longevity as compared to the untreated check. In this case the adults lived for a mean of 280.56 h as compared to 329.36 h in control (Fig 11).

c) *A. b. biguttula*

Sex-ratio

The influence of sub-lethal concentrations of decamethrin and carbaryl on the sex ratio (female:male) of *A. b. biguttula* showed appreciable changes (Table 9). There was a shift towards males at LD_{25} concentrations for both insecticides and LD_{50} of decamethrin. At LD_5 of decamethrin a strong shift in favour of females was recorded. Decamethrin at LD_{10} and carbaryl at LD_5 also resulted in more number of females. The ratio was on par with untreated check at the other two tested levels.

Table 9. Effect of sub-lethal concentrations of insecticides on the reproductive rate, nymphal duration, adult longevity and sex ratio of A. b. biguttula

Insecticide	Lethal dose	Fecundity		Nymphal duration (h)	Adult longevity (h)	Sex ratio (female: male)
		No.of eggs laid/10 females in 24 h.	Transformed values			
Decamethrin	5	218.36 (25.85)	14.78 c	140.80 e (12.10)	259.20 c (107.69)	2.87 d (115.10)
	10	276.52 (41.62)	16.63 d	132.00 de (5.1)	166.40 b (33.33)	1.77 bc (32.56)
	25	113.29 (-9.35)	10.64 a	110.40 cd (-12.10)	152.80 b (22.44)	0.89 a (-33.23)
	50	106.01 (-12.31)	10.29 a	61.60 a (-50.96)	70.40 a (-43.58)	1.17 ab (-12.45)
Carbaryl	5	171.14 (11.41)	13.08 b	101.60 bc (-19.11)	246.40 c (97.44)	2.03 c (52.51)
	10	163.48 (8.89)	12.79 b	114.40 cde (-8.92)	237.60 c (90.38)	1.33 abc (-)
	25	143.30 (1.95)	11.97 ab	82.40 ab (-34.39)	64.80 a (-48.08)	1.00 ab (-24.98)
	50	140.97 (1.12)	11.87 ab	119.12 cde (-5.16)	71.20 a (-42.95)	1.33 abc (-)
Untreated check	DEW	128.39	11.33 ab	128.80 cde	128.80 b	1.77 bc
"	Plain	137.87	11.74 ab	125.60 cde	124.80 b	1.33 abc

Figures in parentheses denote per cent increase or decrease over untreated check.

Values followed by common letters within a column are not significantly different at 5% level (DMRT)

Reproductive potential

Ten day old adult females were exposed to terminal plant parts treated with the sub-lethal doses of decamethrin and carbaryl to study the influence of such exposures on their reproductive potential. The method followed for A. gossypii did not succeed for A. b. biguttula due to failure of realising the fecundity potential under continuous laboratory rearing from treated nymphs.

The rate of reproduction of the hoppers exposed to four sub-lethal concentrations of the two insecticides released on plant parts in 24 h was thus recorded (Table 9). There were significant differences among the different treatments in respect of fecundity. Decamethrin at two lower sub-lethal levels could be ranked as LD_5 and LD_{10} in the descending order in terms of fecundity levels realised (Fig 6a). The differences between the doses LD_{25} and LD_{50} were not significant. At the LD_{25} and LD_{50} levels, there were reduction in fecundity to the time of 9.35 and 12.31 per cent over control but the differences from control were not significant. In the case of carbaryl, for LD_{25} and LD_{50} levels, the mean number of eggs deposited were on par with the untreated check (Fig 6 b). The two lower levels of LD_5 and LD_{10}, however, showed a slight increase in oviposition to the extent of 8.89

and 11.41 per cent over control at LD_{10} and LD_5 respectively. But in this case the differences with the control was not significant.

Nymphal duration

It was found that topical application of the sub-lethal concentrations of decamethrin had a direct influence on the nymphal duration of the resulting offsprings than in the case of carbaryl (Fig 12). The duration of the nymphal stage was maximum in the case of survivors from the treatments with decamethrin at LD_5 (140.80 h) and this was minimum at LD_{50} (61.60 h) level, the difference between the four tested sub-lethal levels of decamethrin being statistically significant (Table 9). In the case of carbaryl treatment, the nymphal duration at sub-lethal doses showed relatively less amount of variation as compared to control. The LD_{10} and LD_{50} levels were on par with the untreated check, while LD_5 and LD_{25} has showed a significant reduction in the nymphal duration over the untreated check.

Adult longevity

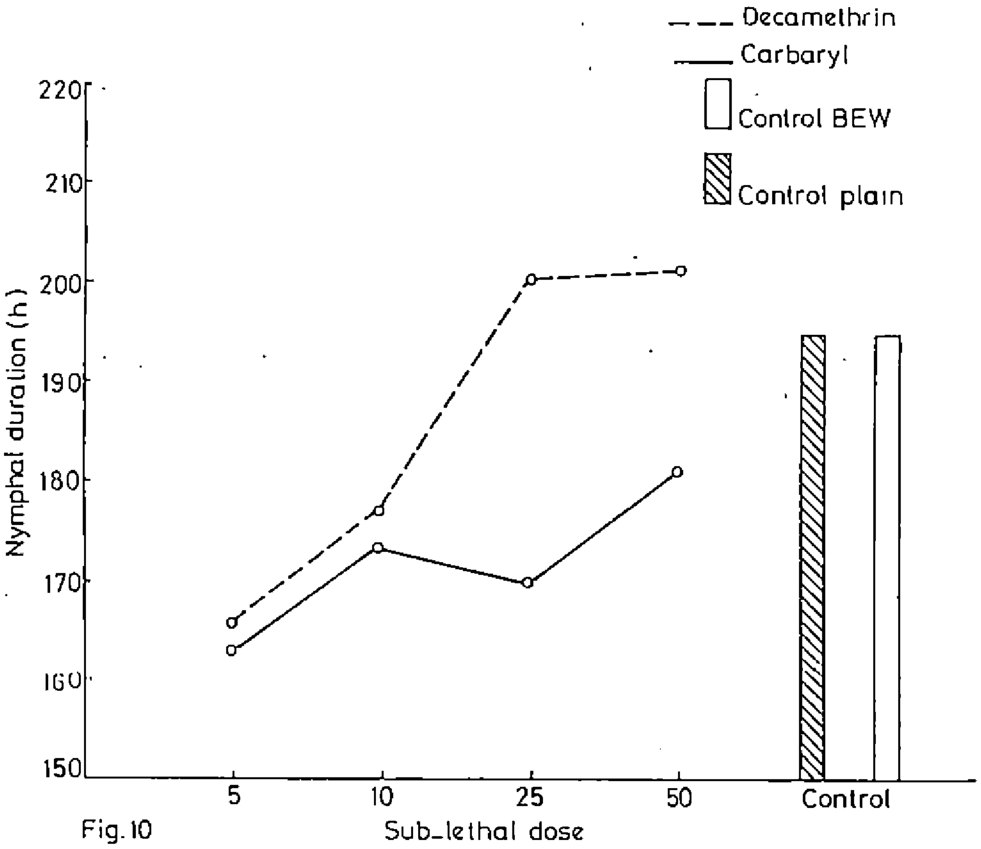
There was a significant difference in the longevity of the emerging adults which were topically treated with the four sub-lethal concentrations of the two test insecticides during their last nymphal instar (Table 9). Adults lived for a shorter time at the highest sub-lethal concentrations of both chemicals. On an average, the hoppers lived for only 70.40 h at LD_{50} of decamethrin and for 74.8 and 71.2 h respectively at LD_{25} and LD_{50} of carbaryl (Fig 13). But a remarkable prolongation in the adult duration was recorded at treatments of decamethrin at LD_5 and carbaryl at LD_5 and LD_{10}. They lived up for a considerably longer periods of about 107.69 per cent more than the untreated check when they were topically exposed with LD_5 concentrations of decamethrin.

4.2.4. Effect of application of sub-lethal concentrations of decamethrin and carbaryl on the reproductive rates of the F_1 and F_2 generations.

a) H. 28 punctata

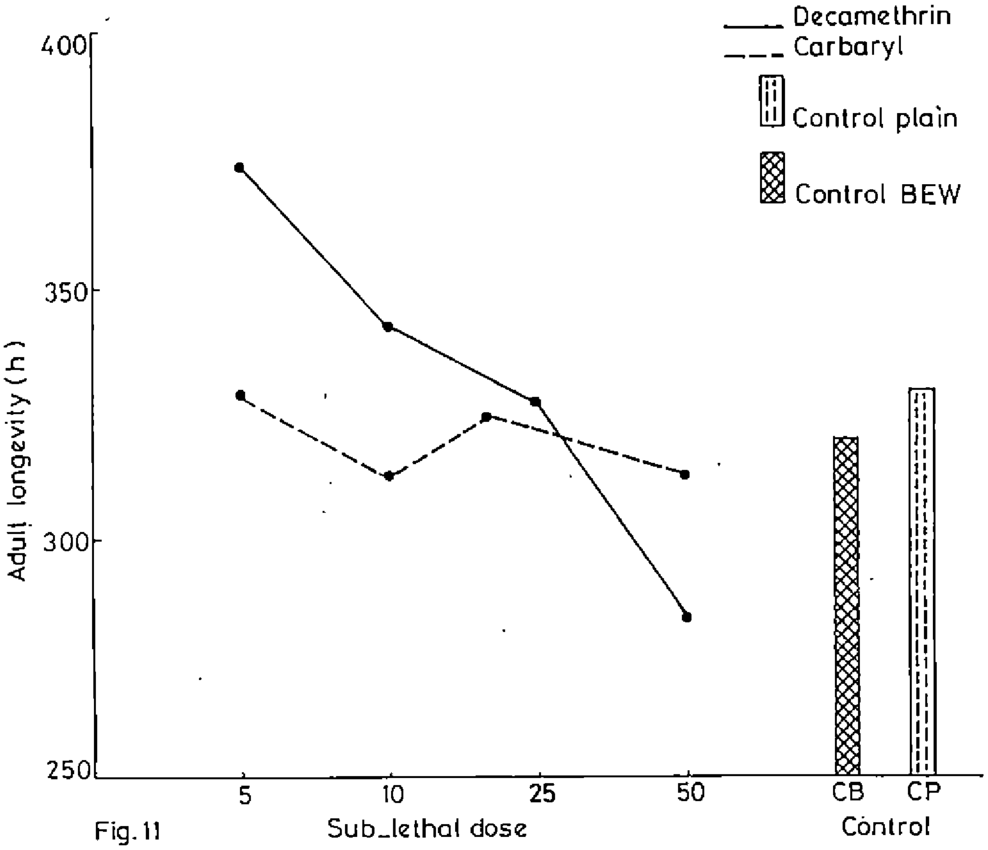
Fecundity

The effect of exposure of sub-lethal doses of the two insecticides on the reproductive rate of H. 28 punctata up to three generations is presented in



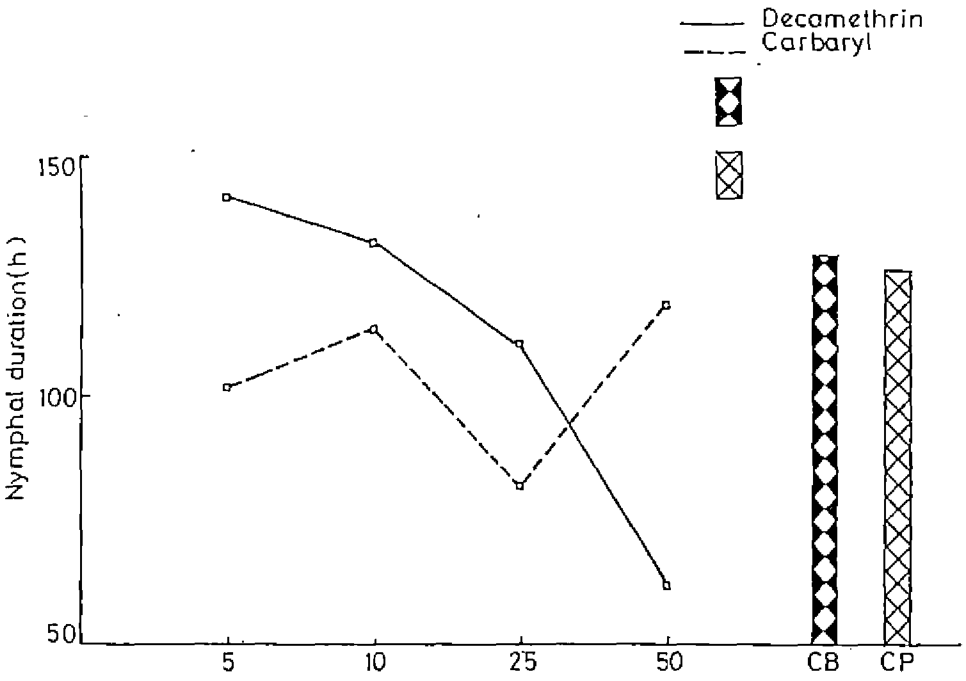
– – – Decamethrin
—— Carbaryl
☐ Control BEW
▨ Control plain
220
210
200
190
180
170
160
150
Nymphal duration (h)
5
10
25
50
Control
Sub_lethal dose

Fig. 10



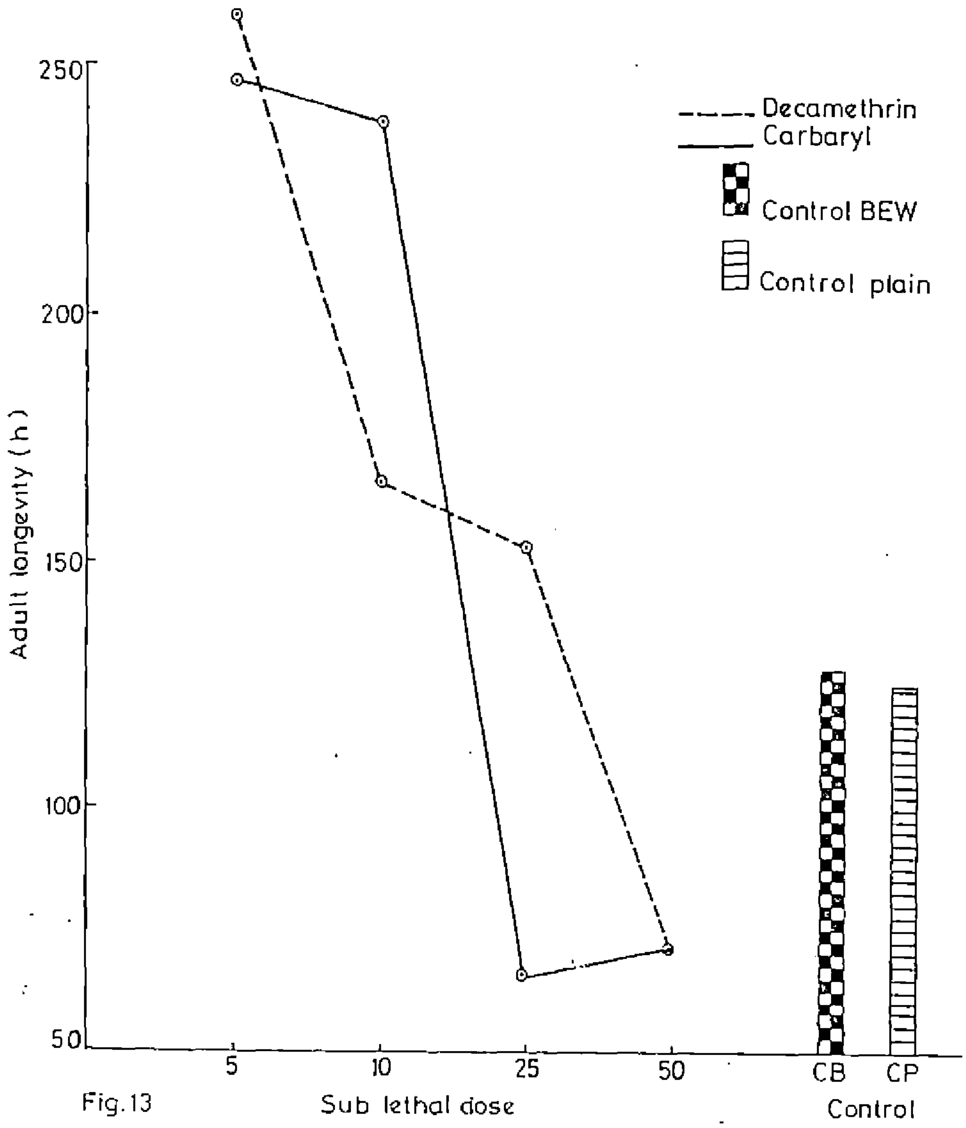
—— Decamethrin
– – – Carbaryl
▥ Control plain
▩ Control BEW
400
350
300
250
Adult longevity (h)
5
10
25
50
CB
CP
Sub_lethal dose
Control

Fig. 11



Decamethrin
Carbaryl
150
100
50
Nymphal duration(h)
5
10
25
50
CB
CP
Sub lethal dose
Control

Fig.12



Decamethrin
Carbaryl
Control BEW
Control plain
250
200
150
100
50
Adult longevity (h)
5
10
25
50
CB
CP
Sub lethal dose
Control

Fig.13

Table 10. The treatments in all generations showed significant differences. Between the generations also there was a significant difference in their reproductive rate. In general, the fecundity of *H. 28 punctata* when exposed to sub-lethal concentrations in each generation was not stable and with the third generation there was more a tendency for a lesser egg production (Fig 14).

Taking into consideration the parental generation alone, decamethrin and carbaryl at LD_{50} registered a very low reproductive potential. For both insecticides, at the three lower sub-lethal concentrations tested, there was a perceptible increase in the mean number of eggs deposited. Maximum number of eggs were produced by those adults which had emerged out from treatments with LD_{25} of decamethrin, in which case it was 145.74 per cent higher than in the untreated check.

In the F_1 progeny, increased egg production was noticed at all the four sub-lethal concentrations of decamethrin. The treatment at which this trend showed more prominence was LD_5 of decamethrin. The

Table 10. Effect of successive application of sub-lethal doses of decamethrin and carbaryl on the reproductive rate of *H. 28 punctata* on the F_1 and F_2 generations

Insecticide	Lethal dose	Total number of eggs deposited by a female					
		Parent		F_1		F_2	
		Number	Percentage increase/ decrease over control	Number	Percentage increase/decrease over control	Number	Percentage increase/decrease over control
Decamethrin	5	25.76 f (663.58)	+ 72.05	27.99 e (783.44)	+111.00	26.00 f (676.05)	+ 87.67
	10	27.60 g (761.93)	+ 97.55	19.37 b (375.27)	+ 1.07	20.45 de (418.37)	+ 16.14
	25	30.78 h (947.78)	+145.74	22.92 cd (525.46)	+ 41.52	18.02 c (324.58)	- 9.90
	50	14.94 b (223.08)	- 42.16	21.12 bc (446.22)	+ 20.18	15.81 b (249.83)	- 30.65
Carbaryl	5	19.75 cd (389.98)	+ 1.11	24.49 d (599.66)	+ 61.51	21.59 e (466.30)	+ 29.44
	10	20.89 de (436.60)	+ 13.19	23.71 cd (562.02)	+ 51.37	19.98 cd (399.20)	+ 10.81
	25	21.78 e (474.32)	- 76.52	16.10 a (259.31)	- 30.16	15.31 ab (234.43)	- 34.93
	50	9.52 a (90.55)	- 8.03	14.95 a (223.38)	- 39.84	13.76 a (189.39)	- 47.43
Untreated check	BHN	18.83 c (354.72)		20.05 b (402.16)	+ 8.31	19.06 cd (363.17)	
"	Plain	19.64 cd (385.69)		19.27 b (371.29)		18.98 cd (360.24)	

Analysis was carried out after square root transformation.

Figures in the parentheses are retransformed values. The values within a column followed by a common letter are not significantly different at 5% level (DMRT)

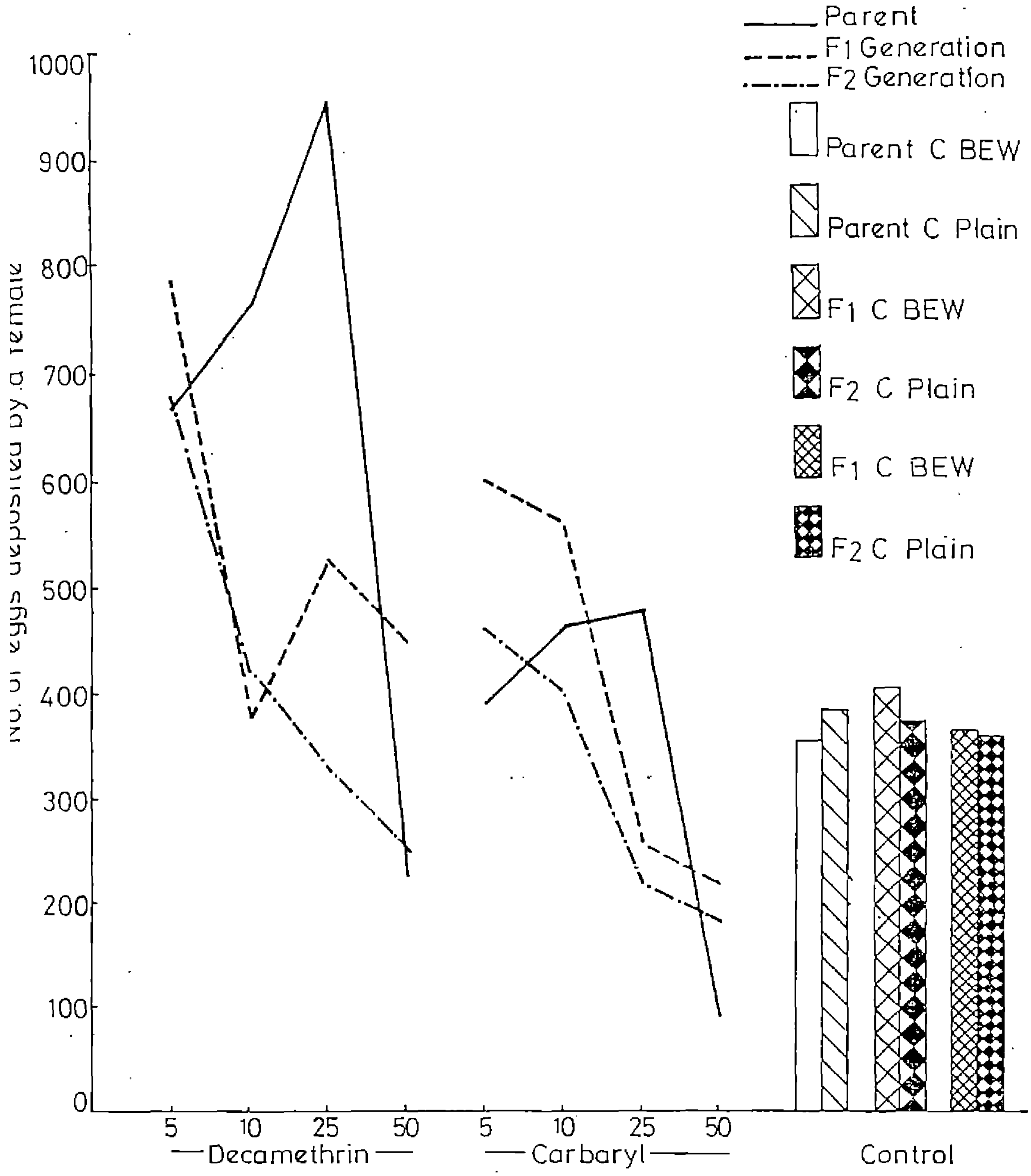

Parent
F1 Generation
F2 Generation
Parent C BEW
Parent C Plain
F1 C BEW
F2 C Plain
F1 C BEW
F2 C Plain
No. of eggs deposited by a female
1000
900
800
700
600
500
400
300
200
100
0
5
10
25
50
5
10
25
50
Decamethrin
Carbaryl
Control
Sub_lethal dose

Fig.14

increase was by 110.0 per cent over control. Unlike the parents, at LD_{50} levels too, there was an increase in egg production in the F_1 generation. Besides, with an increase in the concentration from LD_5 to LD_{25} there was a decrease in the production of eggs. With carbaryl, a similar trend was maintained and at LD_{25} and LD_{50} the progeny was still lower than the untreated check. However, the increase with the lower tested levels of carbaryl were 61.51 and 51.37 per cent respectively, at LD_5 and LD_{10}.

The resulting adults of the F_2 progeny showed reduced fecundity at LD_{25} and LD_{50} levels of both test insecticides. The capacity to produce more eggs was retained in the F_2 generation by the survivors from the two lower concentrations, this being more prominent at LD_5 of decamethrin.

Egg hatch

The influence of exposure of sub-lethal concentrations of the test insecticides on the per cent egg survival up to the F_2 generation is summarised in Table 11. Uniform reduction in egg hatch was maintained with the sub-lethal concentrations of decamethrin and

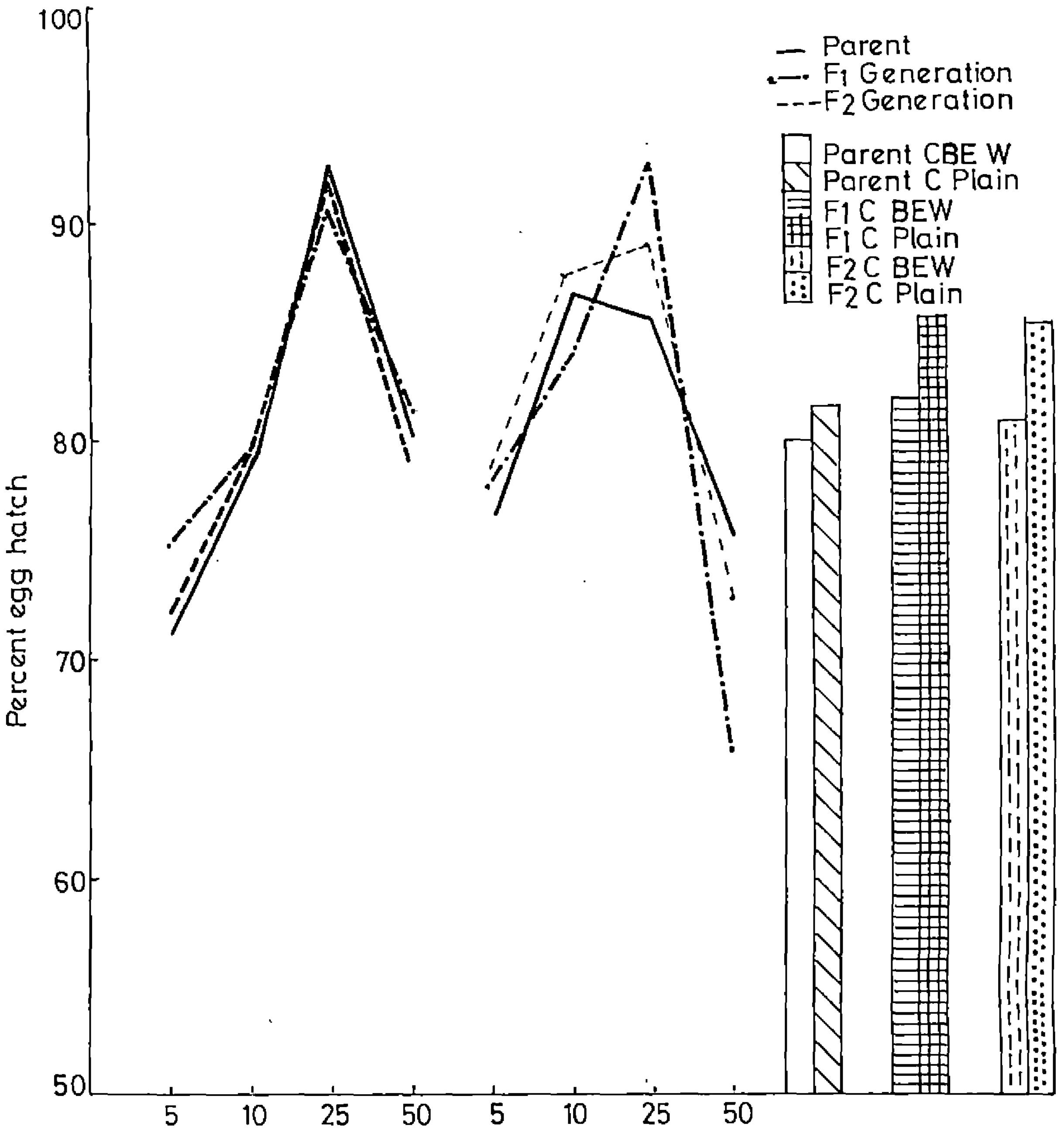
Table 11. Effect of successive application of sub-lethal doses of decamethrin and carbaryl on the per cent egg hatch of H. 28 punctata on the F_1 and F_2 generations

Insecticide	Lethal dose	Per cent egg hatch					
		Parental		F_1 generation		F_2 generation	
			Per cent increase/decrease over control		Per cent increase/decrease over control		Per cent increase/decrease over control
Decamethrin	5	46.78 a (71.29)	- 14.2	46.18 a (72.16)	- 18.69	48.70 ab (75.13)	- 15.03
	10	51.91 ab (78.70)	- 4.79	52.04 ab (78.84)	- 9.54	52.59 b (79.44)	- 8.23
	25	67.85 d (92.61)	+ 24.44	67.59 e (92.45)	+ 17.50	66.82 c (91.93)	+ 16.59
	50	53.31 abc (80.25)	- 2.13	52.25 ab (79.07)	- 9.18	54.30 b (81.21)	- 5.26
Carbaryl	5	49.83 a (76.41)	- 8.61	52.04 ab (78.85)	- 9.53	51.97 b (78.77)	- 9.32
	10	60.10 c (86.69)	+ 10.24	61.09 cde (87.54)	+ 6.19	57.04 b (83.91)	- 0.47
	25	58.85 abc (85.58)	+ 7.94	62.54 de (88.73)	+ 8.71	67.33 c (92.27)	+ 17.47
	50	48.69 a (75.11)	- 10.69	46.30 a (72.30)	- 19.51	41.94 a (66.83)	- 26.82
Untreated check	BHW	53.04 abc (79.90)		54.52 bc (81.43)		53.73 b (80.63)	
"	Plain	54.52 abc (81.43)		57.52 bcd (84.36)		57.31 b (84.16)	

Analysis was carried out after square root transformation.

Figures in the parentheses are retransformed values. The values followed by a common letter within a column are not significantly different at 5% level (DMRT) carbaryl except for the LD_{25} level (Fig 15). In the parental populations of *H. 28 punctata* the egg hatchability showed significant variability, but the reduction was perceptible only in the case of LD_5 and LD_{10} of decamethrin and LD_5 and LD_{50} of carbaryl. In the case of LD_{25} of decamethrin and LD_{10} of carbaryl there was increase in the hatching percentage over control. In the F_1 generation the trends in egg hatch was almost similar to the parental population. The maximum depression of egg hatch was in carbaryl at LD_{50} and also in decamethrin at LD_5. There was increase in hatchability by 17.50 per cent in decamethrin at LD_{25} dose. There was increase in hatchability at the LD_{10} and LD_{25} dose of carbaryl but the quantum of increase was only marginal being 6.19 and 8.17 per cent.

In the F_2 generation, the increase in egg hatch was recorded only in the case of LD_{25} treatment with decamethrin and carbaryl, the increment being significant as compared to control. At the LD_{50} dose of carbaryl there was a distinct reduction in egg hatch while in the case of decamethrin at the same level the extent of reduction was not as spectacular as in the case of carbaryl.



100
90
80
70
60
50
Percent egg hatch
Parent
F1 Generation
F2 Generation
Parent CBE W
Parent C Plain
F1 C BEW
F1 C Plain
F2 C BEW
F2 C Plain
5
10
25
50
5
10
25
50
Decamethrin
Carbaryl
Control
Sub lethal dose

Fig. 15

Larval duration

The larval durations of H. 28 punctata grubs which were offsprings from the parents which had been topically treated with sub-lethal concentrations of the test insecticides in their last instar larval stages were recorded up to the F_2 generations. In all the generations the trend was almost similar (Table 12). At LD_{50} dose there was not any change in the average larval period and this was on par with the untreated check. With the lower sub-lethal levels, larval duration was extended and this was the highest at LD_5 for both insecticides in the F_1 and F_2 generations. Decamethrin showed decrease in the total mean larval duration for the F_1 generation for treatments at LD_5, LD_{10} and LD_{25} levels; as compared to the parents. In the F_2 generation, there was an increase in the larval duration with increase in the doses through LD_{10} and LD_{25} (Fig 16).

A similar fall in the total mean larval duration was noted in the case of carbaryl at LD_{10} in the F_1 generation, which also showed an increase in F_2 generation. With the other three sub-lethal levels, there was a general prolongation in the larval period with each generation. Grubs

Table 12. Effect of sub-lethal concentrations of decamethrin and carbaryl on the larval duration of the F_1 and F_2 populations of *H. 28 punctata*

Insecticide	Lethal dose	Larval duration-hours Parent	 F_1	 F_2
Decamethrin	5	502.67 f	488.57 d	469.60 e
	10	468.67 e	459.52 cd	460.80 de
	25	410.67 c	400.97 b	408.00 c
	50	330.33 a	320.00 a	331.20 a
Carbaryl	5	470.33 e	477.60 d	478.40 e
	10	440.00 d	433.20 bc	441.76 d
	25	384.33 b	400.80 b	405.60 c
	50	334.00 a	353.60 a	361.92 b
Untreated check	BEW	333.33 a	337.60 a	336.63 a
"	Plain	333.00 a	329.60 a	334.40 a

The values followed by a common letter within a column are not significantly different at 5% level (DMRT)

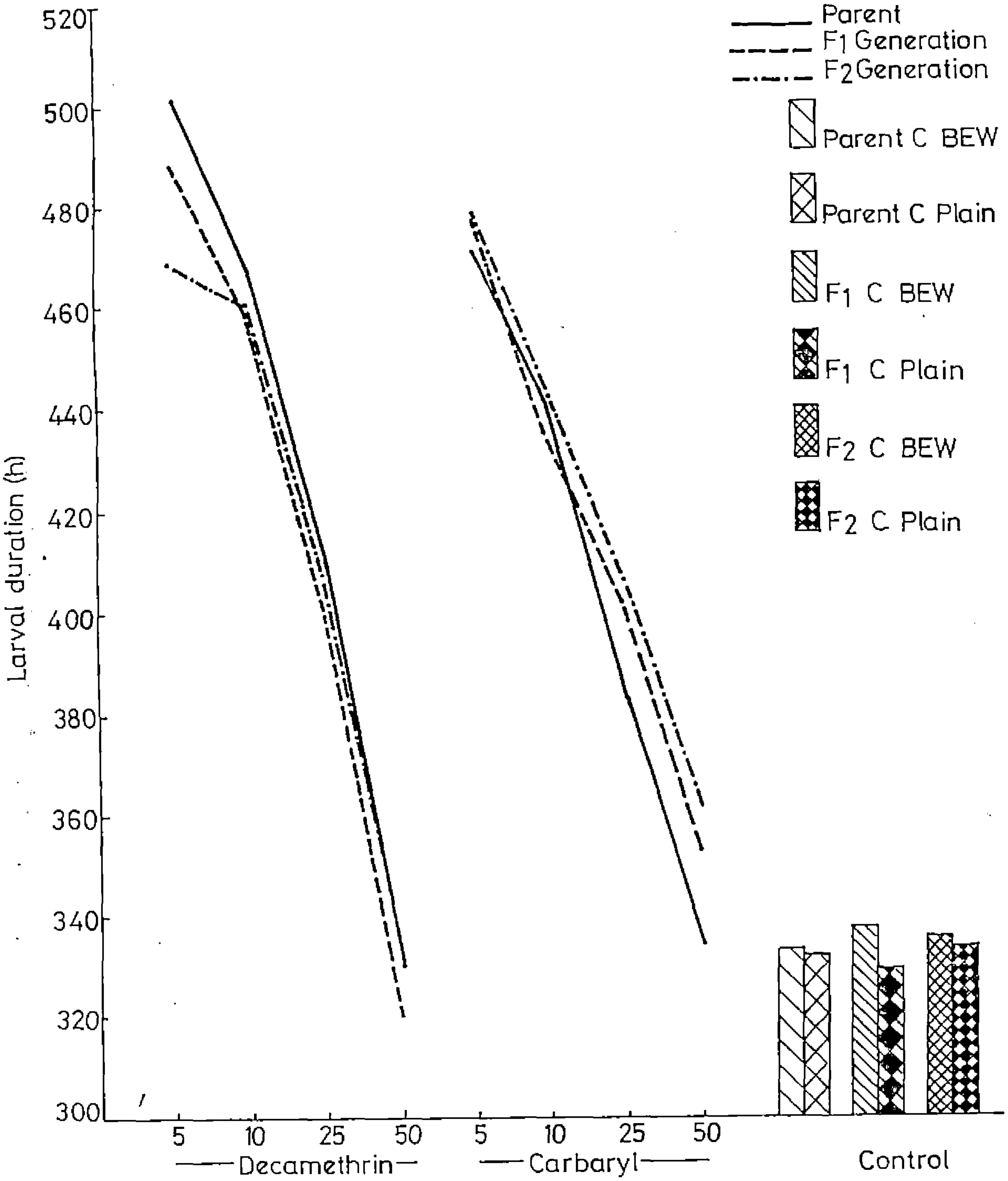

Parent
F1 Generation
F2 Generation
Parent C BEW
Parent C Plain
F1 C BEW
F1 C Plain
F2 C BEW
F2 C Plain
Larval duration (h)
520
500
480
460
440
420
400
380
360
340
320
300
5
10
25
50
5
10
25
50
Decamethrin
Carbaryl
Control
Sub lethal dose

Fig. 16

continued in the same stage for a maximum time of 502.67 h in parental generation at LD_5 which was an increase by 50.95 per cent over the untreated check. With carbaryl at this dose, the duration was 478.40 h which was an increase by 43.06 per cent over the untreated check.

Adult longevity

The influence of sub-lethal concentrations of decamethrin and carbaryl on adult longevity when topically applied on fourth instar grubs was studied upto F_2 generation (Table 13). Other than carbaryl at LD_{50}, no striking variations were observed between the treatments in the parental generation. The adult life of those subjected to exposure to carbaryl LD_{50} was as short as 28.67 days as compared to 35.33 days in normal untreated check. In the F_1 generation too carbaryl at LD_{50} registered a shortening in adult longevity. But both the insecticides exhibited a prolongation in adult longevity at LD_5 in the F_1 generation. It was 27.72 and 29.70 per cent higher than the untreated check respectively (Fig 17), for decamethrin and carbaryl. This increase in the adult longevity was also recorded for the survivors exposed to LD_5 decamethrin in their F_2 generation. It was 22.91 per cent more than the untreated

Table 13. Effect of sub-lethal concentrations of decamethrin and carbaryl on the adult longevity of the F_1 and F_2 populations of _H. 28 punctata_

Insecticide	Lethal dose	Adult longevity - Days generation		
		Parent	F_1	F_2
Decamethrin	5	34.33 bc	43.00 c	39.33 d
	10	33.00 abc	37.33 bc	29.33 bc
	25	31.33 abc	30.33 ab	33.00 c
	50	32.33 abc	30.67 ab	30.33 c
Carbaryl	5	32.00 abc	43.67 c	32.67 c
	10	30.67 abc	32.67 ab	33.00 c
	25	32.00 abc	29.67 ab	23.67 ab
	50	28.67 a	29.00 a	23.00 a
Untreated check	NEW	30.33 ab	29.67 ab	27.00 abc
"	Plain	35.33 bc	33.67 ab	32.00 c

The values followed by a common letter within a column are not significantly different at 5% level (DMRT)

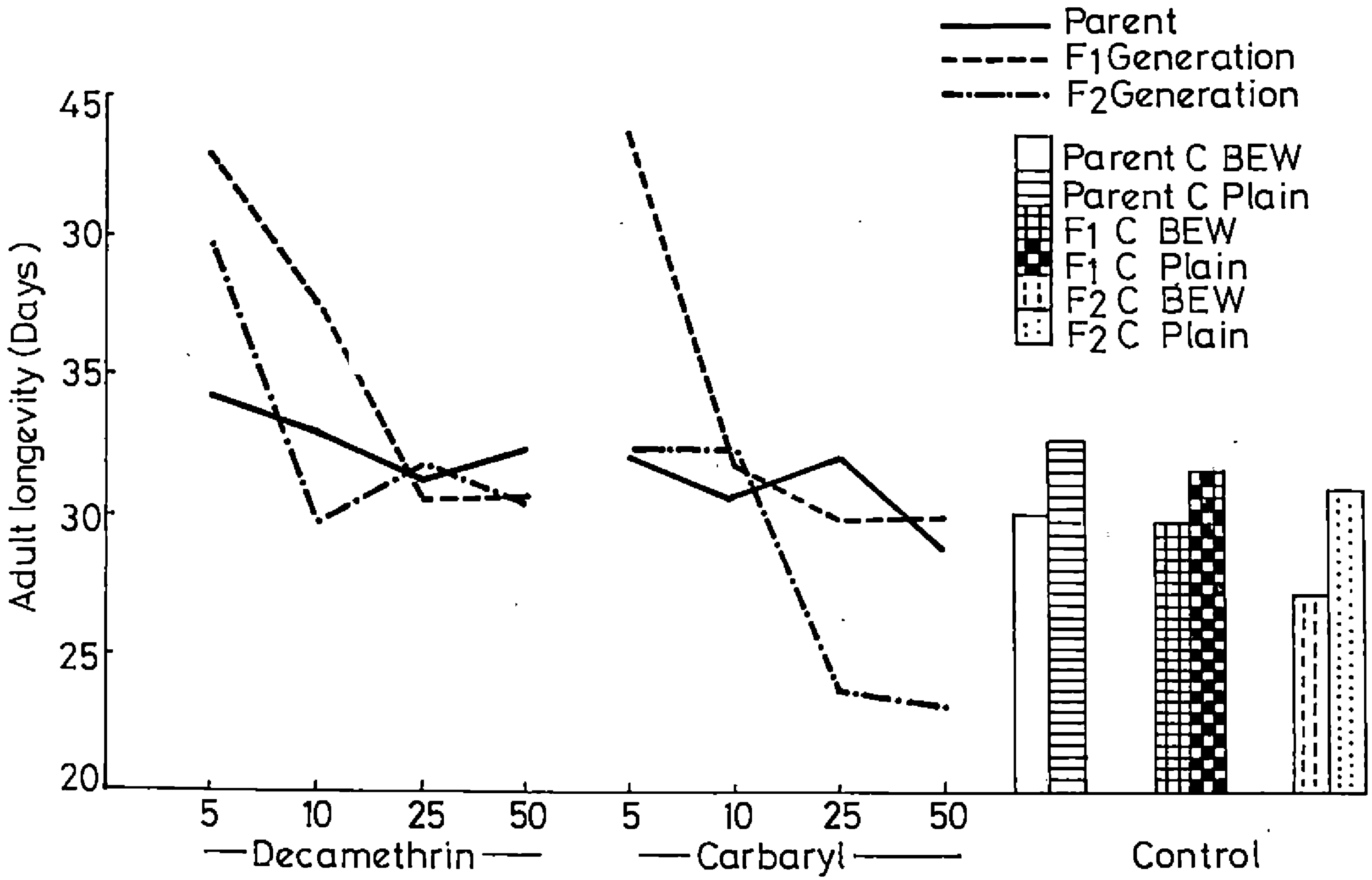


Fig. 17 Sub-lethal dose

check. But for this, all other treatments in F_2 were not significant and were on par with the untreated check.

b) A. gossypii

Reproductive potential

The reproductive rate of A. gossypii, when exposed to sub-lethal doses in each generation during the fourth instar nymphal stage, differed significantly between treatments within a generation and also between generations (Table 14). The mean number of nymphs/ten adults in the parental generations was increased except at LD_{25} and LD_{50} levels where it was lower than the untreated check. As it reached the F_2 generation, in all treatments other than LD_{50} of carbaryl the reproductive rate was higher than that in the untreated check. Though decamethrin at LD_{50} registered a low reproductive rate in parental generation it was not so in the F_1 and F_2 generations. But carbaryl, continued to produce fewer offsprings with each of the generations at this level. Adults surviving from treatments with decamethrin at LD_5 continued to record the highest mean number of nymphs in all generations. In parental population, the increase over untreated check was

Table 14. Effect of sub-lethal concentrations of decamethrin and carbaryl on the reproductive rate of the F_1 and F_2 populations of *A. gossypii*

Insecticide	Lethal dose	No. of nymphs/10 aphids					
		Parent		F_1		F_2	
		Number	Per cent increase/decrease over check	Number	Per cent increase/decrease over check	Number	Per cent increase/decrease over check
Decamethrin	5	31.61 e (999.38)	147.88	31.06 d (964.48)	142.77	31.15 d (970.45)	133.17
	10	24.11 de (581.19)	44.16	24.30 bc (590.59)	48.65	24.28 bc (589.32)	41.60
	25	19.95 bcd (397.92)	- 1.30	19.76 b (390.38)	- 1.74	20.66 b (426.84)	2.55
	50	19.35 bc (374.58)	- 7.09	20.24 b (409.58)	3.09	20.46 b (418.61)	0.58
Carbaryl	5	26.66 e (711.02)	76.36	26.34 c (693.64)	74.59	26.48 c (700.93)	68.41
	10	22.71 cde (515.70)	27.91	22.65 bc (513.07)	29.14	22.91 bc (524.82)	26.17
	25	17.69 ab (313.13)	- 22.32	20.87 b (435.47)	9.61	21.58 b (465.92)	11.85
	50	10.32 a (106.40)	- 73.60	11.31 a (127.94)	- 67.79	10.37 a (107.62)	- 74.14
Untreated check	BEU	19.88 bcd (395.17)		19.86 b (394.58)		20.31 b (412.33)	
"	Plain	20.08 bcd (403.17)		19.93 b (397.28)		20.40 b (416.20)	

Analysis was carried out after square root transformation. Figures in parentheses are the retransformed values. Values followed by a common letter within the column are not significantly different at 5% level (DMRT) by 147.88 per cent while, it was 142.77 and 133.17 per cent respectively, for F_1 and F_2 generations (Fig 18). At this dose, carbaryl also had a high reproductive potential.

c) A. b. biguttula

Reproductive potential

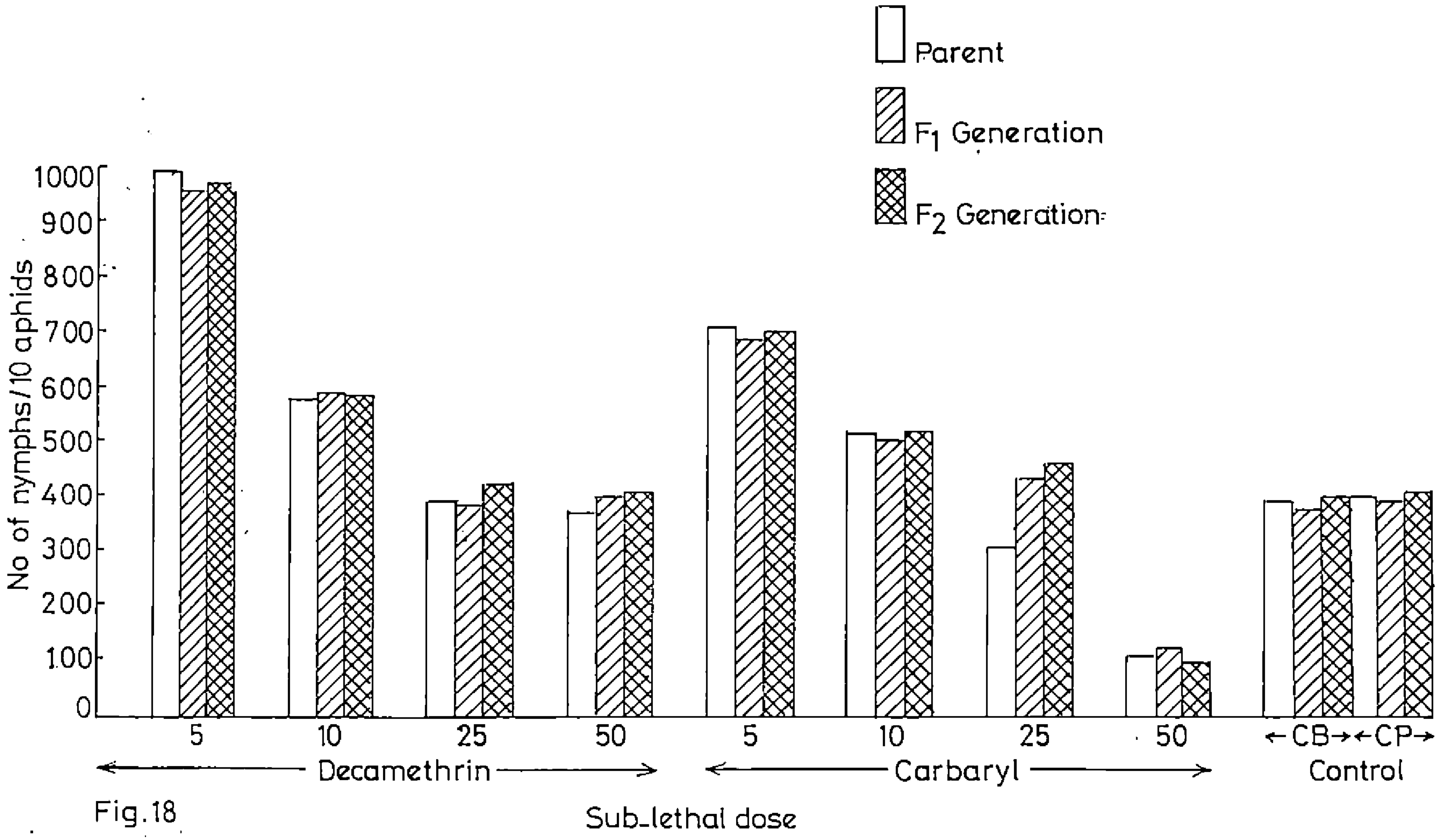
The effect of exposure of sub-lethal concentrations of the insecticides on the reproductive rate of A. b. biguttula up to the F_2 generation is summarised in Table 15. The treatments in parental and F_2 generations differed significantly while in F_1 the variations were less pronounced (Fig.19).

Decamethrin recorded low level of progeny production at the two higher sub-lethal levels tested. The increase in progeny production was maintained at LD_{10} as compared to LD_5 in the case of decamethrin. Carbaryl at LD_{25} and LD_{50} levels were on par with the untreated check up to the F_2 generation. At LD_5 and LD_{10} though a slight increase was recorded in the parental generation, there was no variation from the untreated check in the F_1 generation. But in the F_2 generation counts of the offsprings

Table 15. Effect of sub-lethal concentrations of decamethrin and carbaryl on the reproductive rate of the F_1 and F_2 populations of <u>A. b. biguttula</u>

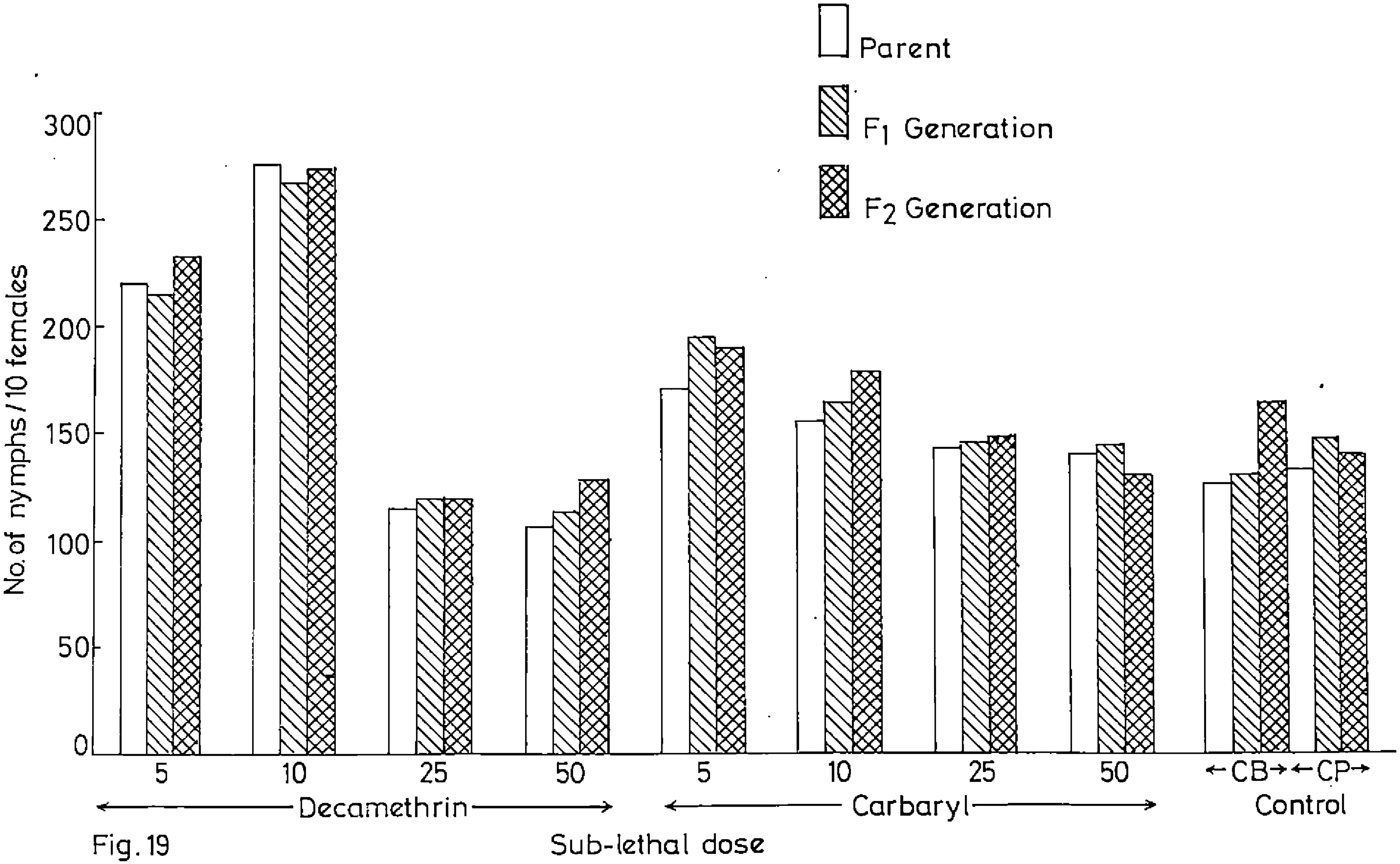
Insecticide	Lethal dose	No. of nymphs/10 female hoppers					
		Parent		F_1		F_2	
		Number	Per cent increase/decrease over check	Number	Per cent increase/decrease over check	Number	Per cent increase/decrease over check
Decamethrin	5	14.78 c (218.36)	58.36	15.08 ab (227.44)	53.54	15.30 de (234.21)	67.83
	10	16.63 d (276.52)	100.56	16.72 b (279.66)	88.79	16.56 e (274.07)	96.40
	25	10.64 a (113.29)	-17.83	11.12 a (123.72)	-16.48	11.13 a (123.81)	-11.28
	50	10.29 a (106.01)	-23.11	10.67 a (113.91)	-23.10	11.30 a (127.75)	-8.46
Carbaryl	5	13.08 b (171.14)	24.13	13.57 ab (184.12)	24.30	13.91 cd (193.49)	92.10
	10	12.79 b (163.48)	18.58	12.92 ab (166.82)	-1.69	13.35 bcd (178.14)	27.65
	25	11.97 ab (143.30)	3.94	12.07 ab (145.64)	-1.68	12.29 abc (150.99)	8.19
	50	11.87 ab (140.97)	2.25	12.09 ab (146.31)	-1.22	11.66 ab (135.88)	-2.62
Untreated check	DEW	11.33 ab (128.39)		11.38 a (129.48)		12.86 abc (165.30)	
"	Plain	11.74 ab (137.87)		12.17 ab (148.13)		11.81 ab (139.55)	

Analysis was carried out after square root transformation. Figures in the parentheses are the retransformed values. Values followed by a common letter within the column are not significantly different at 5% level (DMRT)



Parent
F1 Generation
F2 Generation
No of nymphs/10 aphids
1000
900
800
700
600
500
400
300
200
100
0
5
10
25
50
Decamethrin
5
10
25
50
Carbaryl
CB
CP
Control
Sub-lethal dose

Fig.18



Parent
F1 Generation
F2 Generation
300
250
200
150
100
50
0
No. of nymphs / 10 females
5
10
25
50
5
10
25
50
← CB → ← CP →
Decamethrin
Carbaryl
Control
Sub-lethal dose

Fig. 19

were little higher as compared to LD_{25} and LD_{50} levels and also from the untreated check lot.

4.2.5. Influence of sub-lethal concentration of decamethrin and carbaryl on the survival of adults

a) H. 28 punctata

The survival of the adult emergents of H. 28 punctata exposed to sub-lethal concentrations of the test insecticides during their last instar larval stage are presented in Table 16. Since the survival of the adults up to six days after emergence was not showing any apparent variations, statistical analysis of that part of data was not carried out.

An overview of the survival pattern up to twenty days from the date of emergence showed that the adults from treatments with carbaryl at LD_{50} dose led to relatively heavier casualities. Though decamethrin too, at this particular concentration resulted in lesser survival percentages, the extent of casualities was not as higher as carbaryl, particularly 12th, 14th and 16th days after treatment. With the lower levels of sub-lethal concentrations, though there were no increase in the survival

Table 16. Effect of sub-lethal concentrations of decamethrin and carbaryl on the survival of adults of *H. 28 punctata*

Insecticide	Lethal concentration	Adult survival per cent - days after emergence (DAE)									
		2 DAE	4 DAE	6 DAE	8 DAE	10 DAE	12 DAE	14 DAE	16 DAE	18 DAE	20 DAE
Decamethrin	5	90.0 (100.0)	90.0 (100.0)	90.0 (100.0)	90.0 c (100.0)	90.0 c (100.0)	90.00 d (100.0)	85.86 d (99.73)	75.00 e (96.59)	75.00 d (96.59)	66.15 cd (91.45)
	10	90.0 (100.0)	90.0 (100.0)	90.0 (100.0)	90.0 c (100.0)	75.00 bc (96.59)	63.93 bc (89.82)	61.71 bc (88.05)	61.71 d (88.05)	57.00 c (83.86)	57.00 bc (83.86)
	25	90.0 (100.0)	90.0 (100.0)	75.23 (96.70),	75.00 bc (96.59)	61.22 ab (87.64)	57.00 ab (83.86)	52.78 abc (79.62)	50.77abcd (77.46)	45.0 ab (70.71)	44.03 ab (69.50)
	50	90.0 (100.0)	90.0 (100.0)	71.80 (95.0)	56.79 a (83.66)	52.78 a (79.62)	50.77 ab (77.46)	48.85 ab (75.29)	43.08 ab (68.29)	37.22 a (60.49)	37.22 a (60.49)
Carbaryl	5	90.0 (200.0)	90.0 (100.0)	90.0 (100.0)	81.15 c (98.80)	73.55 bc (95.90)	72.40 c (95.32)	67.91 c (92.65)	54.75 bcd (81.66)	52.74 bc (79.59)	49.83 ab (76.41)
	10	90.0 (100.0)	90.0 (100.0)	90.0 (100.0)	82.40 c (99.12)	76.26 bc (97.13)	76.26 c (97.13)	59.71 abc (86.34)	57.00 cd (83.86)	52.78 bc (79.62)	46.92 ab (73.04)
	25	90.0 (100.0)	75.24 (96.7)	75.02 (96.6)	74.81 bc (96.50)	73.55 bc (95.90)	59.01 ab (85.72)	51.96 abc (78.75)	48.85 abc (75.29)	45.00 ab (70.71)	42.12 ab (67.06)
	50	90.0 (100.0)	90.0 (100.0)	64.16 (90.0)	61.22 ab (87.64)	57.00 a (83.86)	47.91 a (74.20)	45.00 a (70.71)	42.12 a (67.06)	37.20 a (60.46)	36.24 a (59.11)
Untreated check	BEW	90.0 (100.0)	90.0 (100.0)	90.0 (100.0)	90.00 c (100.0)	90.00 c (100.0)	90.00 d (100.0)	90.00 d (100.0)	90.00f (100.0)	90.00 e (100.0)	52.78 c (79.63)
"	Plain	90.0 (100.0)	90.0 (100.0)	90.0 (100.0)	90.0 c (100.0)	90.00 c (100.0)	90.00 d (100.0)	90.00 d (100.0)	83.85 e (100.0)	61.71 c (88.05)	55.86 bc (82.76)

Analysis was carried out after arc sine transformation. Figures within the parentheses are the retransformed values. Values followed by common letters within a column are not significantly different at 5% level (DMRT) percentages than that in untreated check up to 16th day, in the case of decamethrin at LD_5, there was a rise in survivorship after the 18th day. Besides, a uniform rate of increase was recorded with decrease in the sub-lethal concentration levels. In the case of decamethrin on the 20th day, the survival percentages were 60, 69, 83 and 91 per cent at LD_{50}, LD_{25}, LD_{10} and LD_5 levels respectively. With carbaryl, the survivorship levels were 59, 67, 73, and 76 per cent respectively at the above LD levels as compared to 82 per cent in the untreated check.

b) A. gossypii

Studies on the influence of sub-lethal concentrations of the two test insecticides on topical application to last instar nymphs of A. gossypii on the survival of their adults have revealed a slow action of the insecticides (Table 17). On the first day, the mortality rates of different treatments were not significantly different from the untreated check, except for the LD_{50} treatment with decamethrin. Effects of treatments with LD_5 and LD_{10} concentrations of decamethrin and carbaryl were both comparable with the results obtained in the untreated check.

Table 17. Effect of sub-lethal concentrations of decamethrin and carbaryl on the adult survival of *A. gossypii*

Insecticide	Lethal dose	Adults - percent survival Days after emergence (DAE) 1	2	3	4	5
Decamethrin	5	90.00 b (100.00)	75.00 b (96.59)	64.05 b (89.91)	59.48 cd (86.14)	53.17 b (80.03)
	10	86.15 b (99.77)	81.15 b (98.80)	61.71 b (88.05)	54.09 c (80.99)	52.08 b (76.88)
	25	83.85 b (99.42)	60.54 a (87.06)	36.44 a (59.39)	10.45 a (18.14)	-
	50	62.22 a (88.47)	48.46 a (74.84)	-	-	-
Carbaryl	5	90.00 b (100.00)	79.13 b (98.20)	73.29 b (95.77)	70.47 d (94.24)	56.82 b (83.69)
	10	78.83 b (98.10)	72.03 b (95.12)	72.03 b (95.12)	54.81 c (81.72)	50.33 b (76.64)
	25	76.53 b (97.24)	68.07 a (92.76)	39.06 a (63.00)	31.38 b (52.07)	20.62 a (35.21)
	50	83.85 b (99.42)	60.53 a (87.05)	-	-	-
Untreated check	Dcw	90.00 b (100.00)	90.00 b (100.00)	70.08 b (94.01)	59.01 c (85.72)	54.79 b (81.69)
"	Plain	90.00 b (100.00)	83.85 b (99.42)	61.22 b (87.64)	59.01 c (85.72)	55.97 b (82.87)

Analysis was carried out after arc sine transformation. Figures in parentheses are the retransformed values. Values followed by a common letter within a column are not significantly different at 5% level (DMRT) but the other two tested levels showed a higher rate of mortality, the per cent survival being lesser at the higher sub-lethal concentrations.

Though LD_{25} treatments resulted in a significantly lower survival percentages of adults, with LD_{50} complete mortality of the adults was the result from third day for both the tested chemicals.

On the fourth day a notable increase in the adult survival was recorded at LD_5 of both insecticides, and this trend was maintained with carbaryl on the fifth day also.

c) A. b. biguttula

Treatments with sub-lethal concentrations of decamethrin and carbaryl on the last instar nymphs of A. b. biguttula had a direct influence on the survival of their adults right from the first day of emergence (Table 18). Decamethrin at all the four tested sub-lethal levels and carbaryl at its two higher levels caused a lesser survival as compared to control on the day of emergence itself. From the second day at LD_5 of both test chemicals and at LD_{10} of carbaryl, the mortality rates were lesser as compared

Table 18. Effect of sub-lethal concentrations of decamethrin and carbaryl on the adult survival of A. b. biguttula

Insecticide	Lethal dose	Adults - per cent survival Days after emergence 1	2	3	4	5
Decamethrin	5	86.15 cd (99.77)	86.15 d (99.77)	86.15 d (99.77)	69.91 b (93.91)	67.55 d (92.42)
	10	77.77 c (97.72)	70.44 c (94.23)	67.63 c (92.47)	63.01 b (89.15)	50.81 c (77.50)
	25	64.47 b (90.23)	54.75 b (81.66)	48.46 a (74.84)	45.38 a (71.17)	12.21 a (21.15)
	50	56.05 b (82.95)	38.32 a (62.00)	-	-	-
Carbaryl	5	90.00 d (100.00)	84.52 d (99.54)	84.52 d (99.54)	68.73 b (93.19)	65.94 d (91.31)
	10	90.00 d (100.00)	87.29 d (99.88)	85.27 d (99.65)	73.92 b (96.08)	72.07 e (95.14)
	25	81.43 c (98.88)	70.52 c (94.27)	55.61 ab (82.52)	34.84 a (57.13)	22.12 b (37.65)
	50	44.60 a (70.21)	30.58 a (50.87)	-	-	-
Untreated check	BHW	90.00 d (100.00)	81.43 cd (98.88)	66.45 c (91.67)	64.06 b (89.92)	61.19 d (87.62)
"	Plain	90.00 d (100.00)	75.38 cd (96.76)	64.47 bc (90.23)	61.19 b (87.62)	57.21 c (84.07)

Analysis was carried out after arc sine transformation. Figures in parentheses are the retransformed values. Values followed by a common letter within a column are not significantly different at 5% level (DMRT) to the untreated check. With carbaryl at LD_{10} on the fifth day, the per cent survivors were maximum, being 95.14 an increase over the untreated check by 11.07 per cent. No individuals survived in those lot treated with LD_{50} concentrations of both chemicals since the third day of their emergence.

4.3. Field Studies

4.3.1. Assessment of pest distribution

a) *H. 28 punctata*

The data recorded on the mean counts of different stages of the epilachna beetles occurring on the brinjal crop after spraying and the population trend after spraying sub-lethal and lethal doses of the test insecticides are presented in Table 19. In respect of post-treatment counts at seven days after application, the standard field dose of the insecticides showed very low values and the two insecticides were almost equitoxic to the eggs. The counts showed a trend of gradual increase from LD_{50} to LD_5 levels in both insecticides but the ascending trend was more discernible in the case of decamethrin. Carbaryl

Table 19. Influence of sub-lethal doses of decamethrin and carbaryl on the distribution of the epilachna beetle, *H. 28 punctata*

Insecticide	Lethal dose	Mean distribution of *H. 28 punctata*/5 plants					
		Eggs		Grubs		Adults	
		Post treatment counts (7 DAT)	Percent surviving over pre-treatment counts (7 DAT)	Post treatment counts (7 DAT)	Per cent surviving over pre-treatment counts (7 DAT)	Post treatment counts (7 DAT)	Per cent surviving over pre-treatment counts (7 DAT)
Decamethrin	5	360.33 h	164.68 e	130.00 h	155.50 f	106.67 f	141.30 cd
	10	296.67 g	148.43 de	123.00 gh	151.57 ef	95.00 ef	166.13 d
	25	230.00 ef	143.35 cde	88.33 de	122.30 bc	60.33 c	121.66 cd
	50	138.33 c	114.24 b	70.33 bc	130.84 bcde	13.33 ab	65.14 b
Standard dose		34.67 ab	54.36 a	1.67 a	5.98 a	1.00 a	5.30 a
Carbaryl	5	236.00 f	145.18 de	102.00 ef	237.94 bcdef	84.00 de	143.16 cd
	10	243.33 f	145.83 de	107.33 fg	145.24 def	70.00 cd	135.42 cd
	25	185.67 d	126.86 bcd	87.00 cde	119.18 b	70.00 cd	146.83 cd
	50	70.33 b	101.14 b	58.33 b	141.54 cdef	25.67 b	111.04 c
Standard dose		20.00 a	44.97 a	1.00 a	4.23 a	1.00 a	8.51 a
Untreated check	DEW	174.33 cd	117.98 bc	63.00 b	125.82 bcd	95.33 ef	128.66 cd
"	Plain	192.67 de	127.44 bcd	75.00 bcd	122.87 bcd	104.67 f	135.56 cd

Figures followed by common letters within a column are not significantly different at 5% level (DMRT) at LD_5 and LD_{10} showed equitoxicity to eggs while a similar trend was lacking for decamethrin.

In terms of the survivorship at seven days after application over pre-treatment level also, the trends were in consonance with the observations relating to post-treatment counts.

In respect of post-treatment counts of grubs the standard doses of carbaryl and decamethrin showed equitoxicity in the suppression of populations. At the sub-lethal levels, the post-treatment counts were distinctly higher. The LD_5 and LD_{10} levels of both insecticides were on par. The survival of grubs as compared to the pre-treatment levels also showed a trend similar to the post-treatment counts.

A comparison of the number of adults on the plants after treatment with different doses of the two insecticides at their sub-lethal level showed a gradual increase in their counts after treatment in the case of the lower three sub-lethal doses of decamethrin and for all the four sub-lethal doses of carbaryl.

In respect of survival of adults the sub-lethal doses of 5, 10 and 25 of the two insecticides were on par.

b) A. gossypii

Influence of sub-lethal doses of decamethrin and carbaryl on the pattern of distribution of the brinjal aphid A. gossypii is given in Table 20. A marked increase in the mean number of aphids after spraying with LD_5 of both the test insecticides and LD_{10} of decamethrin was quite evident. In respect of survivalship of the aphids as compared to pre-treatment levels the trends were almost similar but the extent of survival in decamethrin treatment at LD_5 was markedly higher than at LD_{10} level of the same insecticide and the LD_5 and LD_{10} levels of carbaryl.

c) A. b. biguttula

A mean post-treatment counts on the total number of the leaf hoppers A. b. biguttula after spraying with sub-lethal doses of test insecticides (Table 20) showed a higher values for the first two sub-lethal doses of decamethrin. With carbaryl too, the two lower tested doses (LD_5 and LD_{10}) resulted in an increased count after treatment. The survival of the hoppers as compared to the pre-treatment counts, in the case of decamethrin

Table 20. Influence of sub-lethal doses of decamethrin and carbaryl on the distribution of *A. gossypii* and *A. b. biguttula*

		A. gossypii		*A. b. biguttula*	
Insecticide	Lethal dose	Post treatment counts (7 DAT)	Survival over pre-treatment counts (7 DAT)	Post treatment counts (7 DAT)	Survival over pre-treatment counts (7 DAT)
Decamethrin	5	18.62 g (346.61)	15.01 e (225.43)	21.40 d (458.06)	11.99 c (143.80)
	10	17.89 g (320.10)	12.02 d (144.58)	21.69 d (470.61)	11.41 c (130.25)
	25	14.27 def (203.73)	10.28 cd (105.63)	19.12 cd (365.74)	11.55 c (133.41)
	50	10.47 b (109.54)	8.92 c (79.49)	11.73 b (137.81)	8.07 b (65.15)
Standard dose		1.88 a (3.54)	2.41 a (5.80)	2.40 a (5.75)	2.39 a (5.72)
Carbaryl	5	16.92 fg (278.62)	12.03 d (144.67)	21.22 d (450.26)	12.58 c (158.13)
	10	11.18 bc (124.97)	10.28 cd (105.67)	22.52 d (507.15)	12.18 c (148.25)
	25	16.01 efg (256.17)	11.84 d (140.16)	18.00 cd (323.90)	11.24 c (126.25)
	50	3.96 a (15.65)	4.73 b (22.34)	14.05 bc (197.48)	9.90 b (98.00)
Standard dose		2.21 a (4.86)	3.02 ab (9.10)	3.64 a (13.21)	3.99 a (15.88)
Untreated check	DEW	13.57 cde (184.09)	10.94 cd (119.69)	19.35 cd (374.23)	10.76 c (115.68)
"	Plain	12.83 bcd (164.60)	10.69 cd (114.30)	18.61 cd (346.36)	10.50 bc (110.22)

Analysis was carried out after square root transformation. Figures in parentheses are retransformed values. Figures followed by common letters within a column are not significantly different at 5% level (DMRT).

there was a gradual increase in survival of the hoppers at lower levels of the sub-lethal doses. However all the three levels were not significantly different from the untreated check. Carbaryl too resulted in a gradual decrease in survival with an increase in the sub-lethal doses. Maximum control was the result when sprayings with standard dose was adopted.

4.3.2. Plant growth attributes

In field studies it was found that decamethrin and carbaryl when applied at their sub-lethal doses or as their standard field doses with three sprays had no effect on the growth and productivity characters of the brinjal crop (Table 21, 22). Statistical analysis of the data did not show any significant difference in the general growth parameters of the crop such as plant height, plant spread and number of branches. In respect of fruit number also significant variation could not be detected among the various insecticidal treatments. In the case of fruit yield (g) the control plots showed parity with the field doses of the two insecticides. The sub-lethal doses also did not show marked variations in the fruit output in quantitative terms.

Table 21. Effect of sub-lethal doses of decamethrin and carbaryl on plant height, spread of the plant and number of branches

Insecticide	Lethal dose	Changes in plant growth		
		Plant height (cm)	Spread of the plant (cm)	No. of branches
Decamethrin	5	72.67	160.27	7.60
	10	73.27	169.20	8.13
	25	70.07	145.60	6.73
	50	69.53	160.60	7.27
Standard dose		69.10	153.53	7.00
Carbaryl	5	74.13	157.27	7.27
	10	66.07	142.73	6.00
	25	72.13	166.33	7.40
	50	71.67	157.67	8.13
Standard dose		70.53	155.67	6.97
Untreated check	DEW	68.60	156.27	7.13
"	Plain	69.67	151.27	7.33
		NS	NS	NS

Table 22. Effect of sub-lethal doses of decamethrin and carbaryl on the yield of brinjal crop

Insecticide	Lethal dose	Changes in the yield	
		Fruit No.	Fruit weight (g)
Decamethrin	5	24.43	1936.67 b
	10	22.00	1507.33 a
	25	22.37	1964.00 b
	50	19.83	1708.33 b
Standard dose		20.23	1760.00 b
Carbaryl	5	23.20	1788.00 b
	10	17.67	1068.67 a
	25	21.97	1641.53 a
	50	24.80	1499.33 a
Standard dose		21.87	1724.33 b
Untreated check	DEW	22.10	1851.33 b
"	Plain	20.23	2021.33 b
		NS	-

In the second column, the numbers followed by common letters are not significantly different at 5% level (DMRT)

4.3.3. Effects on natural enemies associated with crop pests.

In the field experiment, observations were taken on the incidence of the three test insects. It was only in *A. gossypii*, that the associated enemies showed sparse populations. *Menochilus sexmaculatus* and *Coccinella transversalis* were relatively important among these natural enemies, but their populations were so sparsely distributed that quantitative data could not be generated to draw meaningful conclusions on the impact of insecticidal treatments on their survival.

4.3.4. Effects on residue dynamics

Initial deposits of carbaryl in/on the brinjal fruit after spraying was very low far below the tolerance level of 10 ppm fixed by WHO/FAO for fruit, for all the doses tested.

Since the sub-lethal doses of decamethrin were too low as compared to carbaryl and as the residues of carbaryl itself were well below the tolerance limits, soon after spraying, residue analysis of decamethrin on the fruit was not carried out.

Discussion

5. DISCUSSION

The biological effects of sub-lethal doses of decamethrin and carbaryl at their LD_5, LD_{10}, LD_{25} and LD_{50} doses on the epilachna beetle Henosepilachna 28 punctata, the aphid Aphis gossypii and the hopper Amrasca biguttula biguttula in terms of orientational stimuli, feeding, reproductive potential and survival have been assessed in the present studies. The results generated in these studies are discussed in this chapter.

Orientation

The response of H. 28 punctata towards plants treated with sub-lethal doses of the toxicants and to untreated check plants was monitored at 24 h interval upto seven days (Table 3). The adults alighted more on the untreated check plants than on the treated ones. This clearly shows that, the odour emanating from the insecticide-residues left from sub-lethal concentration did not influence the orientation of H. 28 punctata. Among the different concentrations tested, counts of insects settling on plants receiving the lower sub-lethal concentrations were significantly higher than at higher concentrations. This trend showed distinct progressive increase at decreasing levels of toxic stimulus. As the toxicity of the substrates increases the insects might tend to be repelled on account of the chemosensory perception of the volatile components of the toxic compounds. Alternatively they might evade the treated substrates after picking up the stimuli through contact receptors.

In the case of brinjal plants treated with sub-lethal concentrations of decamethrin and carbaryl, all these treatments elicited no positive orientational response among *A. gossypii*. As in the case of epilachna beetle, the plants treated with the lowest levels of sub-lethal doses of these toxicants showed more number of settlement. The orientational response of the hoppers *A. b. biguttula* was also of a very similar nature.

In the present studies, sub-lethal concentrations of decamethrin and carbaryl did not reveal any positive orientational responses to *H. 28 punctata*, *A. gossypii* and *A. b. biguttula*. This clearly indicates that the odour emitted from residues from sub-lethal doses of insecticides did not cause a positive orientational response. The present findings are in general agreement with the results obtained by Chelliah and Heinrichs (1980) for the brown plant hopper N. lugens. They found that odour released from the residues of the insecticides methyl parathion, decamethrin, diazinon and perthane had no influence on the orientation of the test insects. Volney and Mc Dougall (1979) however reported that permethrin acted as a motor stimulant to virgin females of C. fumiferana. The present study rules out any positive orientational response to plants receiving sub-lethal doses of toxicants as a factor regulating resurgence of the insects studied.

Feeding

In feeding experiments using leaves treated with sub-lethal concentrations of decamethrin and carbaryl, there was considerable reduction in feeding rate of H. 28 punctata as compared to untreated leaf material under laboratory conditions (Table 4). When different sub-lethal concentrations of decamethrin and carbaryl were used against H. 28 punctata for studying their influence on the feeding rate, it was observed that, both insecticides at all the four sub-lethal concentrations reduced the feeding rate, whereas in the untreated check, moderate feeding rate was noted in the laboratory conditions. The range of reduction in food intake was 28-71 per cent for decamethrin and 26-63 per cent for carbaryl. These results indicate that, the higher sub-lethal concentrations reduced the feeding rate of *H. 28 punctata*. Though there were no significant difference between the sub-lethal doses tested, feeding rate was slightly higher at LD_{10} than at LD_5.

Indirect assessment of food intake in *A. gossypii* and *A. b. biguttula* by the radioisotope studies indicated variation between different treatments. With these two insects, reduction in the feeding rate was more prominent at the highest sub-lethal level tested. For decamethrin, at the LD_{50} dose, against *A. gossypii*, the reduction in feeding was to 20.11 per cent while for *A. b. biguttula*, the reduction was 18.57 per cent. With carbaryl, it was still higher being 24.96 and 19.7 per cent respectively, for the above two test insects.

The influence of sub-lethal concentrations of insecticides on the feeding behaviour and food intake has been reported by several workers. In the case of the brown plant hopper *N. lugens* the feeding rate increased substantially when the rice plants were treated with sub-lethal concentrations of decamethrin, methyl parathion and diazinon.

In the case of cotton plants treated with sub-lethal doses of DDT and sumithion, the larvae of the cotton semilooper *A. janata* showed a reduced feeding rate, but there was increase in the weight gain and digestibility (Ramdev and Rao, 1980). Thus it is reasonable to assume that a sub-lethal level of insecticide in the plant may modify the feeding behaviour of insects.

Investigations with two synthetic pyrethroids (cypermethrin and permethrin) by Tan (1981) on leaf discs of brussels sprouts showed that as an antifeedant, permethrin was more effective than cypermethrin at sub-lethal levels to the fifth instar larvae of the cabbage worms *P. brassicae*. Sub-lethal doses of the carbamate insecticide Isolan caused reduction in feeding by *M. domestica* (Georghion, 1965).

However, tests with sub-lethal doses of deltamethrin, methyl parathion, monocrotophos and carbaryl on the nymphs of A. gossypii, resulted in an increased food intake for deltamethrin at LD_{10} by 21.29 per cent (Gajendran et al., 1986). But methyl parathion at LD_{35} and monocrotophos at all sub-lethal dosages tested resulted in reduced feeding rates.

It will thus be seen that the effect of the insecticides including those used in the present studies on the food intake varied in different insects, positively in some and negatively in others. Such variations are quite expected on account of the variations in the nature of the feeding stimuli required to sustain active feeding by insects. The present results that the sub-lethal doses of the test insecticides reduced feed intake by A. gossypii is apparently in conflict with Gajendran's (1986) positive results. The methodology followed in the present experiments was indirect, using radioactivity counts of insects feeding on labelled plants. The variations could be ascribed to the methodologies adopted and perhaps due to the changes in the ambient environments at two locations which interacted differently in the two environments. It is clearly established that in the case of decamethrin and carbaryl, the sub-lethal doses did not cause any increase in feed intake in the test insects, namely, *H. 28 punctata*, *A. b. biguttula* and *A. gossypii*. Increase in feeding rate and consequential positive influence on growth and development leading to resurgence can thus be ruled out at least for the sub-lethal doses under evaluation in this experiment.

Sex ratio

At the LD_5 level of decamethrin, there was a perceptible increase in the proportion of females of *H. 28 punctata*, while at LD_{50} level for decamethrin and carbaryl, there was a perceptible fall in the proportion of females.

Laboratory trials carried out under confinement to induce alate forms of *A. gossypii* did not succeed. Emergence of males could not be obtained. This may be because of the unfavourable conditions prevailing for development of males (M.G. Ram Das Menon, Personal communication).

In the case of A. gossypii, sex-ratio as a parameter could not be studied to assess the variations of this factor and the possible influence on population build up and resurgence.

Studies on the influence of sub-lethal concentrations of decamethrin and carbaryl on the sex-ratio of A. b. biguttula (Table 9) showed that LD_{10} of decamethrin and LD_5 of carbaryl and decamethrin induced the production of more number of females. For treatments with LD_{25} concentrations for both insecticides and LD_{50} of decamethrin the shift was towards males. Treatments with LD_{10} and LD_{50} of carbaryl showed no significant difference from the untreated check.

In the present studies it is found that for decamethrin at the LD_5 dose showed favourable influence on the development of females of H. 28 punctata, while at LD_5 dose of the same insecticide there was similar increase in the emergence of more females of A. b. biguttula in the F_1 population. Such favourable influence was also recorded for carbaryl at its LD_5 and decamethrin at LD_{10} doses for A. b. biguttula.

A similar shift in sex ratio in favour of females was observed in the broods of T. urticae reared on carbaryl and DDT residues leading to their resurgence was reported already by Dittrich _et al_. (1974).

The increase in the proportion of females can be due to positive stimulation of neural activity (Roan and Hopkins, 1961) which might be selectively more favourable to females or due to the revealation of hormoligosis (Lucky, 1968) in which the stressing agents selectively stimulate the females through better fitness to sub-optimum environment.

Whatever be the mechanism, significant increase in the proportion of females due to sub-lethal doses of decamethrin and carbaryl can certainly be very favourable for progressive population build up of _A. b. biguttula_ and _H. 28 punctata_ perhaps leading to resurgence. However, Singh and Lal (1966) did not observe any significant difference in the sex-ratio of the first and second generations of _D. koenigii_ developing from adults surviving exposure to various doses of DDT and endrin. In the case of _N. lugens_ also foliar application of methyl parathion, decamethrin, diazinon and phenthoate did not influence the proportion of females significantly (Chelliah and Heinrichs, 1980).

Reproduction

Topical application of sub-lethal concentrations of decamethrin and carbaryl on the last instar grubs of H. 28 punctata (Table 9) led to reproductive stimulation of the adult emergents, although the dose which induced maximum stimulation differed in the case of the two insecticides. The highest degree of stimulation was recorded in decamethrin at the LD_{25} dose. Adult emergents from grubs treated with decamethrin at the three sub-lethal concentration of LD_5, LD_{10} and LD_{25} showed a significant increase in fecundity which was higher than in the case of corresponding doses of carbaryl. For both insecticides the LD_{50} dose tended to suppress fecundity.

In the F_1 and F_2 generations also the capacity to produce more number of eggs persisted in the case of LD_5 dose of decamethrin (Table 10). The increase in fecundity in the F_1 generations was more prominent in the case of treatment with LD_5 of decamethrin, the increase being 110 per cent over control. Among the parents, the LD_{50} level of both insecticides registered a significant reduction in fecundity, but in the F_1 generations the LD_{50} dose also tended to promote fecundity.

The results of the studies on reproductive potential of H. 28 punctata shows that consistent improvement in fecundity over generations is realised in the case of the LD_5 dose of decamethrin as compared to other doses of this insecticide and doses of carbaryl.

The studies on the effect of sub-lethal concentrations of decamethrin and carbaryl on the reproductive potential of A. gossypii indicated that the lower concentrations of LD_5 and LD_{10} produced more offsprings than the higher concentrations and the untreated group. Here, the untreated check and the adults subjected to higher sub-lethal concentrations did not show any significant difference between them, though the counts in the treated lot were lesser. As it reached the F_2 generation, in all treatments other than LD_{50} of carbaryl, the reproductive rate was higher (Table 10) than that in the untreated population.

In A. b. biguttula, studies on the effect of sub-lethal concentrations on the reproductive rates revealed that the lower concentration resulted in more egg laying in the parents and also in the F_1 and F_2 generations.

With decamethrin, average fecundity rate was more at LD_{10} than at LD_5. But, at LD_{25} and LD_{50}, there was a decrease in the oviposition rate. Whereas with carbaryl at these two levels, the average fecundity rate was similar to that of untreated check. When the influence of the insecticides at sub-lethal doses up to the F_2 generation was recorded, there was a significant difference between treatments in the F_1 generations from the untreated check to a lesser extent. In this insect too, decamethrin at LD_{10} continued to show stimulatory effect for producing offsprings.

The present studies show that the stimulation of reproductive potential of the test insects is dependent on the insecticide dosage applied. The insecticide residue at sub-lethal levels or its metabolites or the chemical changes brought about due to interaction with plants, singly or in combination must have been responsible for the increase in the reproductive potential. A number of workers have reported positive correlation between exposure to sub-lethal insecticide on the one hand and increase in reproductive rate on the other

(Campion 1970; Abo-Elghar *et al.*, 1972; Dittrich *et al.*, 1974; Chelliah and Heinrichs, 1978; Chelliah *et al.*, 1980; Heinrichs *et al.*, 1982; Balaji *et al.*, 1986; Gajendran *et al.*, 1986).

Sub-lethal doses of DDT or methyl parathion on the colarado potato beetle *L. decemlineata* were reported to have stimulatory effect on the egg production (Kuipers, 1962). When carbaryl, methyl parathion and endrin were applied topically to the larvae of *S. littoralis*, Essao *et al.* (1963) recorded an increase in the number of eggs produced by treated larvae. It was later confirmed by Abo-Elghar *et al.* (1972) that carbaryl and sumithion increased the egg counts at the LD_{30} dose. Campion (1970) also found an increase in the rate of oviposition of red boll worm *D. castanea* due to sprays of carbaryl at the sub-lethal doses. A significantly higher fecundity as compared to untreated individuals in *T. urticae* has been attributed to sprays of carbaryl at a very low level (Dittrich *et al.*, 1974). Adult females of the F_1 populations also had a significantly higher egg production when kept on substrates having residues of carbaryl.

Chelliah and Heinrichs (1978) reported increase in fecundity of the brown plant hopper N. lugens, when sprayed with sub-lethal concentrations of methyl parathion, WL 43467 and FMC 35001. Heinrichs et al., (1978) suggested the utilisation of methyl parathion and decamethrin at sub-lethal doses as a tool to induce resurgence in this insect so as to ensure effective screening of rice varieties to infestation by N. lugens. Chelliah et al., (1980) further confirmed these results and reported that the sub-lethal doses for maximum reproductive stimulation differed between the insecticides tested. While investigating the influence of insecticide application in low land rice, Heinrichs et al., (1982) came out with the suggestion that the stimulation of reproduction could be the cause for resurgence in the brown plant hopper.

When applied topically on the western corn root worm D. virgifera, sub-lethal doses of carbaryl produced females which were able to deposit more number of eggs per female per day. This effect was more pronounced at low doses.

When the effect of spraying with synthetic pyrethroids on the population build up of *N. lugens* for two generations was investigated, the lower doses of decamethrin showed a stimulatory effect which persisted even on the third generation progeny (Chelliah, 1986). A reproductive stimulation was identified to be the cause for such resurgence. In chillies, the flare up of the yellow mites *P. latus* following the application of sub-lethal doses of monocrotophos, methyl demeton, thiometon, phosphamidon, formothion and neem cake extract was attributed to the stimulation in the reproduction following insecticide application (David,1986). Similarly Gajendran *et al*. (1986) recorded an increased reproductive rate in *A. gossypii* following sub-lethal application of deltamethrin, methyl parathion, monocrotophos and carbaryl.

It is interesting to note that contrary results were also reported by some other workers in which the reproductive rates of different insects such as *P. gossypiella*, *C. oryzae*, *A. aegypti*, *M. domestica*, *G. m. morsitans* and *P. xylostella* showed reduction following the application of insecticides at sub-lethal levels (Adkinson and Wellso 1962, Chadwick, 1962; Duncan, 1963; Georghiou, 1965; Kwan and Gatehouse, 1978 and Kumar and Chapman, 1984).

Incubation period

At LD_5 of decamethrin and LD_5 and LD_{10} of carbaryl, there was a remarkable decrease in the incubation period of eggs deposited by H. 28 punctata (Table 6). Here the grubs emerged out in a shorter period than in treatments involving higher sub-lethal concentrations and the untreated check. At the levels of LD_{25} and LD_{50}, increased rate of incubation period was noted.

Application of LD_{25} of both compounds and LD_{10} of carbaryl, promoted an increase in the rate of egg hatchability in H. 28 punctata. All other treatments showed a reduction in the rate of the viability of eggs which was lesser to the extent of 5.11 and 17.02 per cent as compared to the untreated check. Chauthari and Adkinson (1966) could not observe any change in the viability of eggs deposited by moths of H. virescens and H. zea larvae which were exposed to sub-lethal doses of toxicants. The incubation period of D. koenigii resulting from exposure to the sub-lethal and lethal doses of DDT did not differ substantially (Singh and Lal, 1966). Ganejdran et al. (1986) reported that the four insecticides decamethrin, methyl parathion, monocrotophos and carbaryl belonging to diverse groups showed least influence on the egg period and hatchability of D. cingulatus when exposed at their sub-lethal levels.

Larval duration

Sub-lethal concentrations of decamethrin and carbaryl at all the tested levels except at LD_{50} showed significant increase in the larval period of H. 28 punctata (Table 7). At the highest sub-lethal dose tested (LD_{50}) of both insecticides the larva attained pupal stage within a relatively shorter time as in the untreated check. However, maximum larval period was recorded in those insects subjected to the LD_5 dose of decamethrin.

When sub-lethal concentrations of test chemicals were applied topically on the aphids, A. gossypii (Table 8) the higher concentrations (LD_{25} and LD_{50}) of carbaryl only showed a prolongation in the nymphal period. The lower sub-lethal concentrations of this chemical as well as all sub-lethal doses of decamethrin reduced the nymphal duration which was significantly different from the untreated check. This clearly indicate that, decamethrin at all tested sub-lethal levels and the lower sub-lethal concentrations of carbaryl tended to shorten the nymphal duration of A. gossypii. Similar observations have been reported by Chelliah (1979). A decrease in nymphal duration of N. lugens was the result when lower dosages of diazinon were applied to rice plants. The hoppers completed their nymphal stage 1.1 days earlier on deltamethrin treated rice plants than on control plants (Chelliah and Heinrichs, 1980).

The topical applications of decamethrin and carbaryl on A. b. biguttula, have shown that carbaryl at all the sub-lethal doses reduced the nymphal duration. Lower concentrations of decamethrin (LD_5 and LD_{10}) caused maximum prolongation in the nymphal stage and the higher concentrations (LD_{25} and LD_{50}) showed minimum prolongation in the nymphal period.

From these results it is evident that, the direct influence on the larval duration of the test insects is very much dose dependent. Minimum sub-lethal concentrations of decamethrin and carbaryl were found to cause prolongation of larval period in *H. 28 punctata*. But in *A. gossypii* and *A. b. biguttula* it was at the higher sub-lethal levels tested (LD_{25} and LD_{50}) that prolongation of larval duration was recorded. These findings generally agree with the observations reported by Madhaven *et al.* (1970) on *T. castaneum*. They investigated the effect of sub-lethal doses of DDT, endrin, carbaryl, endosulfan and parathion on growth, developmental period and fecundity in *T. castaneum*. Treatment with sub-lethal doses prolonged the larval period and was directly proportional to the concentration of the insecticide used.

The average duration of the larval period of the boll worm *H. zea* surviving egg treatment with endrin and a 1:1 mixture of azinphos-methyl and azinphos-ethyl was approximately two days longer than for untreated control groups, whereas in the tobacco bud worm *H. virescens*, apparently there was no difference in larval period by egg treatment (Chauthari and Adkinson, 1966) indicating differential reaction of some insecticides in two different species. Singh and Lal (1966) also could not detect significant differences in the nymphal period of *D. koenigii* when subjected to treatments with sub-lethal doses of DDT and endrin.

Adult longevity

Topical application of sub-lethal concentrations (LD_5, LD_{10}, LD_{25} and LD_{50}) of carbaryl on the adult longevity of A. gossypii resulted reduction in the adult life span (Table 8). With decamethrin at higher concentration (LD_{50}) there was a significant reduction in the adult life span. At lower concentration of decamethrin (LD_5), it caused a prolongation of adult life span.

When decamethrin and carbaryl were applied on t the last instar nymphs of A. b. biguttula, there was a reduction in the adult life span at higher sub-lethal concentrations. (LD_{50}). Prolongation of the adult life-span was observed when lower sub-lethal doses of carbaryl (LD_5 and LD_{10}) and decamethrin (LD_5) were topically applied on A. b. biguttula.

From the studies on the adult longevity of A. gossypii and A. b. biguttula it is thus found that higher sub-lethal concentrations of decamethrin and carbaryl reduced their adult life span. Lower sub-lethal concentrations of decamethrin (LD_5) and carbaryl (LD_5 and LD_{10}) showed prolongation in the adult life span. However in the treatments with decamethrin (LD_5) which had stimulated reproductive rate of A. b. biguttula, the longevity of the adult was higher than the control indicating that adults lived longer in such treatments thereby increasing their progeny production. The increase in the reproductive potential of A. b. biguttula and A. gossypii on treatment with decamethrin at LD_5 dose and the prolongation in their adult life-span in such cases point out the potential for prolificity in breeding and increase in the potential for inflicting crop damage.

Afifi and Knutson (1956) reported that the life-span of the treated female housefly was higher when exposed to sub-lethal doses of dieldrin coupled with increased weight of the progenies. In contrast to this finding, the longevity of the adult pink boll worm that survived low dosages of DDT was shortened (Adkinson and Wellso, 1962). The longevity of adult D. koenigii surviving sub-lethal doses of DDT and endrin was significantly reduced as compared to control. The longevity of the female western corn root worm D. virgifera was significantly greater when topically treated with sub-lethal doses of carbofuran (Ball and Su, 1979). The shortening or lengthening of the life-span is thus found to be dependent on the type of the insecticide, the dosage level and the insect involved and a generalisation is not possible unless the foregoing factors are taken into account for specific situations.

Survival

The sub-lethal concentrations of decamethrin and carbaryl on the survival of *H. 28 punctata* did not show any immediate difect effect on the adults upto six days after emergence (Table 16). For carbaryl and decamethrin at their LD_{50} dose the casualities were relatively heavier. In the case of decamethrin at the LD_5 dose level there was a rise in survivorship after the 10th day. In carbaryl also the trend was similar but not as striking as in the case of decamethrin. This might be due to stimulatory effect of decamethrin at lower concentrations on *H. 28 punctata* populations.

In studies on the influence of mortality on *A. gossypii* under treatment with the two insecticides, it was found that at LD_{50} of decamethrin, there was a higher survival rate on the first day (Table 17). The effects of the treatments with LD_5 and LD_{10} concentrations of decamethrin and carbaryl were comparable with the pattern of survival in the untreated check. The LD_{25} and LD_{50} showed distinctly higher level of mortality.

When the last instar nymphs of A. b. biguttula were treated with sub-lethal concentrations of decamethrin and carbaryl (Table 18), direct influence on the survival rate was noted on the first day of emergence itself. All the sub-lethal concentrations of decamethrin and two higher concentrations of carbaryl showed high mortality levels as compared to lower levels and the untreated check. Complete mortality was noted on the third day of emergence at LD_{50} of both chemicals. In A. b. biguttula also, the lower concentrations stimulated to prolong the life period than in the untreated check.

From the studies on the influence of sub-lethal concentrations of decamethrin and carbaryl on the above test insects, the emerging trend is an increase in survivorship at lower doses of the sub-lethal scale, particularly so for decamethrin irrespective of the test insects. Similar variations in the adult life span were observed in the cotton boll weevil A. grandis and the cotton white fly *B. tabaci*. Dariola and Lindquist (1970) reported increased mortality when *A. grandis* was exposed to sub-lethal doses of the systemic insecticides as disulfoton, dicrotophos, monocrotophos and aldicarb. Carbaryl at LD_{30} increased the adult longevity in *S. litura* (Abo-Elghar *et al.*, 1972). The spectacular increase of *B. tabaci* populations on cotton and brinjal was ascribed to the indiscriminate use of synthetic pyrethroids (David *et al.*, 1986, Ravindranath and Pillai, 1986).

Field studies

Pest distribution

In the field experiment the effects of applying decamethrin and carbaryl at their LC_5, LC_{10}, LC_{25} and LC_{50} were assessed in terms of post-application population trends of *H. 28 punctata*, *A. gossypii* and *A. b. biguttula*. The counts of viable eggs of *H. 28 punctata* a week after treatment was distinctly more on those plants treated with lower sub-lethal doses of decamethrin and carbaryl. Maximum viable eggs were recorded on those plants treated with the LC_5 of decamethrin. A similar trend was observed for the population of grubs.

In respect of the adults, though a uniform increase in adult counts was recorded for the lower three sub-lethal doses of dedamethrin and for all four doses of carbaryl, the trends showed no significant difference from the untreated check.

With *A. gossypii*, decamethrin at LC_5 showed a tremendous increase in populations over pre-treatment levels. Though the same chemical at LC_{25} was comparable to the untreated check, the population was distinctly lower at the LC_{50} level. With carbaryl too at LC_5, there was a remarkable increase in the population build up after treatment.

A. b. biguttula recorded a gradual increase in the survival of hoppers with decrease in the sub-lethal doses of both insecticides.

The observations from the field experiment corroborates the general trend emerging from the laboratory studies in which sub-lethal doses particularly at the low tested levels promoted fecundity and survival.

An increase in the population of insects after application of sub-lethal doses of insecticides has also been reported in a number of instances. Reghupathy and Jayaraj (1973) observed an increasing trend in the populations of the leaf hopper A. devastans on bhindi plants, which received low toxic stimulus of the systemic insecticide disulfoton. They have also (1974) reported a flare up of A. gossypii and A. devastans following the loss of toxic stimulus of phorate which had been applied through soil. Sithanandam et al. (1973) have also reported that population of A. gossypii showed increasing trend on cotton plants that had previously received soil application of phorate and disulfoton granules. The fecundity of the brown plant hopper N. lugens increased on rice plants which had been previously treated with NRDC 161, diazinon and methyl parathion soon after the toxic stimulus had vanished, thereby causing population build up (Chelliah and Heinrichs, 1978).

Plant growth attributes

Field studies (Table 21, 22) have shown that the two tested insecticides decamethrin and carbaryl had no impact on the growth rate and yield attributes of the brinjal crop. Though there was no significant variation with regard to the number of fruits under insecticidal treatments there was increase in fruit weight in plots treated with decamethrin at LD_{10} and carbaryl at all sub-lethal levels except LD_5. Such quantitative variations in fruit yield were not significant.

Studies of Mistric and Mitchell (1966) showed delaying in fruiting and an increase in the yield of seed cotton with low concentrations of phorate, toxaphene and DDT. Sub-lethal concentrations of different insecticides such as phorate, carbofuran, quinalphos and methyl demeton increased the plant height, number and weight of fruit of chilli (Sinha and Roy, 1977). Patel (1980) reported increase in the plant growth of okra when treated with different insecticides including carbaryl. Similar results were obtained by Heinrichs et al. (1982) on rice plants sprayed with sub-lethal doses of methyl parathion and decamethrin. In the present studies the sub-lethal concentrations of decamethrin and carbaryl did not reveal any stimulatory influence either on plant growth or fruit yield. In the present studies altogether three rounds of sprayings were given and the last round was given at 72 days after transplanting and it is quite likely that the three rounds of sprayings could not bring about any favourable influence on plant growth or on fruit yield.

Natural enemy distribution

Regarding the occurrence of natural enemies, there was no difference between the untreated and the treated group of plants.

Residue dynamics

Deposits of carbaryl on the fruit after the spray was far below the tolerance level. In the case of the insecticide decamethrin which is far less persistent than carbaryl, the residues can be expected to be well below the tolerance limit and hence the residues of decamethrin were not assayed.

Summary

SUMMARY

Laboratory studies were conducted to evaluate the effect of sub-lethal doses of the two insecticides decamethrin and carbaryl at their LD_5, LD_{10}, LD_{25} and LD_{50} levels on the orientation, feeding, reproductive potential and survival of the three important pests of brinjal crop, namely, the epilachna beetle Henosepilachna 28 punctata, the aphids Aphis gossypii and the leaf hopper Amrasca biguttula biguttula. In a field experiment the population fluctuations of these three insects after applying the two insecticides at their sub-lethal levels were monitored and recorded. The plant growth characters and fruit yield were also recorded from the experimental crop.

The salient features of the study are as follows:

In all the three test insects, all the tested sub-lethal concentrations of decamethrin and carbaryl did not reveal any positive orientational response.

All the four sub-lethal doses of both the insecticides caused a decrease in feeding rate in H. 28 punctata as compared to untreated check plants. In the case of A. gossypii and A. b. biguttula, where the food intake was assessed indirectly by the radio isotopes studies, there was a prominent reduction in the food intake at the LD_{50} levels of the test insecticides.

Influence of sub-lethal doses of the two test insecticides on the sex-ratio resulted in a significant increase in the proportion of females of H. 28 punctata at the LD_5 level of decamethrin. With LD_{50} level for decamethrin and carbaryl, there was a sharp fall in the proportion of females. In the case of A. gossypii, sex-ratio as a parameter could not be studied since under laboratory conditions of rearing male populations failed to develop in the cultures. With A. b. biguttula at LD_{10} of decamethrin there was a strong shift in favour of females. At LD_5 of carbaryl and decamethrin also the production of females showed increase. As a factor that can cause resurgence, the increase in the proportion of females is found to be relatively more important in the case of H. 28 punctata and A. b. biguttula.

The present studies revealed that topical application of the sub-lethal concentrations of decamethrin and carbaryl on the last instar grubs of H. 28 punctata led to enhancement of the reproductive potential, of the adult emergents. Highest degree of stimulation was recorded in the case of decamethrin at the LD_{25} dose. As compared to decamethrin, the sub-lethal doses of carbaryl showed a lower degree of reproductive stimulation potential. But, for both insecticides, the LD_{50} dose suppressed the reproductive potential.

In the F_1 and F_2 generations of H. 28 punctata the increase in fecundity was manifested as in the parental population. In the F_1 generation the LD_{50} dose tended to promote fecundity. The survivors from the LD_5 treatments showed more prolificity in egg production in the F_1 and F_2 generations as compared to the parental population.

In the case of A. gossypii at the lower levels (LD_5 and LD_{10}) of both insecticides, there was an increase in the reproductive rate in the parent, F_1 and F_2 generations. The untreated check and the adults subjected to higher level of sub-lethal concentrations did not show any significant difference. As it reached the F_2 generation, in all treatments other than LD_{50} of carbaryl, nymphal production was higher than that in the parental population.

In A. b. biguttula, the lower concentrations of both insecticides resulted in more egg production in the parents as well as in the F_1 and F_2 generations.

The present studies show that the stimulation of reproductive potential of the two test insects is dose-dependent.

Attempts to study the influence of the sub-lethal doses of the insecticides on the duration of the immature stages of the test insects have revealed that, in H. 28 punctata, lower doses of both decamethrin and carbaryl shortened the incubation period, whereas with the higher dose (LD_{50}) there was an increase. At the dose LD_{25} for both toxicants and at LD_{10} for carbaryl, maximum egg hatchability was recorded. Maximum larval period was in the emergents from decamethrin treated at LD_5.

Aphids completed their nymphal stage earlier at all the tested sub-lethal doses of decamethrin as well as at the two lower doses (LD_5 and LD_{10}) of carbaryl. Topical application of decamethrin and carbaryl on

A. b. biguttula have shown that carbaryl at all the sub-lethal doses reduced the nymphal duration. Maximum nymphal duration was observed with decamethrin at LD_5 and it was minimum at the LD_{50} level. The direct influence on the larval duration of the test insects is found to be very much dose dependent.

From the studies on the adult longevity of A. gossypii and A. b. biguttula it was found that higher sub-lethal concentrations of decamethrin and carbaryl reduced their adult life-span and the lower sub-lethal concentration of decamethrin (LD_5) and carbaryl (LD_5 and LD_{10}) showed a prolongation.

The studies on the influence of sub-lethal concentrations of decamethrin and carbaryl on the survival of test insects have revealed that, at the lower concentrations of both insecticides there were more survivors as in the case of untreated check, particularly so for decamethrin, irrespective of the test insect. The higher concentrations resulted in bringing down the rate of survivors at an earlier date.

The results of the field experiment showed the occurrence of H. 28 punctata to be more on plants treated with lower sub-lethal doses of both insecticides. Between the two insecticides, plants treated with sub-lethal doses of decamethrin showed relatively more number of insects.

In the case of A. gossypii, treatments with decamethrin and carbaryl at the LD_5 dose and at LD_{10} of decamethrin there was a maximum increase in post-treatment populations counts. In A. b. biguttula there was a gradual increase in the survival of hoppers at the lower levels of the sub-lethal doses of both the insecticides.

The present study has also shown that the two insecticides - decamethrin and carbaryl at their sub-lethal doses have no effect on growth rate and yield characteristics of brinjal crop.

With regard to the incidence of natural enemies, there was no difference between the untreated and the various treated group of plants.

Deposits of carbaryl in the fruit after a sub-lethal spray was far below the tolerance level.

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*** Originals not seen**

Appendix

APPENDIX I

Ambient temperature and humidity condition for the laboratory studies for the period from April, 1983 to March, 1985 (recorded at Vellanikkara).

Month	Temperature Minimum (°C)	Temperature Maximum (°C)	Mean relative humidity (%)
April 1983	25.8	36.2	56
May	25.5	35.1	59
June	24.5	31.9	79
July	23.7	29.7	87
August,	23.8	29.1	87
September	23.4	29.5	84
October	23.1	31.2	77
November	22.3	31.8	71
December	23.9	31.2	53
January 1984	23.3	32.4	58
February	24.2	34.3	56
March	24.3	35.2	67
April	24.9	34.8	73
May	25.8	34.5	71
June	22.7	29.0	87
July	22.7	28.6	87
August	22.9	29.3	87
September	22.2	30.4	84
October	23.2	29.9	80
November	23.1	32.1	67
December	20.8	31.9	58
January 1985	22.6	32.5	67
February	22.8	34.7	58
March	24.6	36.1	63

Effect of Sub-lethal Doses of Decamethrin And Carbaryl on the Orientation, Feeding Reproductive Rate and Survival of Key Pests of Brinjal, *Solanum melongena* L.

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The effect of sub-lethal doses of decamethrin and carbaryl at their LD_5, LD_{10}, LD_{25} and LD_{50} levels on orientational stimuli, feeding, reproductive potential and survival of the three important pests of brinjal, namely, the epilachna beetle *H. 28 punctata*, the aphids *A. gossypii* and the leaf hopper *A. b. biguttula* have been studied in the laboratory.

In all the three test insects, positive orientational stimuli were not detected at all the tested sub-lethal levels of the two insecticides.

A decrease feeding rate in *H. 28 punctata* was detected when the insects were exposed to the sub-lethal dose treatments. In *A. gossypii* and *A. b. biguttula*, the reduction in the feeding rate was more pronounced at the LD_{50} level of both insecticides.

A sharp increase in the proportion of females in *H. 28 punctata* on treatment with LD_5 of decamethrin and a reverse effect at the LD_{50} level of both

insecticides was observed. Treatment with decamethrin and carbaryl at LD_5 and with decamethrin at LD_{10} level led to an increase in the proportion of females in A. b. biguttula.

Topical application of sub-lethal concentrations of both insecticides on last instar grubs of H. 28 punctata led to reproductive stimulation of adult emergents except at LD_{50} dose where there was a suppression of this trait. This tendency to produce more number of eggs was also recorded in the F_1 and F_2 generations as well. In the case of A. gossypii at the lower levels (LD_5 and LD_{10}) of both insecticides, there was an increase in the reproductive rate of parents, F_1 and F_2 generations. In A. b. biguttula too there was more egg laying in the parents, F_1 and F_2 generations with lower sub-lethal doses.

The incubation period of H. 28 punctata was shortened at the lower sub-lethal doses and showed prolongation at the LD_{50} level. Egg hatchability was maximum at LD_{10} of carbaryl and LD_{25} of both toxicants.

Larval duration was maximum at LD_5 dose of decamethrin. In A. gossypii, nymphal period was minimum at all levels of decamethrin and also at LD_5 and LD_{10} of carbaryl. Carbaryl at all the sub-lethal doses shortened the nymphal duration in A. b. biguttula. Decamethrin at LD_{50} dose also resulted in such shortening in the nymphal duration. At higher sub-lethal concentrations of decamethrin and carbaryl the adult life span in A. gossypii and A. b. biguttula showed reduction.

Lower sub-lethal concentrations had resulted in more survivorship of the test insects.

In the field experiment post-treatment counts of H. 28 punctata and A. gossypii were relatively more on plants treated with the lower levels of the lethal concentrations. In the case of A. b. biguttula there was a gradual increase in post-treatment counts at lower levels of the sub-lethal concentrations.