SHOOT AND FRUIT BORER (*Leucinodes orbonalis* G.) IN SOUTH INDIA

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INTRODUCTION

Vegetables are one of the most important components of Indian horticulture and in India a meal without vegetables is supposed to be incomplete. Vegetables are important source of vitamins, minerals, proteins in human diet and are rapidly becoming important source of income for the rural population by providing nutritional security and higher economic returns to the consumers and farmers throughout the world. India is a leading vegetable producing country in the world and grows maximum number of vegetables (over 60 in number) in one or other parts of the country. Presently, India occupies 722.07 thousand hectares with an annual production and productivity of 13443.59 thousand MT and 18.43 mt per hectare (Anon*.,* 2013a). Further, West Bengal ranks first among vegetable growing states of india with an average total production of 2965.60 thousand metric tons during the year 2012-2013 (Anon.*,* 2013b), contributing one-fifth of the country's total vegetable production followed by Odisha and Andhra Pradesh. In North and South India West Bengal and Andhra Pradesh stands first in production. Tamil Nadu and Karnataka in south are the other leading vegetable producing states in the country. Among the commercial vegetables, brinjal is the one which also occupy major share in area and widely cultivated throught the year all over India.

Egg plant or Brinjal, *Solanum melongena* Linnaeus (2n =24)) belongs to the family Solanaceae and genus Solanum commands an important place in the world and Indian vegetable market. It is highly cosmopolitan, commonly grown vegetable and popular as poor man's crop among economically low-income consumers in South Asia (Bangladesh, India, Nepal, and Sri Lanka). This region accounts for almost 50% of world's area under eggplant cultivation. This sturdy crop is cultivated throughout the year, even in the hot wet monsoon season when other vegetables are in short supply. Eggplant is practically the only vegetable that is available at an affordable price for rural and urban poor. This vegetable is cultivated on small family farms, where almost daily sale of produce, through a 5–6 month long season harvesting goes on and thus it is serves a ready source of income to farmers. Besides income, it is a valuable member of the human diet in Asia, which is a primary diversity center of the species. It is a rich source of vitamins B_6, C, K, thia-min, niacin and pantothenic acid, minerals such as magnesium, phosphorus, potassium, manganese, copper, dietary fiber and folic acid. It is used in Ayurvedic medicine for curing the diabetes. It is also used as a good appetizer and acts as a good aphrodisiac, cardiotonic, laxative and reliever of inflammation. Cultivated varieties of brinjal can be easily distinguished from wild relatives on the basis of phenotypic and morphological characteristics such as lack of prickles on stem, leaves and calyx and the size and colour of fruits (Kumar, 1998).

Brinjal is infested by a plethora of more than 70 insect pests (Subbaratnam and Butani, 1982) of which, the important pests are shoot and fruit borer, *Leucinodes orbonalis* (Guen.), whitefly, *Bemicia tabaci* (Genn.), leafhopper, *Amrasca biguttula biguttula* (Ishida), Epilachna beetle, *Henosepilachna vigintioctopunctata* (Fab.) and non insect pest, red spider mite, *Tetranychus macfurlanei (*Baker and Pritchard). During the past two decades, this crop has been increasingly ravaged by brinjal shoot and fruit borer, *Leucinodes orbonalis* (Guenée) (Pyraustidae: Lepidoptera) which is considered as most important, noxious, cosmopolitan insect pest and the main constraint in brinjal production, which damages the crop throughout the year. The infestation rate and yield loss varies from season to season and location to location. This pest is reported from all brinjal growing areas of the world including Germany, Burma, USA, Srilanka and India. Fruit and shoot borer (SFB) larvae bore into tender shoots and fruits, retarding plant growth and causing fruit damage as high as 92% (Mall *et al*., 1992). It is known to damage shoot and fruit of brinjal in all stages of its growth. The yield loss due to the pest is to the extent of 70-92 per cent (Eswara Reddy and Srinivas, 2004).

Despite the importance of brinjal and the severity of the *L. orbonalis* problem, the management practices to combat this pest are still limited to frequent sprays of toxic insecticides (Kabir *et al.,* 1996). However, due to the cryptic nature of their feeding habits, it is difficult to deliver pesticides to kill the insect, unless they are applied frequently to kill the neonate larvae during the very brief period that they are on plant surface. Farmers usually spray twice a week, applying 15 to 40 insecticide sprays, or more, in one season depending on infestation levels. The decision of farmers to spray is influenced more by subjective assessment of visual presence of SFB rather than guided by the more objective science-based methodology of economic threshold levels and control failures are the common feature in farmers' fields who adopt unilateral chemical control strategies. This reliance on subjective assessment of visual presence leads to a tremendous misuse of pesticides, insecticide resistance, increase in production costs, higher insecticide residues, elimination of natural enemies and harmful effects to consumer health.

The genetic plasticity of *L. orbonalis* is apparent in ability to detoxify many synthetic insecticides in addition to the secondary plant metabolites present in their narrow array of host plant species. Despite the concerted efforts, *L. orbonalis* remain a major recurring pest requiring considerable control, and there is little prospect of change in the immediate future unless novel approaches are adopted. In this regard continuous monitoring of insecticides resistance and revisiting the susceptibility level to various insecticides is very important to make suitable temporal and spatial modifications in the existing spray schedule.

In India, transgenic overexpression of *Bacillus thuringiensis* Berliner endotoxins (Bt Cry proteins) in several plant species has proved to be effective against lepidopteran insect pests, including *L. orbonalis* (Singh *et al*., 2005). Since usage of Bt spray formulations against *L. orbonalis* has been low in India, the introduction of insect resistant transgenic crops is expected to be of immense value in pest management programmes. In the event of its introduction, the large-scale cultivation and long term exposure to transgenic brinjal in the coming years may possibly impose selection pressure on the insect pest depending upon the species, geographical origin of the founder colony. In this view, baseline susceptibility of different populations of *L. orbonalis* will help in providing a database for developing transgenic crops with the right kind and amount of Cry toxin expression, and would also serve to monitor spatial and temporal development of resistance in target insect species, which is a primary regulatory requirement for transgenic crop technology.

Despite its obvious agricultural importance, very little is known about its population structure at molecular level. Populations of brinjal shoot and fruit borer, *L. orbonalis* are distributed over geographic areas with different seasonal environments. Genetic variation, predominated by natural selection process, occurs through the interaction of genetic forces and changing environmental factors through space and time, and provides the basis for evolutionary change. In response to the stresses, the populations of *L. orbonalis* have changed to adapt the ill effects by changing their eco- behavioural pattern, feeding physiology and reproduction, in addition to changes in their molecular machineries. During the present study an effort was made to compare the responses of such groups.

Development of tolerance by *L. orbonalis* to chemical insecticides, the high cost of insect control, environmental concerns, legal restrictions on the use of chemicals and frequent outburst of *L. orbonalis* leading to social disturbances suggest that efforts are now needed to understand the molecular diversity and genomic flux. Any management strategy to control the pest, in a given ecosystem, needs to consider the extent of genetic variability in the pest population, resistance status to various xenobiotics and the influx efflux of populations during the cropping season. Studies of genetic variability could help to determine whether the entire *L. orbonalis* population is truly a single interbreeding population in which intense gene flow can occur and could help to design the present and to formulate future management strategies of the insect pest accordingly.

The resistance to most eggplant insect pests has been found to be partially but often at rather low levels. Obviously, there is a great need for total or very high resistance to the main pests and diseases, and wild genetic resources deserve fuller investigation in this respect. In contrast, the majority of wild species are resistant to nearly all known pests of eggplant and thereby is a source of desirable traits for crop improvement. Use of resistant varieties is recognized as an important tool in the biologically intensive pest management system. To look for antixenosis due to the morphology of the plant and possibility of transferring resistance from wild relatives would be desirable and needs thorough investigation.

Insecticide resistance management (IRM) has become an important component in developing IPM package for brinjal crop in India. Several location specific IPM modules have been developed in the country. All the IPM packages mainly involve integration of biological agents with use of selective and effective pesticides on the basis of monitoring of insecticide resistance (Patil, 1998).Use of pheromones can provide a means of monitoring and controlling insects, which is non-toxic to animals and plants and specific for the target pest. As such, they are fully compatible with other methods of pest control and thus ideal components of IPM programmes. It is expected that IPM technologies have multiple dimensions of impacts and the adoption of IPM will not only reduce the pesticide contents in brinjal, but also increase the profitability of brinjal cultivation. In this regard it is therefore, important to evaluate the IPM technologies in brinjal ecosystem.

In the context of ensuring food safety, minimization of severity and environmental hazards, appropriate management practice for brinjal shoot and fruit borer incorporating different methods are needed and thoughts to be devised consistent with modern pest management. However, none of the individual methods also provides expected protection of the crop against this obnoxious pest and farmers need access to reliable, cost- effective and simple techniques for monitoring insect pest population. Nevertheless, their combination in a best compatible manner is expected to render desirable protection of the crop and pave the way for safe and sustainable vegetable cultivation. Keeping these issues in view, studies on various aspects of geographical populations of BSFB, *L. orbonalis* occurring in south Indian brinjal ecosystem were carried out in the present investigation with the following objectives.

1. To study the insecticide usage pattern in major brinjal growing regions of South India.
2. To monitor the baseline susceptibility in SFB populations of South India to different group of chemistries and *Cry*1Ac protein.
3. To assess the genetic diversity of brinjal shoot and fruit borer (*Leucinodes orbonalis* G.) populations occurring in south India using mitochondrial DNA markers.
4. To study the population dynamics of SFB in selected wild species of brinjal.
5. Development and validation of IRM/IPM strategies for SFB management in brinjal.

REVIEW OF LITERATURE

The present study envisages the pattern of the insecticide usage, population dynamics, development of IPM modules, baseline susceptibility to xenobiotics and Cry1Ac protein and genetic diversity in Brinjal shoot and fruit borer, *Leucinodes orbonalis* (Guene) across geographical locations of South Indian brinjal ecosystem. The retrospection of literature pertaining on enlisted objectives is scanty. Hence, available literature of different insecticides on different lepidopteran pests attacking other related crop was thoroughly reviewed and the same is presented here under.

2.1 To study the Insecticide usage pattern in major brinjal growing regions of South India.

Ali (1994) opined that in summer season for controlling eggplant shoot and fruit borer the farmers of Bangladesh are spraying almost daily, where as in West Bengal, India, frequency of application exceeds three sprays per week.The pesticide use is equally intensive in the Philippines. It was about 56 times during a cropping season and the total quantity of pesticide used per hectare was about 41 of the different brands belonging to the four major pesticide groups (Gapud and Canapi, 1994).

Surveys conducted in Bangladesh indicated that farmers spray insecticides up to 84 times during a 6-7month cropping season. About 47 percent of the total insecticides used in vegetables are used against *L. orbonalis* and the use for growing brinjal is 1.41 kg or L per ha (Anon, 1995). Similarly, Sabur and Mollah (2000) reported that, in Dhaka an increased use of pesticides by farmers, a wide range of organo- phosphorus, carbamate and synthetic pyrethroid insecticides with various spray formulations have been advocated from time to time against this pest. Fruit and shoot borer are only vulnerable to sprays for a few hours before they bore into the plant. Therefore, farmers spray insecticides as many as 80 times over a 7-month cropping season (Anon., 2002).

George *et al*. (2002) opined that in orissa, majority of the farmers (41.7%) commonly use carbaryl, endosulfan, carbofuran and cypermethrin in a seven to eight spraying schedule to control shoot and fruit borer and about 56.7 % farmers have found it expensive to control *L. orbonalis* though the use of insecticides.

A survey encompasing sixty farmer's fields was conducted in Orissa, India regarding the severity of *L. orbonalis* infestation in aubergine and local practices used for their management. Farmers found this insect pest as the most dangerous for the brinjal crop and considered blanket spraying as the most important management tool using Carbaryl, Endosulfan, Carbofuran and Cypermethrin. The farmers growing vegetables like aubergine were having negligible knowledge of beneficial insects (Babu *et al*., 1999).

Socio-economic studies of prevailing BSFB control practices in Jessore District of Bangladesh indicated that 98% of farmers relied exclusively on the use of insecticides and more than 60% of farmers sprayed their crop 140 times or more in the 6-7 months cropping season (Alam *et al*., 2003). They have also concluded that, farmers used to spend Rs. 3,570/acre (1 US$ = Rs. 44) on insecticides, 64% of which was intended to control ESFB in South india. On average, for a crop of 180 days 2.34kg/acre of active ingredient were applied in 30 sprays (Rashid *et al*., 2003).

Jeyanthi and Kombairaju (2005) observed that the number of sprays on brinjal to control FSB varies widely from 15 to 40 or more in a single crop season depending on the level of infestation in different areas. The farmers growing the open-pollinated varieties use 26.7 litres of pesticides per hectare as against the estimated economically optimal use of 4.9 litres per hectare and those growing hybrids use 54.3 litres per hectare against the optimal level of 16.0 litres per hectare. The minimum range of pesticide use intensity is 3.1 kg to 8.6 kg of active ingredient per hectare with an average of 4.6 kg active ingredient per hectare, which is the second largest, after chilli among all vegetable crops. An average farmer spends Rs. 12,000 ($270) per hectare on pesticide sprays.

Shivalingaswamy *et al*. (2005) surveyed and reported misuse index of insecticides at three sites of Uttarpradesh viz., Basavn, Salarpur and Araziline. The *misuse index* of insecticides varied from 6.07-7.88. In all the sites 87.18 to 92.60 per cent of the farmers were misusing insecticides by applying the toxic chemical at the less than the recommended interval. With respect to dose, the misuse index was 25.64, 45.46 and 59.26 per cent at all the sites respectively and 50-70.37 per cent of farmers were using more than one insecticide.

Survey conducted by AAS (Agricultural Advisory Society) on behalf of the Global Plant Clinic, during three successive cropping seasons, summer-I (Kharif-I), Summer-II (Kharif-II) and Winter (Rabi), 2004, using a novel method at 35 villages in 6 upazilas of Natore (Boraigram and Sadar), Norsingdi (Raipura and Shibpur) and Moulvibazar (Srimangal and Sadar) revealed that in Natore district, in a single season for brinjal crop, farmers sprayed pesticides 60-80 times and in some cases farmers used the pesticides almost everyday and 150-200 times in a single crop season. In Norsingdi district farmers applied pesticides at least 1-3 times in a week on Brinjal crop. Indiscriminate use of pesticides at high concentrations and frequent intervals was exceedingly common in all three survey areas (Rashid *et al*., 2006). Survey of pesticide use in Bangladesh indicated that farmers spray up to 180 times with chemical insecticides during a year to protect their eggplant crop against EFSB (Anon, 2007).

Prabuddha Ray and Chowdhury (2007) studied extent of use of pesticides by vegetable growers in 18 villages in Katwa-1 block, Bardhaman district, West Bengal. Over the 5 years most of the farmers applied pesticides on aubergine and cabbage, but the application rates, number of chemical groups of pesticides, and application frequency adopted by the farmers were greater than recommended in aubergine followed by cauliflower, cabbage and pointed gourd.

Rashid *et al*. (2008) made survey at Hathazari, Satkania and Fatikchari upazila in Chittagong district to identify major insect pest and pest management practices used by the brinjal growers. They revealed that among twenty five selected growers from each area, ninety-nine percent of growers relied solely on pesticide use to control brinjal shoot and fruit borer pest. The growers have used a variety of pesticides belonging to various chemical groups with various formulations and have applied insecticides more than 23 times in a season.

Mohiuddin *et al.* (2009) conducted rowing survey in Chittagong district to identify different pest problems and practices, input use and economic returns at farmers' levels. Majority of the farmers of Patiya sprayed insecticides more than 40 times in brinjal cultivation. Especially for Satkania, majority of the farmers sprayed every alternative day while in the winter, the spraying frequency was reduced once a week. Pesticide dealers were the major source of information to farmers on the selection of chemicals and application methods in Satkania, Patiya and Hathazari upazilas.

2.2 To monitor the baseline susceptibility in SFB populations of South India to different chemistries and Cry1Ac protein

2.2.1 Baseline susceptibility to insecticide chemistries in BSFB

The literature pertaining to the baseline susceptibility in geographical populations of brinjal shoot and fruit borer is lacking and hence information on related reports on other species are reviewed below.

Razmi *et al.* (1991) persistented toxicity of nine insecticides, *viz*., fenitrothion, methyl parathion, malathion, endosulfan, monocrotophos, quinalphos, phosphamidon, carbaryl and dimethoate to the neonate larvae of *Leucinodes orbonalis* Guen. Amongst these insecticides, the residues of malathion, quinalphos and dimethoate were found to have the quickest knock-down meet till four days as evidenced by LT_{50} values, being 3.33, 3.35 and 3.97 days, respectively. The residues of methyl parathion, endosulfan, monocrotophos and phosphamidon took six days to effect the same mortality of the brinjal shoot and fruit borer. The persistent toxicity (PT) of phosphamidon was the highest while malathion proved to be the less persistent insecticide.

Rahman (2009b) studied relative toxicity of different insecticides against second instar larvae of *Leucinodes orbonalis* collected from Jessore and Gazipur district of Bangladesh using leaf round, petridish, leaf containing petridish and leaf disc containing petridish techniques of bioassay. He concluded that leaf round method was found to be the best in estimating the toxicity of Marshal 20 EC, Ripcord 10 EC and Basathrin 10 EC . The observed mortalities in 0.1 concentrations of Marshal 20 EC, Ripcord 10 EC and Basathrin 10 EC for Jessore and Gazipur districts were 73.33%, 80.00%, 73.33%, 73.33% and 73.33%, 80.00% .The percentage of resistance was higher (18.19%) to Marshal 20 EC in Jessore BSFB population than in Gazipur (11.52%).

Similarly Latif *et al.* (2010) conducted laboratory experiment to test nine insecticides such as azadirachtin 0.03EC, abamectin 1.8EC, flubendiamide 24WG, chlorpyriphos 20EC, cartap 50SP, carbosulfan 20EC, thiodicarb 75WP, cypermethrin 10EC and lambdacyhalothrin 2.5EC belonging to different chemical groups against eggplant shoot and fruit borer. Among them, carbosulfan and flubendiamide showed the highest toxicity against fourth instar larvae of *L. orbonalis* after 24 and 48 hours of exposure.

Kavuri Yogi and Ashwani kumar (2010) studied the efficacy of insecticides against *Leucinodes orbonalis* Guenee under laboratory conditions. Larval mortality in 3rd instar larvae ranged between 52.87-81.78 in treatments Emmamectin benzoate, Chlorofenpyar, and Novaluron on 3rd day. Observations on 5th and 7th day indicated a greater per cent kill of the larvae and treatments indoxacarb, spionsad and Neem have not given expected kill. Treatments Novaluron, Emmamectin benzoate and Chlorofenpyar recorded larval mortality of 88.83, 92.52 and 94.34 per cent on 10th day.In all other treatments the per cent mortality ranged between 85.36 to 71.82 over untreated control.

For monitoring insecticide resistance, a sound insect rearing system is essential. Hence, an attempt has been made to address the deficiencies in existing artificial diets for rearing *L. orbonalis* larvae. The nutritional and phagostimulancy improvements in diet combinations developed herein are useful for rearing of *L. orbonalis* larvae under laboratory conditions. For insecticide resistance monitoring in *L. orbonalis*, the filter paper residue assay was found simple, precise and consistent in larval mortality. Four *L.orbonalis* populations collected from Bangalore, Guntur, Dharmapuri and Coimbatore were subjected to dose mortality bioassays against three insecticides to estimate resistance ratio. The study revealed up to six fold variation in susceptibility with respect to fenvalerate, phosalone and Emamectin benzoate in the populations of *L. orbonalis* tested. Quantification of midgut carboxylesterase from these four populations of *L. orbonalis* revealed significantly elevated activity in larvae collected from Guntur region (Anon., 2013).

Kodandaram *et al.* (2013) studies were conducted to determine the baseline toxicity and laboratory efficacy of cyantraniliprole 10% OD against *L. orbonalis* The LC_{50} values for cynatriniliprole, chlorantraniliprole and flubendamide were 0.000062 % (0.62ppm), 0.00018 % (1.8 ppm) and 0.00112 % (11.2 ppm), respectively for *L. orbonalis*. The descending order of toxicity for *L orbonalis* is cynatriniliprole > chlorantraniliprole> flubendamide. The relative toxicity of cynatriniliprole to *L. orbonalis* was evaluated by considering LC_{50} of flubendamide. On the basis of LC_{50} values cyantraniliprole and chlorantranilprole was 18 and 6.2 times more toxic to *L. orbonalis* as compard to flubendamide. This study highlights that among different diamide insecticides the new molecule cyantraniliprole 10% OD was highly effective to *L. orbonalis* which can be taken advantage for developing pest management strategies for these two pests of vegetables.

2.2.2 Baseline susceptibility of different insecticides on other lepidopteran insect pests

2.2.2.1 Resistance monitoring to old chemistries

Renuka and Regupathy (1996) reprted that, the extent of resistance varied from 66.7–100.0% for fenvalerate, 45.5–92.3% for quinalphos, 32.6 to 85.7% for monocrotophos, 14.3 to 55.2% for carbosulfan and 17.9 to 52.4% for cartap hydrochloride. Oddanchatram population showed high degree of resistance to fenvalerate. Irrespective of the locations high frequency of resistance was observed to fenvalerate > quinalphos, monocrotophos > cartap hydrochloride>carbosulfan.

Lande and Sarode (1993) worked out the LC_{50} of endosulfan to be 0.243 per cent with the feducial limits of 0.203 as lower and 0.29 as higher upper limit. Whereas, quinalphos was computed as 0.66 per cent with feducial limits as 0.52 for lower and 0.084 per cent as upper limits, in comparision with the usual dosages it was revealed that values are invariably higher indicating a significant change in the susceptibility of *Helicoverpa armigera* population and became less sensitive to these insecticides revealing the development of resistance. Susceptibility response to five commonly used insecticides *viz.,* endosulfan, chlorpyriphos, profenophos, fenvalerate and deltamethrin on *Spodoptera litura* (Fabricius) field population was determined by topical application and LD_{50} values were 0.7628, 0.0355, 0.3710, 0.0672 and 0.0647 ppm for endosulfan, chlorpyriphos, profenophos, fenvalerate and deltamethrin, respectively (Niranjan and Regupathy, 2000)

Monitoring for organophosphate and carbamate resistance for the period 1995–1999 on 53 field strains of cotton bollworm collected from 22 cotton-growing districts across India revealed that, of the 53 *H. armigera* strains only four were found to exhibit resistance to quinalphos, the highest 15-fold, whereas all 16 field strains tested were found to be resistant to monocrotophos. All the *H. armigera* susceptible strains exhibited low LD_{50} values to quinalphos ranging from 0.08 to 0.17 µg per larva, with steep slopes of 3.26 to 3.67. The field strains exhibited LD_{50} values within a range of 0.09 to 1.5 µg per larva with slopes of 1.1 to 3.7. In general, resistance across the country was low, with the highest levels of 10 to 15-fold observed in strains collected from the districts of Yavatmal, Prakasam and Guntur in South India. In contrast, the strains from Guntur exhibited appreciable resistance to quinalphos (i.e. > 8-fold) over a period of four years (Kranthi *et al.*, 2001).

Sharma and yadav (2001) studied the susceptibility status of *Helicoverpa armigera* (Hub.) to insecticides and neem seed kernel extract on pigeonpea and found fenvalerate registering lower value of LC_{50} compared to other insecticides. Fenvalerate and monocrotophos proved to be 3.903 and 1.019 times more toxic than endosulfan, Dimethoate was found less toxic. LT_{50} value was lowest (42.92 hrs) and highest (136.83 hrs) for dimethoate and fenvalerate at 0.08 and 0.005 per cent concentration, respectively on chickpea.

Kapoor *et al.* (2002) studied relative toxicity of different insecticides against third instar larvae of *H. armigera* using leaf disc residue technique of bioassay and revealed that the order of toxicity was deltamethrin> fenvalerate> chlorpyriphos> quinalphos> carbaryl> alphametrin> endosulfan. They revealed that about 2 to 112-folds decrease in susceptibility of the pest population to different insecticides and the decrease in susceptibility of *H. armigera* to synthetic pyrethroids was maximum. Where as in chlorpyriphos the effective dose and the recommended dose were found to be comparable.

The Mahbubnagar population recorded a maximum LD_{50} value to monocrotophos (80µg/µl) followed by the population from Buldana (36 µg/µl). The lowest LD_{50} value was observed in the population from Jalna (0.37µg/µl) followed by Karimnagar (13µg/µl) and Parbhani (18µg/µl). The Mahbubnagar strain showed the highest resistance to monocrotophos (216 fold) and the least resistance was observed in the population of Karimnagar (35 fold). Slopes of regression lines ranged from 2.3-2.6 for five strains and less than two for the remaining strains. The Parbhani and Buldana strains showed higher slope values of 2.61 and 2.49, respectively (Chaturvedi, 2004).

Jhansi *et al.* (2004) reported 120-287 folds of resistance to fenvalerate, 40-750 folds resistance to cypermethrin, 13.8 folds resistance to deltamethrin and 1.3-12.5 folds resistance to lambda cyhalothrin from Guntur region. Donald *et al.* (2005) evaluated Dose–mortality studies using diet overlay bioassays using first instar *Helicoverpa zea* and tobacco budworm, to Indoxacarb and pyridalyl.They revealed that The LC_{50} values of indoxacarb and pyridalyl for these insect species ranged from 1.05 to 1.33 ppm and 1.54 to 1.55 ppm, respectively. The indoxacarb LC_{90} for tobacco budworm was 4.54 ppm. For pyridalyl, the LC_{90} values ranged from 3.13 to 7.91 ppm for both species. Kathuria *et al.* (2005) observed strong larvicidal effects on *H. armigera* and reported that LC_{50} value of cypermethrin is 178.6ppb and was more toxic than endosulfan (LC_{50} = 484.1 ppb), quinalphos (LC_{50} = 535.3 ppb) and monocrotophos (LC_{50} = 643.4 ppb).

Kodandaram and Swaran Dhingra (2007) reported that the third instar larvae of *Spodoptera litura* obtained from Kapurthala were 20.74, 15.46, 12.9, 9.59 and 7.05 and 16.74, 13.22, 21.18, 11.50 and 4.83 fold resistant to deltamethrin, alphacypermethrin, cypermethrin, β- cyfluthrin and fenvalerate, respectively, when applied by direct spray and leaf dip method, respectively, as compared to Delhi population. Regardless of method of application β- cyfluthrin was the most effective against Delhi and Kapurthala population.

Chaudhari *et al.* (2008) conducted bioassay of five insecticides *viz.,* fenvalerate, cypermethrin, quinalphos, carbaryl and endosulfan under laboratory against populations of *Helicoverpa armigera* collected from known pesticide usage locations in Maharashtra. The log dose probit assays indicated that *H. armigera* population from Amalner with heavy pesticide usage area recorded higher LD_{50} values compared to Madha population representing low pesticide usage area. Irrespective of locations, fenvalerate was most toxic to *H. armigera* followed by cypermethrin, Endosulfan was least toxic to *H. armigera*.

2.2.2.2 Resistance monitoring to new chemistries

Lahm *et al*. (2005) revealed that the LC_{50} values of rynaxypyr were 0.002 ppm for *Plutella xylostella* (L.) and *Spodoptera frugiperda* (J.E.Smith) While LC_{50} values for *Heliothis virescens* (F) was about 0.04 ppm. Thilagam (2006) concluded that the median lethal dose of flubendiamide was 0.00131, 0.00043, 0.00062 and 0.00024 µg/g larva against *H.armigera, Earias vitella* (Boisduval), *Pectinophora gossypiella* (Saunders) and *Cnaphalocrocis medinalis* (Guen.) respectively. The tentative discriminating doses of flubendiamide against *H. armigera* and *C. medinalis* were 0.70 and 0.20 ppm respectively.

Dhawan *et al.* (2007) conducted bioassay studies on *Spodoptera litura* (Fabricius) larvae against some novel insecticides using topical bioassay technique and reported that LC50 values of emamectin benzoate, novaluran, pyridalyl, flubendiamide, chlorantraniliprole and thiodicarb were 0.0001, 0.0020, 0.0037, 0.0040, 0.0390 and 0.0410 per cent respectively. On the basis of LC50 value, the order of toxicity of different insecticides was emamectin benzoate > novaluran > pyridalyl > flubendiamide > chlorantraniliprole > chlorpyriphos > thiodicarb with relative toxicity of 390.0, 19.50, 10.54, 9.75, 8.86, 1.00 and 0.95 respectively.

The LC_{50} value of flubendiamide was 4.75 ppm and was relatively more toxic to the third instar larvae of *Spodoptera litura* than the other insecticides tested. On the basis of LC_{50} values, the next best insecticides in order of descending effectiveness were emamectin benzoate (5.09ppm), indoxacarb (7.86 ppm) and fipronil (136.48 ppm). Methoxyfenozide showed lowest acute toxic effect with highest LC_{50} value (738.41 ppm). The order of relative toxicity of different insecticides after 24 hr of exposure to *Spodoptera litura* was found as follows: flubendiamide (155.35) > emamectin benzoate (144.93) > indoxacarb (93.93) > fipronil (5.41) > methoxyfenozide (1.00). They concluded that flubendiamide closely followed by emamectin benzoate showed the best efficacy in controlling the test insect in laboratory conditions (Ghosh *et al.,* 2007).

Indira Chaturvedi (2007) reported that among the seven different insecticides *viz*., endosulfan, methomyl, monocrotophos, quinalphos, chlorpyriphos, fenvalerate and cypermethrin tested against second-, third- and fifth-instar *Helicoverpa armigera* larval populations collected from cotton growing regions of central and south India. The *Helicoverpa armigera* exhibited widespread resistance (RF= 48-919) to cypermethrin. Insecticide resistance to chlorpyriphos was low to moderate in the majority of the strains tested.

Bioassay studies conducted on rynaxypyr against bollworm *Heliothis zea* (Boddie), fall army worm *S. frugiperda*, and tobacco bud worm *H.virescens* (F) and found that rynaxypyr was highly toxic in all three bioassay methods. In topical bioassay method the LD_{50} values ranged from 0.5 to 1.43 µg/g larval weight, whereas in diet incorporation bioassay method LC_{50} values ranged from 0.2 to 0.11 µg/ml of diet and in adult vial test LC_{50} values ranged from 1.21 to 1.71 µg/vial for bollworm, fall armyworm and tobacco bud worm, respectively (Mary and Laurie, 2007).

Toxicity of emamectin benzoate against tobacco caterpillar, *Spodoptera litura* by three different assay techniques *viz.,* leaf-dip, potter's tower and thin-film concluded that median lethal concentrations of emamectin benzoate 1.9 EC against 5-day, 7-day and 9-day old larvae were 0.00005, 0.00017 and 0.0007 per cent respectively. Emulsifiable concentrates (1.9 and 5 %) of emamectin benzoate outperformed the water soluble granule (WSG 5%) (Ajanta Birah *et al.,* 2008).

Joshua *et al*. (2008) studied the susceptibility levels of rynaxypyr and cypermethrin against lepidopteran insect pest using adult vial test. The cypermethrin LD_{50} values of two pyrethroid susceptible colonies were 0.20 and 0.21 µg/g larval weight whereas in rynaxypyr treated diet assay several bollworm colonies had LC50 values ranging from 0.038 to 0.089 µg/ml of diet.

Kubendran *et al*. (2008) conducted studies to develop baseline toxicity data of flubendiamide 480 SC against tomato fruit borer, *H .armigera* and results revealed that susceptibility of *H. armigera* increased after five generations in insecticide free exposure culture, and susceptibility index for LD_{50} was 1.023 and it was 1.106 for LD_{95} .The rate of resistance decline 'R' value being negative (-0.003) indicates that 333.33 generations are required for 10 fold decrease.

Johnson Stanley *et al*. (2009) reported high susceptibility of *H.armigera* to emamectin and spinosad. The median lethal dose (LD_{50}) of emamectin is 3.86×10^{-3} µg per larva. The median lethal concentrations (LC_{50}) of emamectin and spinosad were found to be 0.09 and 2.94 ppm, respectively. Based on the LC_{95} of the susceptible population of *H. armigera* discriminating doses were found to be 0.80 ppm for emamectin and 10 ppm for spinosad. Resistance was not observed when the discriminating doses of emamectin and spinosad were applied on field-collected populations of *H. armigera* from two intensive cotton growing areas, Coimbatore and Madurai, India.

Dhamu Lavanya *et al*. (2010) studied the acute toxicity of emamectin 5 SG and spinosad 2.5 SC on Diamondback moth, *Plutella xylostella* collected from three different locations in Tamil Nadu. They revealed that median lethal doses (LC_{50}) values of emamectin and spinosad were found to be 0.066 and 2.12 ppm respectively. Based on LC_{95}, discriminating doses were fixed at 2 ppm and 10 ppm for emamectin and spinosad. Revalidating the discriminating doses on field collected populations found that there was no resistance among the populations of *P. xylostella* from the three locations – Coimbatore, Ooty and Oddanchatram. Rajesh chowdary *et al*. (2010) evaluated the susceptibility of third instar larvae of okra fruit borer *Helicoverpa armigera* to rynaxypyr 20 SC by topical bioassay technique under laboratory conditions. They revealed that, susceptibility of *H. armigera* increased after five generations in insecticide free exposure culture, the susceptibility index for LC_{50} was 0.66.

Wankhede and Kale (2010) laboratory experiment conducted at MPKV, Rahuri during kharif 2007, revealed that critical time required to affect 50 per cent *Leucinodes orbonalis* larval population mortality for emamectin benzoate was 4.46 days with upper and lower fiducial limits of 5.172 and 3.849 days. For novaluron, it was 3.83 days with upper and lower fiducial limits of 4.632 and 3.181 days. The recorded LT_{50} value for diflubenzuron was 2.65 days with 3.398 and 2.067 days upper and lower fiducial limits.

Laboratory bioassay experiment conducted against third instar larvae of *H. armigera* and *Spodoptera litura* to the three insecticides *viz*., indoxacarb, thiodicarb and spinosad (0.0145-0.29, 0.375-3.0 and 0.045-0.45 µg a.i per larva) with standard topical application method revealed that, Indoxacarb and spinosad showed 16.6319 and 7.4872 folds toxic as compared to thiodicarb which recorded highest LD_{50} value of 1.34852 (Venkanna Yasa and Ranga Rao, 2011).

2.2.2.3 Baseline susceptibility of Cry protein to brinjal SFB *Leucinodes orbonalis*

There was almost a linear relationship between insect mortality and Crystal protein concentration (average R^2 = 0.93). The three Crystal proteins IB, Ia and IIA with the highest toxicity to eggplant fruit and shoot borer larvae are considered to be prime candidates for transgenic eggplant studies (Anon, 1998).

Rao *et al*. (1999) studied the efficacy of seven lepidopteran specific delta-endotoxins of *B. thuringiensis* against the second instar larvae of the brinjal shoot and fruit borer by coating the Bt toxins on to the modified semisynthetic diet for bioassay. Larval mortality recorded on every 24 h and the final mortality on the fourth day revealed that Cry2Aa protein was the most potent toxin tested followed by Cry1C, Cry1Ac, Cry1Ab and Cry1B in descending order.

Baseline susceptibility data revealed 12-fold variability in LC_{50} value of 29 populations tested for Cry1Ac susceptibility. The field populations demonstrated 70-fold inter population variation in the insect susceptibility to the Cry1Ac protein indicated by MIC_{50}. The variability was 14-fold when MIC_{95} was considered and values ranged from 0.020-0.138 ppm of diet. Average MIC_{95} was found to be 0.059 ppm (Anon, 2006a). Yashodha and Kuppusamy (2008) reported that median lethal concentration (LC_{50}) of Dipel a Btk formulation was lesser with 83.93, 190 and 310.42 ppm than delfin which recorded 245.24, 372.42 and 536.34ppm against II, III and IV instar larvae of *L. orbonalis*.

Laboratory experiments were conducted at Indian Institute of Vegetable Research, Varanasi to standardise the artificial diet for rearing and conducting bioassay on the Cry 1 Ac-incorporated diets of *Leucinodes orbonalis*. Drying and disinfection of black gram-based diet in the feeding tubes improved the larval survival and adult emergence which was comparable to the brinjal fruits. There was no significant difference in mortality of BSFB larvae among the substrates i.e., brinjal fruit, brinjal flower and artificial diet. Irrespective of the substrates the presence of Cry1 Ac in transgenic plant and diet recorded significantly higher mortality over the normal plant and diet. Although Varanasi population was slightly more susceptible than Mirzapur population, the difference was non-significant. The LC_{50} value of larvae collected from Mirzapur was also marginally more than the Varanasi population. In general the laboratory population was more susceptible to Bt protein than the field population. Although variation in susceptibility to Cry1Ac was observed between the two populations of *L. orbonalis*, the magnitude of the difference was small (Satpathy *et al*., 2009). Wankhede and Kale (2010) reported that, LT_{50} for Bt*K* against *L.orbonalis* is 1.50 days with upper and lower fiducial limits of 2.104 and 1.078 days.

Bacillus thuringiensis (Bt) Cry toxins and Bt strains were evaluated to demonstrate the susceptibility of neonates of brinjal shoot and fruit borer (BSFB), *Leucinodes orbonalis*, collected from Delhi and its suburbs Sonipat, Jhajjar and Sampla. Cry1Ac, Cry1Ba, Cry1Ca, Cry2Ab toxins of Bt and Bt strain Aug05 were tested by diet incorporation bioassays. The seven-day median lethal concentration (LC_{50}) of Cry1Ac ranged from 0.002-0.069 µg/g, Cry1Ba from 0.13-0.21 µg/g for three populations and Cry1Ca from 0.12 -0.39 µg/g for four tested populations. The LC_{50} of Bt strain Aug05 was 0.044 µg/g on the basis of total toxin content, 0.012 µg/g on Cry1Ac and 0.1 µg/g on Cry2Ab content basis for the Delhi population. Cry2Ab was relatively less toxic of all the four Bt toxins and strain tested. These baseline susceptibility studies are useful in developing resistance management tactics in Bt brinjal (Vinay *et al*., 2013).

2.2.2.4 Baseline susceptibility of Cry protein to other lepidopteran pests

Kongming Wu *et al*. (1999) studied geographic variation in the sensitivity of cotton bollworm from 5 ecological cotton areas of China to *B. thuringiensis* insecticide protein CryIA(c). They reported that of LC_{50} and IC_{50} of larvae grown into 3rd instars among different populations were 0.09-9.073 µg/ml and 0.011-0.057 µg/ml.

Gujar et al. (2000) reported from India that the spatial variation in susceptibility of *Helicoverpa armigera* indicating populations from Delhi (F), Raichur (F_1 and F_2) and Bangalore were least susceptible to the toxicity of Btk.On the contrary, the Hyderabad and Madurai population were most susceptible. In Kranthi *et al*. (2001) baseline toxicity studies of Cry1A delta -endotoxins on field populations of the cotton bollworm, *Helicoverpa armigera*, that LC< sub>50< sub> values ranged from 0.07 to 0.99 micro g/ml (14-fold) for Cry1Aa, 0.69 to 9.94 micro g/ml (14-fold) for Cry1Ab and 0.01 to 0.67 micro g/ml of diet (67-fold) for Cry1Ac. The LC< sub>50</ sub> values deduced from the cumulative log dose probit response of the data pooled from all assays, were 0.62 micro g/ml for Cry1Aa, 4.43 micro g/ml for Cry1Ab and 0.100 micro g/ml of diet for Cry1Ac. The LC< sub>99</ sub> values derived from the cumulative data were 515 micro g/ml for Cry1Aa, 13385 micro g/ml for Cry1Ab and 75 micro g/ml of diet for Cry1Ac.

Of the several field strains tested form various locations in the country, *H. armigera* from Akola, Rangareddy and Guntur were found to be the most tolerant to Cry 1Ac toxin (67 fold tolerance) and Prakasham strain exhibited the highest tolerance to Cry 1Ac which was significantly higher than all strains except the Coimbatore strain (Kranthi, 2002).

2.3 To assess the genetic diversity of SFB (*Leucinodes orbonalis* G.) populations occurring in south India using mitochondrial DNA markers and other tools

It is important to understand how the biology of a species affects its geographic population structure. Genetic data obtained from molecular techniques allows us to infer geographic structure by estimating genetic similarities and population subdivision among populations or examining relationships among genotypes from several populations relative to this geographic location (phylogeography) (Roderick, 1996).

Among molecular techniques, mitochondrial DNA (mtDNA) analysis has been extensively used as this marker exhibits several advantages. Mitochondrial DNA is a valuable marker to indicate maternal gene flow, as it is predominantly transmitted through maternal lines and because mtDNA is more numerous than nuclear DNA (the ratio of mitochondria to nuclei being far greater per cell), it can be more easily detected in old samples. This macromolecule evolves faster than most nuclear sequences and lacks recombination (Avise, 1991). Because of these properties, it has been extensively used for analyzing phylogeography and population structure in insects (Chapco *et al*., 1992; Marchant and Shaw, 1993; Rossi *et al*., 1996 and Lunt *et al*., 1998).

Mitochondrial DNA (mtDNA) was used for taxonomic and population genetic studies on biotypes of cereal aphids, fruit flies and hymenopterous parasitoids (Powers *et al*., 1989; Simon *et al*., 1994; Taylor *et al*., 1996) and phylogenetic analysis of leafhoppers (Fang *et al*., 1993), genetic variation in grasshoppers (Chapco *et al*., 1994).

Karthikeyan *et al.* (2005) studied genetic variability of six different populations of *L. orbonalis* in terms of carboxylesterase isozyme pattern and DNA polymorphism using RAPD-PCR. Pattern of carboxylesterase revealed a similar isozyme cluster in the populations namely, Sivaganga (population-3), Dindigal (population-4), Virudhunagar (population-5) and Coimbatore (population-6). Similarly, the populations of *L. orbonalis* recorded 3 distinct randomly amplified polymorphic DNA markers in all populations grouped above.

Geetharajalakshmi *et al*. (2006) for understanding the intraspecific variation, genomic DNA of ten different populations of *L. orbonalis* belonging to different eggplant growing regions were analyzed for RAPD profiles. Twenty-five "lepidopteran specific random primers" generated a total of 279 markers revealing an average of 10-12 markers per primer in each population. The primers generated 249 polymorphic markers, 35 monomorphic markers with a polymorphism percentage of (87.6). The per cent of polymorphism ranged from 46.15-100 for different primers.

AFLP-PCR analysis was used to characterize 29 natural populations from different eggplant growing regions of India. Forty primer combinations were screened initially, of which 15 primer pairs were selected based on the band resolution and PCR reproducibility. The fifteen primer combinations generated AFLP patterns with fragments ranging from 25-60 fragments per primer pair depending on the populations screened and the number and nature of the selective nucleotides used. The results reported in this study demonstrate the utility of AFLP in generating markers useful for genetic analysis in EFSB populations (Tejbhan saini *et al*., 2006)

Murugan Marimuthu *et al*. (2009) carried investigations on genetic diversity of *L. orbonalis* population collected from different locations of Tamilnadu State using RAPD markers. Of 17 RAPD primers screened, only 11 primers generated polymorphic bands (up to 14 bands). Only two major clusters with no variation among population were deduced. Results indicated that there was a steady genetic flow among the population of *L. orbonalis* alleviating genetic variation, which may be attributed to passive and active dispersal of the insect besides absence of host induced variations among the population.

Ghante *et al*. (2013) analysed genomic DNA of ten different populations of *Leucinodes orbonalis* G.from north Karnataka for studying genetic variation among them. Fourty decamer primers were used in this analysis, which generated a total of 244 markers revealing an average of 14.35 markers per primer in each population. Phonetic dendrogram was generated by UPGMA method and principal component analysis separated 12 populations into different groups based on band-sharing data. Populations showed varied degrees of genetic diversity within the range of 0.04-0.52.

Jian Cheng Chang *et al.* (2014) examined genetic diversity and structure of *L. orbonalis* in eight populations from six countries using mitochondrial *cytochrome c oxidase subunit I* DNA sequences. No correlation between genetic diversity and geographic distance was detected among populations. Low levels of haplotype and nucleotide diversities were observed in the Philippines population, suggesting recent colonization. No significant gene flow was found among local populations in different countries. The Vietnam population is highly differentiated, indicated by significant pairwise *FST* values, and may be ascribed to a new subspecies or race. India was confirmed to be the source of genetic variation in *L. orbonalis* populations. Our study showed that *L. orbonalis* formed subpopulations for each local region, and the corresponding pest management technology should be developed at the country scale.

2.3.1 Genetic diversity of other insects using different markers

Fakrudin *et al*. (2004a) reported genetic variability within and between geographic populations of cotton bollworm, *H. armigera* (Hübner) prevailing in south Indian cotton ecosystems using RAPD-PCR. The mean similarity coefficient across populations ranged from 0.75 to 0.82. Samples from Madhira had the highest (0.82) and those from Nagpur, Nanded and Nalgonda had the lowest similarity (0.75). Within populations, it ranged from 0.73 to 0.86 indicating significant amount of genetic heterogeneity. Clustering analysis revealed two major groups, each comprising six populations, corresponding to southern and northern parts of South Indian cotton ecosystem.

Laffin *et al*. (2004) sequenced an 826bp fragment of mt DNA CO1 gene in 130 indiviuals of white pine weevil (*Pissodes strobi*) from 11 locations across, Canada. Nested clade analysis of 36 halotypes yielded three patterns of genetic structuring that are inferred as due primarly to restricted gene flow and contiguous range expansion, with one case of long distance colonization. Analysis of molecular variance also showed significant genetic structures and restricted gene flow among regional population. Eastern and western populations were divergent, as were the four populations surveyed in british Columbia.

Further Vijaykumar *et al.* (2008) made studies on genetic diversity of 12 cotton bollworm, *H.armigera* populations from different geographic regions of South India using mitochondrial DNA-specific markers. Thirteen selected mtDNA universal markers/primers generated a total of 167 PCR amplicons, of which 162 were polymorphic across all 12 populations. Populations showed varied degrees of genetic similarity within a range of 0.04-0.52.

2.4 To study the population dynamics of SFB in selected wild species of brinjal

The reports on alternate host plants of brinjal shoot and fruit borer (*L. orbonalis*) in different parts of the world is summarized in Table 1.

Immunity to *L. orbonalis* was reported only either in wild species of brinjal like *Solanum khasianum*, *S. anomalum* and *S.incanum* (Lal *et al*., 1976). The wild species *Solanum sisymbrifolium*, *S.integrifolium*, *S.xanthocarpum*, *S.nigrum* and *S. khasianum* have earlier been found free from the damage of shoot and fruit borer damage,while *S.incanum* showed infestation of 8.6 % (Dhankhar *et al*., 1980).

Some of the wild Solanum species such as *anomalum*, *gilo*, *incanum*, *indicum*, *integriifolium*, *khasianum*, *sisymbriifolium*, *xanthocarpum*, etc were reported to possess high resistance to EFSB (Khan *et al*., 1978; Sharma *et al*., 1980; Chelliah and Srinivasan, 1983; Singh and Kalda, 1997; Behera *et al*., 1999).

Ishaque and Choudhary (1985) confirmed that, besides brinjal some other plants served as alternative host of *Leucinodes orbonalis* with varying levels of infestation during different periods of the year. These plants were *S. nigrum S. indicum*, *S. torvum* and *S. tuberosum*. In *S. myriacanthum* the larvae bored into the shoots of these species. Kale *et al.* (1986) recorded the shoot infestation (both on number and weight basis) of *S. incanum*, *S. xanthocarpum* and *S. sisymbrifolium* and found that these wild species are immune as they showed no infestation.

Studies by Kumar and Sadashiva (1996) in Karnataka during 1987-96 confirmed resistance in *Solanum macrocarpon* to *Leucinodes orbonalis* and Asphondylia sp. The incidence of fruit damage by *L. Orbonalis* and Asphondylia sp on cultivated aubergine *S. melongena* varieties was 10-50% and less than 1% in *S. macrocarpon*. They revealed that resistance can be incorporated by crossing S. *macrocarpon* with aubergine.

Solanum viarum and *S. macrocarpum* are highly resistant to eggplant fruit and shoot borer. The insect incidence was less than 1% in *Solanum viarum* and 7–8 per cent in *Solanum macrocarpum*, compared with 40–45 per cent infection in the cultivated variety Arka Nidhi and the hybrid Mahyco (Anon., 1998). Somatic hybridization (Symmetrical or asymmetrical fusion) between eggplant and valuable wild species such as *Solanum torvum* and *Solanum sisymbriifolium* is being investigated as a way of overcoming the sexual barriers between eggplant and these two species which carry many valuable pest and disease resistances (Collonnier and Sihachakr, 1998). Among the seven mutant progenies of *Solanum macrocarpon* were subjected to histological and histochemical examination for shoot and fruit borer resistance. The 5 Kr-P33-4, 10 Kr -P3-10 and 10 Kr-P10-22 mutants found to be more resistant and recorded thicker epicarp, compactly arranged larger mesocarp cells and continuous deposition of lignin layer than other mutants (Srinivasappa *et al*., 1998).

Babu *et al*. (1999) reported that, when 1-month-old seedlings of *Solanum macrocarpon* M4 lines (10 Kr-P7-20, 5 Kr-P7-33, 5 Kr-P22-4, 5 Kr-P21-2, 5 Kr-P38-6 and 10 Kr-P2-10), *S. macrocarpon* (control) and *S. melongena* cv. Pusa Purple Long (PPL) were transplanted, the shoots and fruits of cv. Pusa Purple Long were infested with *L. orbonalis* but none of the shoots and only a low percentage of the fruits of M4 lines and the control were infested.

Behera *et al.* (1999) reported that the genetic divergence among 12 genotypes estimated using D^2 analysis formed four clusters. The genotype *Solanum indicum* appearing in cluster III was highly resistant and the genotypes *Solanum gilo, Solanum incanum* and *Solanum anomalum* in cluster 1 were resistant. Pusa Purple Cluster, Bhagyamathi, Annamalai, APAU-4, Nurki and Singhnath genotypes in cluster IV were moderately resistant. The genotypes Pusa Kranti and Aushey in cluster II was susceptible to *Leucinodes orbonalis.*

The seedling infestation was lowest in *S. indicum* (6.6%) among the parents and Pusa kranthi x *S. indicum* (7.46%) among the hybrids. The lowest shoot infestation was found in *S.indicum* (2.99%). The hybrid, Pusa kranthi x *S.indicum* showed less susceptibility shoot damage. With regard to fruit infestation, *S.indicum* was immune to shoot and fruit borer. The hybrid Pusa kranthi X *S.indicum* showed lowest fruit infestation of 9.39 per cent and 10.52 per cent on number and weight basis respectively but the fruits were abnormal in size. *S.gilo* was also found to have high degree of resistance against shoot and fruit borer so also *S.incanum* and *S.indicum* (Behera and Narendra singh, 2002b). Similar reports were also made by Rao and kumar (1980) in case of *S. indicum;* Kale *et al*. (1986) in case of *S. ncanum* and Tejavathu *et al*. (1991) in *S. gilo*.

Sridhar *et al*. (2001) screened fifty-four brinjal germplasms, including 5 wild species and some F< sub>1</ sub> crosses, for resistance to *L. orbonalis*, during 1999-2000, under field conditions in Bhubaneswar. Three wild species, i.e. *S. khasianum*, *S. viarum* and *S. incanum*, were found to be resistant from fruit infestation (0.5-10.0%). Among the cultivated lines, CHB-103, 187 and 259 were fairly resistant. Among the brinjal groups, genotypes with relatively long fruits and tightly arranged seeds, the attack of *L. orbonalis* was less. Some of the wild species possessing resistance were crossed with the brinjal to incorporate the resistance to shoot and fruit borer and to obtain high yield in the hybrids. In brinjal, interspecific crosses were done with wild forms of *Solanum* species namely *S. incanum* L. until F_4 generation, two progenies of each selection were morphologically homogenous and resistant to shoot and fruit borer in the field (Rao, 1981); similarly *S. macrocarpon* L. by Gowda *et al*. (1990) and in *S.indicum* L. by Behera and Singh (2002). The CO2 x *S. viarum* progenies showed a higher rate of shoot and fruit borer infestation manifesting the requirement for suitable cross combination to evolve shoot and fruit borer resistance in brinjal (Preneetha, 2002).

All five accessions Large, Africa2, Cherry, and Africa 4, Tengeru of African eggplant showed significantly less shoot damage compared to land race EG075 (Anon., 2002). Some of the wild *Solanum* species such as *anomalum*, *gilo*, *incanum*, *indicum*, *integriifolium*, *khasianum*, *sisymbriifolium*, *xanthocarpum*, etc., were reported to possess high resistance to ESFB (Behera and Singh, 2002a). *Solanum nigrum*, *S. indicum*, *S. torvum*, *S. myriacanthum*, tomato and potato were recorded as alternative host plants of EFSB (Fletcher, 1916; Menon, 1962; Nair, 1967; Das and Patnaik, 1970; Mehto *et al*., 1980; Isahaque and Chaudhuri, 1983; Srinivasan and Babu, 1998; Murthy and Nandihalli, 2003; Reddy and Kumar, 2004).

Nalwandikar and Puri (2004) conducted laboratory experiments to study the effects of wild aubergine *Solanum khassianum* leaves on feeding of *Helicoverpa armigera* larvae and observed growth inhibition causing larval mortality and prolonged larval and pupal duration. The highest mortality of *H. armigera* was observed on 120 (51.33%) day-old wild aubergine leaves. Larval and pupal duration were prolonged to 22.10 and 21.62 days, and 12.48 and 12.18 days on 120 and 105 day old wild aubergine leaves. The larvae that entered pupal stage showed 48.66 and 50.66% pupation and adult emergence was affected showing the lowest percentage of 64.38 and 65.80 on 120 and 105day old leaves.

Anju Shukla and Khatri (2010) studied effect of different host plants *Solanum melongena*, *Lycopersicon esculentum*, *Abelmoschus escullentus*, *Solanum tuberosum*, *Solanum nigrum*, *Cynodon indicum*, *Oscimum Basilicum* and *Solanum indicum* on the development of brinjal shoot and fruit borer *Leucinodes orbonalisis* Guenee. They concluded that larval period was not uniform on all the tested host plants. It was shortest on *Solanum melongena* (15.75 days) whereas longest (38.72 days) on *Oscimum basilicum*. The shortest period (4.88 days) and the longest period (14.71) was observed to complete the pupal development on *Solanum melongena* and *Oscimum basilicum*.

Vageeshbabu *et al*. (2011) examined the presence of genetic resistance in *S. macrocarpon* against BSFB through a systematic screening involving challenge inoculation with BSFB larvae and shows that *S. macrocarpon* is not an ideal candidate for resistance breeding as it is equally, if not more, susceptible to the pest. This study necessitates the need for rigorous screening of brinjal germplasm using artificial infestation with BSFB to avoid false positives in resistance breeding programmes.

2.5 Development and evaluation of IRM/IPM strategies for SFB management in brinjal

Inclusion of *Trichogramma* for the management of *L. orbonalis* followed by insecticides, botanicals and *Metarhizium* resulted in higher yield (Banerjee and Basu, 1955). Similarly, Quereshi *et al.* (1998) were of the opinion that mixture of Btk 1 ml + methomyl 0.8 g per litre of water was the best treatment in reducing the brinjal fruit damage to 37 per cent with higher fruit yield of 164.10 q per ha. Btk 1 ml + endosulfan 0.75 ml and methomyl 1.6 g per litre of water were also equally effective in reducing fruit damage to 4.74 and 5.60 respectively.

In a field experiment with egg plant, control of *L. orbonalis* by chemical and biological means was examined. The most effective control of the pest was achieved with the application of 4 per cent neem (*Azadirachta indica* L.) oil, the highest fruit yield of 24.48 t per ha. *Trichogramma chilonis*, egg parasitoid released at fortnightly intervals significantly reduced pest damage and produced fruit yield of 20.30 t per ha compared to the control which yielded 13.06 t per ha (Raja *et al.,* 1998). Rouf (1999) found that hand removal of infested shoots and application of insecticides without the use of pheromones did not significantly reduce fruit infestation levels.

Sangappa (1999) opined that release of *T. chilonis* @ 2.0 and 1.5 lakh per ha starting from 30 days after transplanting at an interval of 20 days were found effective in reducing the *L. orbonalis* incidence at shoot and fruit bearing stage of the crop and recorded 152.05 q per ha and 144.5 q per ha healthy fruit yield, respectively.

Table 1: List of host plants for brinjal shoot and fruit borer

Host Family	**Host Genus and species**	**Host Common Name**
Anacardiaceae	*Mangifera indica*	Mango
Chenopodiaceae	*Beta vulgaris*	Beetroot
Convolvulaceae	*Ipomoea batatas*	Sweet Potato
	Ipomoea spp.	Morning Glory
Cucurbitaceae	*Cucurbita maxima*	Pumpkin
Leguminosae	*Pisum sativum*	Pea
	Pisum sativum var. arvense	Austrian winter pea
Gramineae	*Pennisetum spp.*	Feather grass
Solanaceae	*Capsicum spp.*	Peppers
	Lycopersicon esculentum	Tomato
	Solanum aethiopicum	Mock tomato
	Solanum anomalum	--
	Solanum gilo	Gilo
	Solanum indicum	Indian Nightshade
	Solanum macrocarpum	Gboma eggplant
	Solanum melongena	Aubergine
	Solanum myriacanthum	--
	Solanum nigrum	Black nightshade
	Solanum prinophyllum	Forest nightshade
	Solanum torvum	Devil's-fig
	Solanum tuberosum	Potato

Bradley (2000), CABI (2005), EPPO (2005), Hill (1983), Kumar and Sadashiva (1996), Maureal, *et al*. (1982), Patnaik (2000), Robinson *et al.*(2003), Singh and Kalda (1997), Singh and Singh (2003)

Efficacy of different methods either singly or in combinations for control of *L. orbonalis*was observed. *Trichogramma* was found more effective than control plots for the management of shoot and fruit borer. The main results comprised on neem oil (0.2%), neem oil (0.1%) + lufenuron (0.01%), neem oil (0.1%) + B.T. (0.075%), and neem oil (0.1%) + carbaryl (0.075%) which resulted in higher fruit yield compared with control plots (Sasikala *et al*., 1999).

David Abilash (2000) reported that intercropping coriander with brinjal in single line, double line and as border crop reduced the shoot and fruit damage both under protected and unprotected conditions. Among the cropping systems, brinjal with two rows of coriander was found to be the best cropping pattern which resulted per cent shoot damage ranging from 48.76 to 49.85 and also from 89.01 to 61.60 under unprotected condition, respectively as against the sole crop of brinjal which recorded the per cent reduction in shoot damage ranging from 78.30 to 35.54 with protection.

Chakraborti (2001) experiments conducted on biorational integrated approach for the management of brinjal shoot and fruit borer by following components, application of fresh neem cake in nursery @ 3 kg per m^2 at land preparation, fresh neem cake @ 1 kg per plant once in every 30 days after transplanting, foliar application of neem seed kernal extract @ 7 ml a.i./l at an interval of 7 days beginning with 30 days after transplanting, root zone application of benzene @ 1 ml per plant once in every 30 days after transplanting. Clipping and destruction of infested plant parts and single application of carbofuran @ 5 g a.i. per plant on 30 days after transplanting, revealed a minimum average of 4.92 and 5.32 per cent shoot and fruit infestations, while the chemical method recorded 20.42 and 25.24 per cent mean shoot and fruit infestation.

A field experiment was conducted during *kharif* season to evaluate different insecticide mixtures and natural enemies against aubergine (cv. Aruna) pests including shoot and fruit borer (*L. orbonalis*). Minimum shoot borer infestation was recorded in 500 g *Bacillus thuringiensis* subsp. *kurstaki* (Btk) per ha + 126 g monocrotophos per ha treatment. Cartaphydrochloride at 250 g a.i. per ha + 126 g monocrotophos per ha (25.72) recorded the least number of fruit borer infestation. Maximum fruit yield was recorded with application of 500 g Btk per ha + 126 g monocrotophos per ha (169.10 q/ha) (Naitam and Mali, 2001).

Application of neem cake four times during the crop growth decreased the incidence of borer to eight per cent compared to 40 per cent in control plot. The yield increased nearly 68 per cent from 10.93 mt per ha (Sreenivasa Murthy *et al*., 2001).

Muralikrishna *et al.* (2002) tested the field efficacy of different insecticides, *B.thuringiensis* var. *kurstaki* (Bt), neem and diflubenzuron for the control of shoot and fruit borer, *L. orbonalis* on egg plant. They revealed that shoot infestation by *L. orbonalis* was low due to application of phorate at transplanting followed by foliar spray of Bt + carbaryl in reducing the shoot infestation (9.36%). The fruit infestation on number basis was minimum in phorate application at transplanting followed by a combined application of Bt + endosulfan and Bt + carbaryl which recorded 9.71 to 9.93 per cent infestation. Foliar spray of neem and diflubenzuron alone were not effective in reducing the damage of shoot and fruit borer in brinjal.

Saifur Rahman *et al*. (2002) evaluated IPM package 1 consisting of mechanical control on grafted eggplant; IPM package 2 comprising kerosene, neem oil and wild Ipomoea extract application on non-grafted eggplant; IPM package 3 containing Cymbush application on grafted eggplant and untreated plants. The grafted plants treated with Cymbush resulted significantly lowest shoot and fruit infestation compared to those of other treatments. Significantly the highest yield was obtained in plants treated with Cymbush. The diameter and weight of individual fruit was higher in plants under IPM package 1 and 3 utilizing grafted eggplant in late fruiting stage.

Replicated IPM trials in farmers field in Jessore, Bangladesh were conducted with young and mature brinjal crops during 2001 cropping season. Pheromone traps were placed out at a density of 100 per ha and infested shoots were removed weekly in IPM plots. Pheromone trap catches were reduced significantly from 2.0 to 0.4 and 1.1 to 0.3 moths per trap per night both in young and mature crop of check and IPM plots. They revealed that fruit infestation was significantly reduced from an average of 41.8% and 51.2 per cent in check plots of young and mature crops to 22% and 26.4% in the associated IPM plots, respectively (Cork *et al*., 2003b).

Singh (2003) evaluated 10 combination insecticides and plant extract against brinjal shoot and fruit borer *L. arbonalis*. The foliar application of quinalphos with basal application of neem cake reduced the incidence of borer and increased the yield of brinjal. The incidence and yield recorded in basal application of neem cake with foliar spray of neem oil was at par with combination of conventional insecticides.

The use of insecticides was suggested with mechanical clipping of infested shoots along with incorporation of neem as soil and foliar application for managing the brinjal shoot and fruit borer, *L. orbonalis*. The enclosed sowing or under net condition was more successful for better yield of brinjal fruits with less borer's infestation as compared to open field circumstances (Kaur *et al*., 2004).

Krishna Moorthy and Krishna Kumar (2004) reported that the insecticide resistant brinjal shoot and fruit borer was effectively reduced to 6-10% by 2-3 soil applications of neem and pongamia cakes @ 250 kg/ha, Inundative releases of the egg parasitoid, *Trichogramma brasilensis* @ 2, 40,000/ha and use of nylon net as a barrier along with shoot clipping could reduce the borer incidence by 16 per cent.

Sardana *et al.* (2004) evaluated five different crop protection module *viz.,* biointensive (Module-I), cultural + mechanical + biointensive (Module-II), cultural + mechanical + biointensive + chemical (Module –III), farmers practice (Module-IV) and untreated control (Module –V) were evaluated for their comparative effectiveness against major insect pests and diseases of egg plant. Crop protection module (III) comprising cultural + mechanical + biointensive + chemical was found superior over all other modules in managing the pest. Further, Shobarani and Nandihalli (2004b) also reported that botanicals imposed three times against shoot borer indicated that nimbecidine @ 5ml/l and NSKE 5% were proved significantly superior in reducing the shoot infestation and recorded higher potato tuber yields of 35.82 and 33.38 q/ha, respectively. Shobarani and Nandihalli (2004c) reported that bioagents dipel 8L @ 2.0 ml/l sprayed three times and inundative release of *Trichogramma chilonis* Ishii @ 2.0 lakh/ha were found significantly superior in reducing the shoot infestation and recorded higher tuber yields of 33.05 and 29.72 q/ha, respectively.

Evaluation of an integrated pest management module for brinjal shoot and fruit borer (*L. orbonalis*) was done in the fields. This IPM module includes, the application of neem cake at 100 kg/acre (50kg during land preparation, and 50kg at three weeks after transplanting), installation of about 25-30 pheromones traps per acre from flower bud initiation until the final harvesting and for mass trapping changing the lures on monthly basis, mechanical clipping of infested shoot on weekly basis and spraying of neem oil every 10-12 days interval. A socio-economic survey among the users was also conducted. Comparison of IPM and Non IPM plot has demonstrated a clear difference in infested shoots which was 1.83 and 1.79 per cent in IPM plots while 12.67 and 9.52 per cent in Non IPM. Fruit damage in IPM plots was also lower which is 6.56 and 13.07 per cent while in non IPM plots it was 43.34 and 27.30 per cent. This experiment also gave higher average yields (12-20 and 13-10 t/ha.) and cost: benefit ratio (1:1.81 and 1:2.95) (Rath and Dash, 2005)

For two consecutive years at farmer field scale; different integrated approaches were evaluated for better management of *L. orbonalis* in brinjal cultivars. They suggested the use of neem powder at transplanting with pheromone traps for moth capturing. Other techniques included clipping of the infested shoots with neem oil spray. These practices helped to increase the fruit yield with minimum expenditure at pest control level (Rath and Maity, 2005).

Kadam *et al.* (2005) reported that among the treatments the sequence with *Paecilomyces* (2x 10^8) 0.5 % ST and drenching of 5kg/ ha +NSKE 5 % + Bt (dolphin 85 %) 0.05 % + *Trichogramma chilonis* release @ 50000/ha followed by Trichoderma + *Verticillium lecanii* 2x10^5 CFU/ml + NSKE 5 % + Bt @ 0.05 % + *Trichogramma chilonis* emerged as most promising bio-intensive and Trichoderma+ imidacloprid @ 0.004%+ NSKE 5 % +Bt + *Trichogramma chilonis* as the most promising IPM strategies for management of brinjal pests, with a fruit damage of 13.1 to 15.4 per cent and net profit of 50, 820 to 63,245 Rs /ha.

Socio-economic studies in Bangladesh showed that the IPM strategy reduced production costs by 34% compared to the traditional farmer practice of calendar-based pesticide application. An ex-ante evaluation of IPM using the economic surplus model revealed an internal rate of return (IRR) of 39% and benefit-cost ratio (BCR) of 3.25 (Alam *et al*., 2006)

Application of neem cake @ 125 kg/ha during land preparation and three weeks after planting, installation of leucinlure @ 62 /ha starting from 45 DAP up to harvest, changing the lures at monthly interval, mechanical plucking of damaged shoots at weekly interval and spraying Multineem @ 3 ml/l of water at 10 days interval caused less shoot (1.8 + 1.2%) and fruit (13.1 + 7.5%) damage and increased the fruit yield of brinjal (21.4 + 1.6 t/ha) with benefit cost ratio of 1.81 over non IPM plots (Anon , 2006).

Baral *et al*. (2006) reported that in West Bengal, the IPM adopters has reduced their labour requirements by 5.9 per cent, sprayed pesticides 52.6 per cent less often than before and increased their eggplant production area by 21.6 per cent. The economic surplus model revealed an internal rate of return of 38 per cent and a benefit cost ratio of 2.78. Insecticide resistant population of ESFB could be managed successfully in the field by integrating various management strategies *viz.*: clean cultivation, use of resistant/ tolerant varieties, clipping-off of infested shoots and fruits on detection of damage, installation of pheromone traps and baits, inundative releases of parasitoids and integration of biopesticides with need based application of recommended insecticides. (Raju *et al*., 2007)

Yasodha and Natarajan (2007) laboratory experiments conducted to test the oviposition deterrency and ovicidal action of organic solvents and aqueous extract of various tested botanicals against *Leucinodes orbonalis*. At highest concentration of 5 per cent as aqueous and methanol extracts, NSKE+*A. calamus* was found to have minimum oviposition index of 0.22 and 0.14 indicating the strong oviposition deterrent effect. Among wild Solanum spp., *S. mauritianum* at 5% concentration and 0.2 per cent methanol extract of *S. viarum* and *S. lasiocarpum* exhibited strong deterrency. The maximum ovicidal action (62.60%) was achieved with NSKE+ *A. calamus* combination while the minimum was by *S. trilobatum* (25.61%).

Asmita Suradkar *et al*. (2008) reported that among different IPM modules evaluated against brinjal shoot and fruit borer, *Leucinodes orbonalis* Guen with one insecticidal schedule. Spinosad + *Metarrhizium anisopliae* + chelating agent + cartap hydrochloride module was found most effective in reducing shoot infestation (7.47%), number of fruit damage (25.59%), damage to fruits on weight basis (25.83%) and giving maximum yield (81.82 q/ha) with monitory benefit.

An IPM based module consisting of brinjal (PKM 1) + cluster bean (4:1) + six releases of *Trichogramma chilonis* @ 2.5 cc/acre on 15, 22, 29, 36 43 and 50 days after transplanting (DAT) + two releases of *Chrysoperla* eggs @ (20,000 eggs/acre) on 60 and 70 DAT + yellow sticky trap @ 25/acre + *Lencinodes orbonalis* pheromone trap @ 5 /acre (Intercropping system based module I) was found to be the best in managing major pests of brinjal (Elanchezhyan and Murali Baskaran, 2008).

Mandal *et al*. (2008) studied the impacts of IPM in brinjal in Birbhum district of West Bengal. They reported that due to adoption of IPM technology for the controlling of brinjal shoot and fruit borer, there were about 4.7, 34.0 and 53.8% change in yield, fresh fruit and profit amongst brinjal growers. IPM practices could not stop pesticide use but able to reduce it substantially as IPM farmers had to apply 52.6% less quantity of pesticide however, for non-adopters it increased by 14.1%. Profitability of IPM technology were responded by 91, 75 and 71 per cent farmers.

Sardana *et al*. (2008) revealed that the IPM technology for brinjal crop comprising raising healthy nursery using soil solarisation and mixing of Trichoderma along with FYM, application of neem cake @ 250 kg/ha at 30 DAT, erection of bird perches @ 10/ha, installation of delta traps@ 5/ha, periodical collection and destruction of borer affected shoots and fruits and diseased plants, two sprays of NSKE@ 5%, five releases of eggparasite *Trichogramma brasiliensis* and 1-2 sprays of chemical pesticides was very effective in reducing the incidence of pests and minimizing the yield losses. The adoption of IPM technology resulted in reducing the number of sprays to 1-2 from 4-6 in non-IPM fields and with fruit yields of 450.1, 454.1, 484.0 q/ha and 274.1, 354.6 and 405 q/ha in non-IPM fields with higher CBR of 2.27-2.89 in IPM compared to 1.04-2.12 in non –IPM fields.

Srinivasan, (2008) reported that the IPM strategy implemented in farmers' fields via pilot project demonstrations in selected areas of Bangladesh and India for the control of EFSB consists of resistant cultivars, Eggplant accessions EG058, BL009, ISD006 and a commercial hybrid, Turbo possess appreciable levels of resistance to EFSB. Use of EFSB sex pheromone traps based on (E)-11-hexadecenyl acetate and (E)-11-hexadecen-1-ol significantly reduced adult males. In addition, prompt destruction of pest damaged eggplant shoots and fruits at regular intervals, and withholding of pesticide use to allow proliferation of local natural enemies especially the parasitoid, *Trathala flavo-orbitalis* reduced the EFSB population. The profit margins significantly increased, for those farmers who adopted this IPM technology.

Comparative study of different integrated pest management techniques with one insecticidal schedule against brinjal shoot and fruit borer (*L. orbonalis)* was conducted. It was found Spinosad + *M. anisopliae*+ chelating agent + Cartap hydrochloride module the most effective. It reduced shoot infestation (7.47%), fruit damage (25.59%) giving maximum yield (81.82q/ha) and benefit:cost ratio (Suradkar *et al*., 2008).

Abdul Latif *et al*. (2009) concluded that among the 8 different IPM packages evaluated for management of brinjal shoot and fruit borer, package 6 (mechanical control + potash @100 kg/ha + field sanitation in combination with flubendiamide 24WG applied at 5% level of shoot and fruit infestation) showed the better performance by reducing 80.63 per cent fruit infestation over control and produced the highest number of healthy and total fruits/plant (25.0 and 27.20, respectively). The same package also increased 108.83 per cent healthy fruit yield and decreased 74.13 per cent infested fruit yield over control. The BCR of 4.12 and 4.00 was obtained in IPM package 6 with 8 and 5 sprays, respectively.

According to Bhavani *et al*. (2009) among the treatment combinations tested for the management of brinjal shoot and fruit borer. T_8 comprosing of shoot clipping at weekly interval + application of carbofuran 3G @ 5gm/plant at 30 DAT + spraying of profenofos 50 EC@ 0.1 % from flower initiation for 3 times at 15 days for three times recorded significantly less intensity of shoot (13.24%) and fruit (20.65 %) infestation by recording highest per cent reduction over control of 56.01 and 58.03 respectively and registered the highest fruit yield (260.15 q/ha) by recording 63.46 % increase over control.

Studies consisting of spraying of insecticides cypermethrin 25 EC (1.5 ml/l) and Chloropyriphos 20 EC (2.5 ml/l) at 10 days interval beginning from 15 days after planting (DAP) and until 80 DAP, application of neem cake @ 35 kg at 30 DAP at the time of top dressing and at 45 DAP commensurate with flowering, setting up of pheromone impregnated lures on water trap revealed that, the mean number of moths trapped per day was less than 1.There was no significant difference in the number of moths trapped during different weeks of crop growth. The fruit damage ranged from 16.67 to 86.25 % at 60 DAP and 95 DAP which differed significantly. They opined that, combination of insecticide sprays and the use of sex pheromone lures could not check the incidence of *L. orbonalis* in Chennai during summer months (Geetha lakshmi *et al*., 2009).

Removal and destruction of twigs/fallen leaves twice in a week + Bt @ 0.5 kg/ha showed minimum infestation of shoot (1.23 and 1.13%) and fruits (1.10 and 0.90%) and produced maximum healthy fruits over rest of the treatments in managing the shoot and fruit borer infestation is followed by neem gold @ 2 mill + mechanical removal (T1). Cypermethrin @ 0.016% and imidacloprid @ 0.015% were found next effective treatment in order of efficacy (Ghananand *et al* ., 2009b)

Hirak Chatterjee (2009) reported that, three components i.e. pheromone trap, timely mechanical control and application of azadex (neem based insecticides) was found most effective in reduction of shoot damage (76.59%) followed by the farmer's practice (i.e. twenty times application of insecticides) (76.36%). Whereas highest protection in fruit damage (48.26%) and yield increment (53.19%) were obtained from the practices of setting trap + timely mechanical control and trap + application of azadex, respectively. The module having all three components was found next best, which provided 45.91 per cent less fruit damage coupled with 52.29 per cent more production.

Pawar *et al*. (2009) studied IPM technology involving non chemical and ecofriendly components *i.e.* sex pheromones traps, integrated with other practices were tested against brinjal shoot and fruit borer (BSFB) revealed that mass trapping of *L. orbonalis* moths with the help of plastic funnel traps @ 1per 100 sq.m. baited with leucinlure sex pheromone, clipping of infested shoots at weekly interval starting at 20 days after transplanting (DAT), spraying with NSKE 4% four times at an interval of 15 days starting at flowering and destruction of infested fruits after harvest reduced the shoot infestation to the extent of 80.44 % over untreated and 61.64 % over with out mass trapping. The increase in yield was 44.75 % over untreated and 11.76 % over with out mass trapping.

Rajneesh and Nandihalli (2009) revealed that among the three modules at 6^{th} WAP, adaptable module (27.38%) and RPP module (31.49%) were found significantly superior and on par with each other, biointensive module recorded maximum per cent shoot damage (31.37%). The adaptable module recorded maximum tuber yield of 57.88 q/ha with maximum net profit of (Rs.21, 512 /ha) followed by RPP module which recorded tuber yield of 51.03 q/ha. The lowest yield was recorded in biointensive module (44.73 q/ha).

Rahman and Razzab ali (2009) studied the efficacy of 5 selected insecticides, two resistant lines and female sex pheromone against Brinjal shoot and fruit borer (BSFB) (Leucinodes orbonalis Guenee) in Gazipur and Jessore of Bangladesh. They reported that, in all aspects Marshal® 20 EC (Carbosulfan) and Suntap® 50 SP were most effective among insecticides followed by sex pheromone and other options.

Rahman *et al*. (2009c) reported that among all combined treatments comprising, routine spray of Marshal® at 7 days interval (T_7) was better than sole sex pheromone trap placed in the centre of the plot (T_9), which, however, was better than sole mechanical control (T_2) in all considerations. T_1 comprised spraying of Marshal® at 2 days interval, mechanical control and using pheromone trap placed at plant canopy and in the centre of the plot, performed the best in all respects ensuring the lowest shoot (6.27%) and fruit (3.19 % by number and 2.83% by weight) infestation, the highest reduction of shoot (79.65%) and fruit (89.03% by number and 90.72% by weight) infestation compared with control. The maximum fruit yield (32.71 tons/ha) was produced in T_1, which contributed the highest yield of healthy fruits (30.42 t/ha) as well as maximum BCR (2.05).

Shailendra Pratap Singh and Paras Nath (2010) conducted field trials at the Agricultural Research Farm Varanasi, during Kharif, 2003 and 2004. They reported that, the minimum shoot damage and fruit damage (14.59 and 19.75 %), %) was observed in T2 (T1 + soil treatment by carbofuran 3G 1.5 kg/ha at 30 DAT) followed by T4 (Endosulfan 35 EC @ 3 ml/lit + NSKE (5 %) at 30 days after transplanting at 15 days interval) with (14.71 and 22.80 %) shoot a and fruit damage which differed non-significantly from each other.

Sharma Deepak Kumar *et al*. (2012) revealed that three sprays of chlorpyriphos + cypermethrin @ 0.01% active substance (a.s.) in 15 days intervals was found to be the most economical, resulting in minimum shoot (2.15%) and fruit (12.95%) infestation respectively, followed by alphamathrin @ 0.01% a.s. with a highest marketable yield of 87.77 q/ha. Three sprays of NSKE @ 5 ml/l recorded a maximum of shoot (3.91%) and fruit (24.49%) infestation, respectively. However, less shoot and fruit infestation increased marketable yield was observed when these treatments were combined with cultural methods. Hence, they concluded that the combination of chlorpyriphos 50% EC + cypermethrin 5% EC, being the most effective and economically viable insecticide, can be utilized as a valuable chemical component in Integrated Pest Management to manage the *L. orbonalis* in eggplant crop.

Among 11 treatments evaluated under field conditions, the combination of *F. semitectum* $3.6x10^{15}$+ *N. rileyi* $2x10^{8}$+ spinosad (15 g ai/ha) and removal and destruction of infected shoots and fruits reduced the shoot and fruit infestation effectively. The maximum marketable fruit yield (136 q/ha) was obtained in T_4- *F. semitectum* $3.6x10^{15}$+ *N. rileyi* $2x10^{8}$+ spinosad (15 g a.i/ha). The cost economics worked out depicted that T_{10}- Removal and destruction of infected shoots and fruits was the best treatment recording higher benefit cost ratio (4.74) (Koushik *et al*., 2013)

MATERIAL AND METHODS

The details of materials used and the methodology adopted for conducting various experiments to fulfil the objectives set forth during the course of the investigation on brinjal involving both field and laboratory studies are presented in this chapter. All the experiments were carried out at the Bio-control laboratory, Department of Agricultural Entomology, College of Agriculture and Main Agricultural Research Station, University of Agricultural Sciences, Raichur, Karnataka, India between 2009-10 to 2010-11.

Raichur is situated in northern dry region (Zone-2) of Karnataka between 16^0 15^1N latitude, 77^0 20^1E longitude and at 398.37 m above mean sea level. The average rainfall of 660 mm confined to monsoon period between June and November with occasional showers during pre-monsoon months of April and May. Mean maximum temperature is more than 30^0C throughout the year except during December. The relative humidity is high during monsoon months from July to September and uniformly low during summer months from March to May. Meteorological conditions prevailed during the experimentation period between September 2009 to March 2011 are presented as Appendix-IV. The present investigation was carried out on insecticide usage pattern, baseline susceptibility to xenobiotics and Cry1Ac protein and genetic diversity in Brinjal shoot and fruit borer, *Leucinodes orbonalis* populations occurring in south Indian brinjal ecosystems and evaluation of IRM/IPM strategies and population dynamics on wild species are outlined below.

3.1 Insecticide usage pattern in major brinjal growing regions of South India

The survey was confined to major brinjal growing states of South India to determine the insecticide usage pattern and number of sprays used. A roving survey was conducted during 2009-10 and 2010-11 in major brinjal growing areas of *viz.* Karnataka (4 districts), Andhra Pradesh (3 districts), Maharashtra (3 districts), Tamilnadu (3 districts) and Goa (1 district) states (Table 2) (Fig.1). In each state major brinjal growing districts was selected and from each district a total of 20 farmers were interviewed by using the objective oriented structured questionnaire (Appendix I). The farmers who did not grow brinjal since the last one year were excluded from the study to generate recent and precise data. The information was gathered in the same area from where the field populations of SFB were collected for monitoring insecticide resistance. The collected data were coded, edited for processing through tabular method using average and percentage and ratio.

3.2 To monitor the baseline susceptibility in SFB populations of South India to different insecticide chemistries and Cry1Ac protein

The data on area, intensity and spread of brinjal from brinjal growing districts of Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh and goa was collected from Agricultural Research Stations of State Agricultural Universities and State Department of Agriculture of respective states at district level. The data was pooled to create the map of brinjal distribution in South India as main consideration in determining the sampling location was to represent the entire brinjal ecosystem of south India.

As per the information collected from concerned research stations and State Department of Agriculture, based on the transplanting dates of brinjal and peak infestation of shoot and fruit borer in different locations of South India survey were planned and collections were executed. Based on insecticide usage pattern, weather parameters and distribution of brinjal crop, 14 locations, three each in Maharashtra, Andhra Pradesh and Tamil Nadu, four in Karnataka and one in Goa were identified. In Maharashtra larvae were collected from Kolhapur, Parbhani, and Dapoli districts. In Andhra Pradesh, the collections were made from Hydrebad, Vijaywada and West godavari districts. In Karnataka, samples were collected from Raichur, Dharwad, Bangalore and Bijapur districts and in Tamil Nadu, larvae were collected from Coimbatore, Madurai and aduthurai and Goa (margoa) were surveyed for larvae collection

3.2.1 Mass rearing of eggplant shoot and fruit borer, *Leucinodes orbonalis* under laboratory conditions

In order to develop alternative safe, economical and sustainable measures to control this pest, more research is needed to understand the insect and its relationship with its host and the environment. At present, the only way to obtain insects for study is to collect them from infested plants

Table 2. List of sampling locations identified for survey in South India

States	Locations	Longitude	Latitude	Altitude (M)
Karnataka	Dharwad	15^0 27' N	75^0 05' E	750.00
	Bijapur	16^0 50' N	75 ^{0}47' E	537.00
	Bangalore	12^0 58' N	77^0 38' E	920.00
	Raichur	16^0 21' N	77^0 35' E	407.00
Andhra Pradesh	West Godavari	16^0 42' N	81^0 06' E	74.00
	Hyderabad	17^0 20' N	78^0 30' E	536.00
	Vijayawada	16^0 31' N	80^0 39' E	13.00
Tamil Nadu	Chennai	13^0 04' N	80^0 17'E	18.00
	Aduthurai	11^0 00' N	79^0 18' E	19.50
	Coimbatore	11^0 00' N	77^0 00' E	411.00
Maharashtra	Kolhapur	16^0 42' N	74^0 16'E	545.00
	Dapoli	17^0 45' N	73^0 11'E	194.00
	Parbhani	19^0 08' N	76^0 05'E	407.00
Goa	Margoa	15^0 25' N	73^0 43'E	31.00

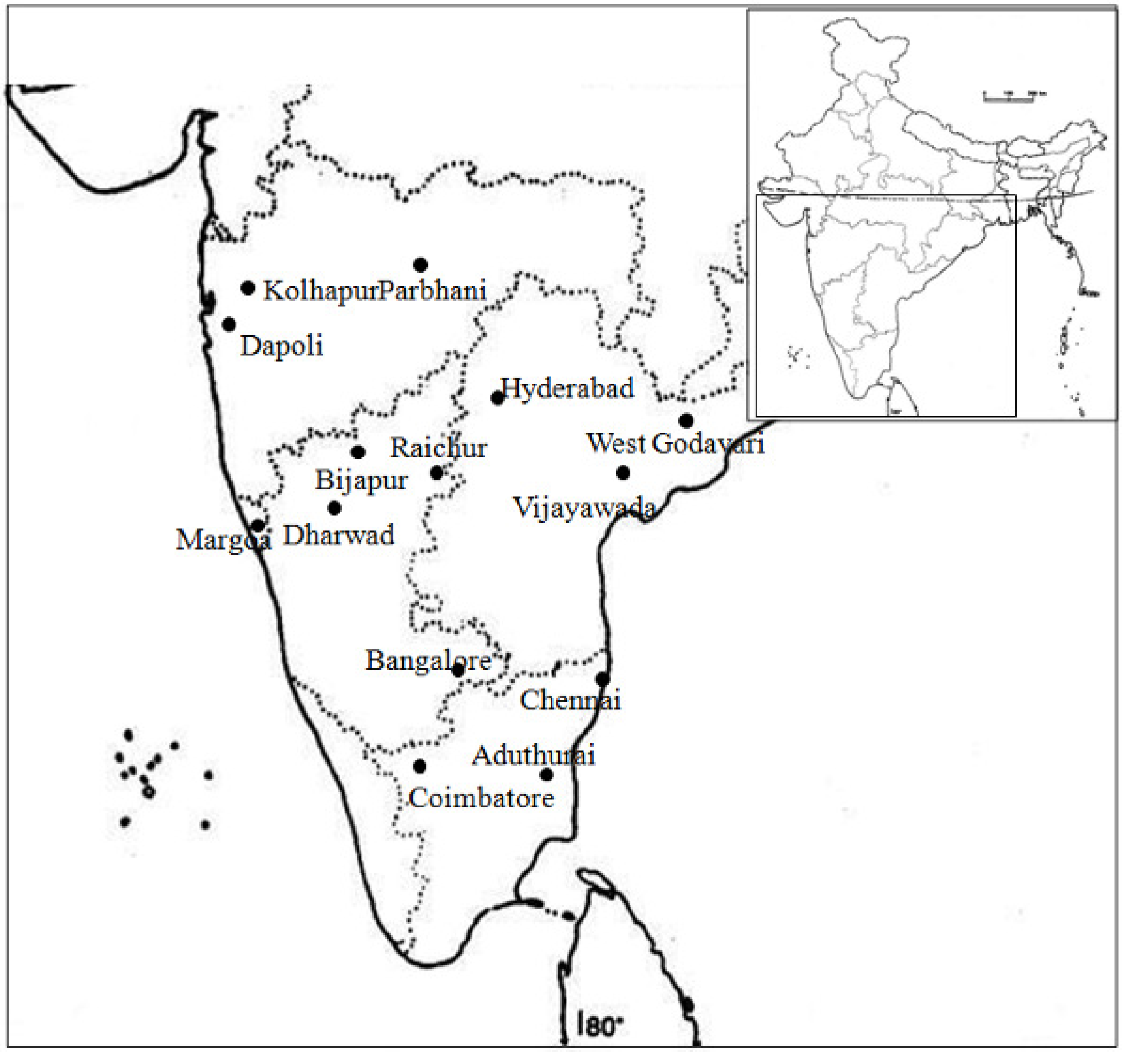


Fig 1. Sampling locations of south India for the collection of Brinjal shoot and fruit borer populations

Fig. 1: Geographic distribution of sampling location

during the eggplant growing season. Not only is it difficult to collect enough uniform-quality insects to produce reliable results, but also research can only be conducted at certain times of the year. In order to overcome these constraints, for mass rearing of brinjal shoot and fruit borer *Leucinodes orbonalis* in the laboratory throughout the year, two diets were developed keeping the diets developed by Asian Vegetable Research and Development Center (AVRDC, 1998) and Indian Agricultural Research Institute (Patil, 1990) as a base. Among the four diets tested, the modified was found to be most suitable for growth and development of *Leucinodes orbonalis* larvae. The composition of all the four diets is given in (Table 3). The procedure for modified diet preparation is outlined below

3.2.1.1 Diet preparation

3.2.1.1.1 Methodology for Diet preparation

3.2.1.1.1.1 Preparation of brinjal fruit powder

To prepare the eggplant fruit powder, young tender fruits were collected from the plants maintained without spraying .The fruits were washed thoroughly with tap water, and they were sliced thinly (2–3 mm). The slices were dried in an oven at 60ºC for 48–72 h. The dried slices were grind in to a very fine powder and refrigerated in tightly sealed containers until needed.

3.2.1.2.1.2 Mixing of diet ingredients

Blackgram was soaked for half an hour prior to use. One liter of distilled water was poured into a stainless steel container. 20 g of agar mentioned in part-B was added to the water and mixed thoroughly. The suspension was boiled slowly by stirring intermittently until it broths. Boil until the solution becomes clear. Shut off the heat and allow the solution to cool. In the meantime, the required quantity of all the ingredients of Fraction A and C (Appendix II) were weighed and mixed well in mixer along with eggplant fruit powder. Molten agar solution was added in to the mixer. Mixture was blended to mix thoroughly for about 2 minutes. The diet was kept for conditioning in an incubator at ambient temperature for 48 h and then preserved in the freezer. It was later used as and when required.

3.2.1.2 Insect mating and oviposition chambers (AVRDC, 1998)

A mating and oviposition cylindrical chamber was constructed from a 15 cm diameter, 30 cm long open acrylic sheets. Based on local facilities and conditions available, slight changes were made in methodology. Inner surface of the cylinder was first lined with rough blue paper and then with a single layer of 16-mesh nylon netting, and it was standed vertically in a petri dish, which was lined with purple paper and nylon netting. Four week-old potted eggplant seedling was placed inside the cylinder. Soil in the plastic pot was covered with aluminum foil and cotton swab dipped in dilute honey in glass vial was placed next to the seedling. Two- three pairs of freshly emerged adults were released inside the chamber. Top of the chamber was covered with purple paper and nylon net secured with an elastic band. Oviposition chamber was placed in a room at 26-30ºC. After four days and daily thereafter eggs were observed on both the nylon netting and purple paper (Plate 1).

3.2.1.3 Maintenance of pure culture

To initiate the pure culture of *L.orbonalis,* about 100-150 larvae were collected from infested brinjal fruits from each sampling location in large size plastic containers with a thin layer of fine sand at the bottom covered with brinjal leaves and they were reared as individual population under laboratory conditions.

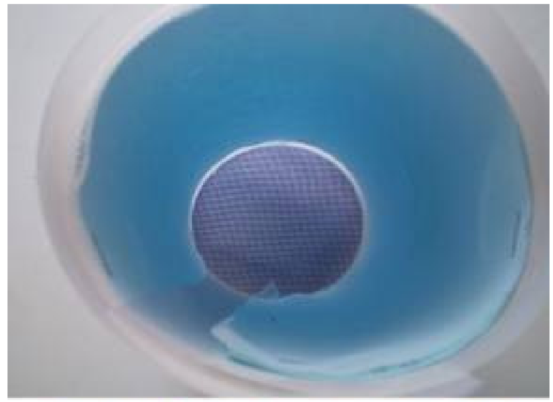
The field collected larval cultures of *L. orbonalis* Guen from infested fruits were reared under laboratory condition on black gram flour and brinjal fruit powder based semi synthetic diet and also on brinjal fruits to advance for F_1 generation. The adults F_1 generation of different locations were caged separately and allowed to lay eggs. The larval culture was maintained in the large size plastic containers of 45× 20 cm. They were sterilized and covered with black muslin cloth and purple paper. At the bottom of the container a thin layer of fine sand was provided to facilitate pupation. The decayed and dried fruits were removed as and when noticed and once in two days the fruits were cut open and larvae were transferred to small size fresh fruits and also to multicavity trays containing artificial diet. After they had undergone pupation, pupae were collected both from sand and also on muslin cloth. The pupae collected were sexed based on the genital operture on abdominal segment and transferred to rearing cage of 20” × 12” size and plastic containers containing thin layer of fine sand. After the moth emergence, the freshly emerged male and female moths of 25 pairs were released in (1:1) ratio in to the rearing containers and also in oviposition chambers (AVRDC, 1998). .

Table 3. Composition of different standard diets for brinjal shoot and fruit borer *Leucinodes orbonalis*

Sl.No.	Ingredients	Quantity/lt	Modified Diet	AVRDC diet (Talekar *et al.*)	IARI diet (P.D.Patil)	Alternate host diet
1	Black gram flour	140.00 g	✓	×	✓	✓
2	Yeast	13.00g	✓	✓	✓	✓
3	Sucrose	20.00g	✓	✓	✓	✓
4	Agar –Agar (powder)	20.00g	✓	✓	✓	✓
5	Methyl para hydroxy benzoate	2.50g	✓	✓	✓	✓
6	Sorbic acid	1.00g	✓	✓	✓	✓
7	Ascorbic acid	4.30 g	✓	✓	✓	✓
8	Formaldehyde 10%	2.00ml	✓	✓	✓	✓
9	Ethanol	5.0 ml	✓	✓	✓	✓
10	Wesson's salt	2.50g	✓	✓	✓	✓
11	Multi Vitamin mix	10.00ml	✓	✓	✓	✓
12	Distilled water	1100 ml	✓	✓	✓	✓
13	Brinjal fruit powder	100 gm	✓	✓	×	×
14	Potato fruit powder	100 gm	×	×	×	✓

P.D.Patil (1990); Talekar *et al.* (1999)

Nylon net with rough surface purple paper



Open ended oviposition plastic cylinders

Potted egg plant seedling

Brinjal fruit powder

Blackgram flour

Rearing diet

Plate 1: Materials used for laboratory rearing of brinjal shoot and fruit borer

The containers were provided with fresh twigs of eggplants, kept inside the small beaker containing 10 per cent sucrose solution to keep twig fresh for longer time. A cotton swab soaked with 10 per cent honey solution was provided as source of food for the adult moths during oviposition. The cotton swab was changed as often as necessary to maintain a constant supply of food. The eggs laid on muslin cloth and purple paper were kept under incubation chamber for larval emergence. The larvae after immediate emergence were transferred with a fine camel's hair brush on artificial diet and on small fruits placed on the leaves inside the rearing containers .The larvae were reared in multicavity trays covered with parafilm and rearing containers untill pupation by changing diet and also providing with small size fresh brinjal fruits at 3 days interval . After the moth emergence the process is continued as above.

3.2.2 Bioassay procedure against *Leucinodes orbonalis*

3.2.2.1 Bioassay procedure for Cry protein

Laboratory strains of *Leucinodes orbonalis* were established from those collected in brinjal fields during cropping season of 2009–10 and 2010-11 from major 14 brinjal growing regions representing brinjal growing ecosystems of south India.Field-collected larvae (F0), along with brinjal fruit/ shoot, were transported to the insect laboratory of the Main Agricultural Research Station, University of Agri-cultural Sciences (UAS), Raichur. The larvae were trans-ferred onto freshly prepared semi-synthetic diet and allowed to pupate. Pupae were collected, surface-sterilized in 0.1% sodium hypochlorite, air-dried at room temperature and kept in separate jars for moth emergence.

Twenty-five pairs of freshly emerged adults were transferred to each oviposition cylindrical chamber (30 cm height and 15 cm diameter, lined with rough blue paper and single layer of 16-mesh nylon netting). Four-week-old potted eggplant seedling was placed inside the cylinder. Soil in the plastic pot was covered with alumi-num foil and cotton swab dipped in 50% honey was placed next to the seedling in the oviposition cage. The top of the chamber was covered with purple paper and nylon net was secured with an elastic band. Oviposition chamber was placed in a room at 26–30 ºC and 65–70% relative humidity (RH). After four days and daily thereafter, the oviposition chamber was examined for eggs on both the nylon netting and purple paper. Eggs were collected and kept for hatching at 26℃ and 70% RH.Larvae were reared individually on soaked black gram flour and brinjal fruit powder based semi synthetic diet in 25-well multicavity trays till pupation. Moths were reared in oviposition chambers kept at 26℃ ± 1℃ and 55-65% RH and fed with 10% honey solution. Laboratory cultures were established for each population and reared to get homogenous F_1 populations before conducting bioassays.

The source of Cry1Ac protein used in the bioassays was the commercial formulation, MVP II that contained 19.7% (by weight) Cry1Ac protein, which was obtained from Monsanto Research Centre, Bangalore and IABT, UAS, Dharwad. Freeze-dried Crystal protein powders were diluted in a buffer stock solution and maintained at 8-12ºC. Appropriate serial dilutions of the stock solutions were made just before the proteins were bioassayed against eggplant shoot and fruit borer larvae. A series of concentrations of Cry1Ac were prepared and added to known volume of aliquot of semi-synthetic diet at room temperature (Appendix-III). The diet were mixed thoroughly and poured into 25-well multicavity culture trays. Bioassays involved exposure of brinjal shoot and fruit borer neonate larvae to various concentrations of diet incorporated with the Cry1Ac protein that produced 0-100% mortality. Cry1Ac protein was assayed by the diet-incorporation method using seven graded concentrations. The insect diet was prepared using the ingredients listed in above, poured in-to sterile glass bottles and kept warm in a water bath maintained at 60^0C. A volume of 111 µl of the primary stock was serially diluted for assaying against *L.orbonalis*. Protein concentrations in the assay ranged from 1.00 to 0.001 ppm. Diet with protein was mixed using a mixer and poured into 25-well insect bioassay trays at 750 µl per well. Newly hatched larvae were transferred onto the solidified diet in the bioassay trays at one larva per well using a fine-hair brush. On completion of larval transfer, bioas-say trays were covered with pull-n-peel tabs. Preparation of bioassay trays and inoculation of neonates were carried out on a laminar-flow clean bench. Infested trays were kept in a BOD incubator maintained at 27 ± 0.5^0C. Thirty larvae were screened at each toxin concentration along with an untreated control. The control consisted of normal diet (without toxin). All assays were repeated three times with each population. Thus, for each population a total of 630 larvae were exposed. The mortality was then pooled for each concentration. The concentrations showing corrected mortality was then pooled for each concentration and corrected mortality between 20 and 80 % at 96 h and 7 days were used for calculation of median lethal concentration (LC_{50} and LC_{95}) and their 95% fiducial limits (FL) were computed by probit analysis. Bioassays were rated after 7 days, and observations of mortality, stage of the surviving larvae and group weight of all the surviving larvae were recorded. The experiments with larval mortality of above 10% in control were discarded and repeated. In bioassay, larvae that did not move when disturbed were considered to be dead. Probit analysis (Finney 1971) of the data was carried out using Finney's method14 to compute LC_{50}, LC_{95}, MIC_{50} and MIC_{95} for each population. The dose-response values were expressed as micro-grams of Cry1Ac/ml of diet (= parts per million, ppm).

3.2.2.2 Bioassay procedure for Insecticides

Twelve insecticides representing eight insecticide groups *viz.*, Rynaxypyr and Flubendiamide (Diamides), Emamectin Benzoate (Avermectins) Spinosad (Spinosyns), Indoxacarb (Oxydiazine), carbaryl, thiodicarb (Carbamates), monocrotophos, quinalphos, chlorpyriphos (Organophosphates), endosulfan (Cyclodine organochlorines) and cypermethrin, (Synthetic pyrethroids) were chosen for determining resistance level across populations. The commercial grade form of the above insecticides was used for bioassay studies.

Methodology

A Stock solution of 1% of 100 ml was prepared for above mentioned each insecticide by dissolving their respective formulations in distilled water. From these, wide range of six concentrations of all the insecticides was prepared subsequently by serial dilution technique using distilled water as solvent. List of insecticide formulation along with chemical group used for resistance monitoring studies are presented in Table 4.

Pure culture of *L. orbonalis* larvae were exposed to preliminary range finding tests to attain suitable series of doses and subsequently narrowed down to the concentrations exhibiting larval mortalities between 20 and 80 per cent for determining the effective dosage. Sufficient replicates (30 larvae /treatment) were used to provide a reliable regression line known as log- dose- probit- mortality (LDPM) line for F_1 generation/ field collected population.

For LC_{50} studies the field collected and laboratory reared F_1 generation third instar of seven to eight days old and breadth of the body 0.81-1.12 mm larvae were used for treatment studies. A batch of ten larvae was taken in separate glass petridish (9 cm dia) for each test concentration of insecticide separately. One ml of requisite concentration of various formulations was directly sprayed on test larvae kept in the petridish with the help of Potter's tower at 340g/ cm sq atmospheric pressure and dried for five minutes. A control was maintained with the larvae treated with distilled water alone. Each treatment was replicated twice. Two minutes after spraying, the individual larva was transferred to a multicavity tray containing fresh artificial diet. Simultaneously, the larvae subjected to distilled water spray were kept as control. The treated larvae were kept at 26±1°C and 55-65% RH under approximately 12: 12 hrs LD photoperiod. Observations on larval mortality were recorded at 24 and 48 hr after treatment. Mortality for each concentration of the insecticide was corrected using Abbott's transformation (Abbott, 1925). The moribund insects were counted as dead. The data on lethal concentration causing 50% mortality were subjected to probit analysis (Finney 1971). The intensity of resistance of a population or a strain of insects to a particular insecticide, frequently quoted as the Resistance factor (RF) or Resistance ratio (RR) was calculated by the formula.

$$\text{RF or RR} = \frac{LC_{50}\text{ of Resistant strain}}{LC_{50}\text{ of susceptible strain}}$$

3.3 Assessment of impact of genetic diversity of *Leucinodes orbonalis* G.populations occurring in south India using mitochondrial DNA specific markers

3.3.1 DNA isolation

About 20 field collected, healthy and well grown fifth instar larval populations were randomly collected in 30 % alcohol from each location. Samples were brought to laboratory and kept at -20°C until the isolation of DNA was done. At the time of isolation of total DNA each larva was dissected and the gut contents were completely removed to avoid any contamination of DNA by the food material present in the gut.The resulting skin and legs were used to prepare total DNA following procedure described by (Doyle and Doyle, 1987) with some modifications.

Table 4. List of chemicals used for bioassay studies against *Leucinodes orbonalis*

Sl. No.	Chemicals	Chemical family (group)	Trade name	Company
1	Rynaxypyr 20 SC	Anthralinic Dimaide	Coragen	E.I.Dupont India Pvt. Ltd.
2	Flubendiamide 480SC	Phthalic acid diamide	Fame	Bayer Crop Science
3	Emamectin benzoate 5% SG	Avermectin	Proclaim	Syngenta India Ltd.
4	Spinosad 45 SC	Spinosyn	Tracer	Dow Agrosciences India Pvt. Ltd.
5	Indoxacarb 14.8SC	Oxadiazine	Auvant	E.I.Dupont India Pvt. Ltd.
6	Quinalphos 25EC	Organophosphate	Ekalux	Novartis India ltd.
7	Chlorpyriphos 20EC	Organophosphate	Dursban	Dow Agrosciences India Pvt. Ltd.
8	Thiodicarb 75 WP	Carbamate	Larvin	Bayer Crop Science
9	Cypermethrin 25EC	Synthetic pyrethroid	Basathrun	BASF India Pvt.Ltd.
10	Endosulphan 35 EC	Organochlorine	Thiokill	United Phosphorus Ltd.
11	Monocrotophos 36 SL	Organophosphate	Nuvacron	Novartis India Ltd.
12	Carbaryl 50 WP	Carbamate	Dhanurvin	Dhanuka Agritech Ltd.

3.3.1.1 Solutions

CTAB extraction buffer

0.1M Tris-HCL (pH 8.0)

1.4mM Nacl

0.02mM EDTA

4% CTAB

0.2% β -Mercaptoethanol.

3.3.1.2 Equipment

Pestle and mortar

Refrigerated centrifuges (Beckman GPR, Beckman G2-21)

Centrifuge tubes 50 ml

Microcentrifuge tubes 1.5 ml

Thermostat at 37 ^{o}C

Waterbath at 60 ^{o}C

- 20^{o}C Freezer

3.3.1.3 DNA extraction

The larvae stored in alcohol were removed and kept on tissue paper for one minute.The larvae was then dipped in liquid nitrogen and immediately transferred into 1.5 ml microcentrifuge tubes. The larvae were ground individually using micropestel in microfuge tubes containing 100 µl of preheated C-TAB extraction buffer and incubated at 65^{0}C for 30–45 min with occasional mixing. After incubation, the tubes were cooled to room temperature and equal volume of chloroform:isoamyl alcohol mixture (24:1) was added and mixed by inversion for 15 min. The suspension was centrifuged at 8000 rpm for 30 min at 4^{0}C. The supernatant was transferred to a fresh tube and 0.7 volume of ice-cold isopropanol was added and mixed gently by inversion and kept at -20^{0}C overnight for DNA precipitation. The clear aqueous phase was transferred to a new microfuge tube and the DNA pellet was separated from aqueous phase by brief centrifugation and the pellet was air-dried. The DNA was dissolved in 100-150 µl of $T_{10}E_1$ (10mM Tris 1mM EDTA) buffer.

To eliminate contaminating RNA, RNase (10 µl /100 µl) was added to DNA and incubated at 37^{0}C for 30 min by adding equal volume of chloroform: isoamyl alcohol (100 µl) and mixed thoroughly by repeated inversions. The mixture was centrifuged at 8000 rpm for 10 min at 4^{0}C, and the aqueous phase was transferred to another microcentrifuge to which two volumes of absolute alcohol was added and incubated at -20^{0}C overnight. The DNA was pelleted by brief centrifugation and the supernatant was discarded. The pellet was washed with 70% ethanol and centrifuged at 8000 rpm for 5 min at 4^{0}C, the alcohol was discarded and the DNA pellet was air-dried completely. Depending upon the size of the pellet, DNA was dissolved in 25– 50 µl of Tris-EDTA and stored at 4^{0}C. In order to make a better representation of each location equal amount of DNA from each of 5 larvae for each location was pooled and the resulting 14 bulked DNA samples were used for PCR analysis. Bulked DNA was diluted to 20-40 ng/ µl before being used in the PCR reaction. The concentration of DNA was measured using NanoDrop® ND-1000 spectrophotometer (Nanodrop Technologies, Wilmington, DE), and the quality was checked by 0.8% agarose gel electrophoresis before being used as template in PCR.

3.3.1.4 Polymerase chain reaction (PCR) amplification and electrophoresis

PCR analyses were performed using insect Mitochondrial DNA specific primer Oligonucleotide set synthesized from Xcelris Labs Ltd, Ahmedabad. A total of 37 oligonucleotide primers (Table 5) were used in PCR reactions.PCR was carried out for each primer in 20 µl standard reaction mixture consisting of 40ng/ µl of template DNA, 0.2mM primer, 25mM magnesium chloride, dimethyl sulfoxide, 10X reaction buffer, 3U /µl Taq polymerase and 10mM each dNTPs, were obtained from Syngene pvt. Ltd., Bangalore. The PCR amplification was performed using a thermocycler (Eppendorf, Master cycler gradient supplied by Eppendorf gradient, 2231, Hamburg Germany).

Table 5. List of UBC insect Mitochondrial DNA O1igonucleotide primer set

Sl. No.	Primer code	Sequence (5' to 3')
1	T1-N-24	ATT TAC CCT ATC AAG GTA A
2	TM-J-206	GCT AAA TAA GCT AAC AGG TTC AT
3	TM-N-193	TGG GGT ATG AAC CCA GTA GC
4	TY-J-1460	TAC AAT TTA TCG CCT AAA CTT CAG CC
5	C1-N-1560	TGT TCC TAC TAT TCC GGC TCA
6	C1-J-1718	GGA GGA TTT GGA AAT TGA TTA GTT CC
7	C1-J-1751	GGA TCA CCT GAT ATA CGA TTC CC
8	C1-J-2183	CAA CAT TTA TTT TGA TTT TTT GG
9	C1-N-2191	CCC GGT AAA ATT AAA ATA TAA ACT TC
10	C1-J-2195	TTG ATT TTT TGG TCA TCC AGA AGT
11	C1-N-2329	ACT GTA AAT ATA TGATGA GCT CA
12	L2-N-3014	TCC AAT GCA CTA ATC TGC CAT ATT A
13	TL2-J-3034	AAT ATG GCA GAT TAG TGC A
14	C2-J-3279	GGT CAA ACA ATT GAG TCT ATT TGA AC
15	C2-N-3389	TCA TAA GTT CAR TAT CAT TG
16	C2-J-3400	ATT GGA CAT CAA TGA TAT TGA
17	C2-N-3494	GGT AAA ACT ACT CGA TTA TCA AC
18	C2-N-3661	CCA CAA ATT TCT GAA CAT TGA CCA
19	C2-J-3696	GAA ATT TGT GGA GCA AAT CAT AG
20	TK-N-3785	GTT TAA GAG ACC AGT ACT TG
21	C3-J-5014	TTA TTT ATT GCA TCA GAA GT
22	C3-N-5460	TCA ACA AAG TGT CAG TAT CA
23	N4-N-8924	AAA GCT CAT GTT GAA GCT CC
24	N4-J-8944	GGA GCT TCA ACA TGA GCT TT
25	CB-J-10612	CCA TCC AAC ATC TCA GCA TGA TGA AA
26	CB-J-10933	TAT GTA CTA CCA TGA GGA CAA ATA TC
27	CB-N-10920	CCC TCA GAA TGA TAT TTG TCC TCA
28	CB-N-11367	ATT ACA CCT CCT AAT TTA TTA GGA AT
29	N1-J-12585	GGT CCC TTA CGA ATT TGA ATA TAT CCT
30	N1-N-12595	GTA GCA TTT TTA ACT TTA TTA GAA CG
31	LR-N-12866	ACA TGA TCT GAG TTC AAA CCG G
32	LR-J-12887	CCG GTC TGA ACT CAG ATC ACG T
33	LR-J-13417	ATG TTT TTG TTA AAC AGG CG
34	LR-N-13398	CGC CTG TTT AAC AAA AAC AT
35	SR-J-14233	AAG AGC GAC GGG CGA TGT GT
36	SR-N-14588	AAA CTA GGA TTA GAT ACC CTA TTA T
37	SR-N-14925	TTA AAG TTT TAT TTT GGC

3.3.1.5 Reaction mix

One primer at a time was used to study the polymorphism between 14 geographical populations by PCR assay with total DNA extracts from all the 14 geographical populations as template DNA with one control. The master mix required was prepared to avoid handling errors. The master mix was distributed to 15 tubes (19 µl per tube) and template DNA (1µl) from the respective location was added to make the total reaction volume to 20 µl.

3.3.1.6 PCR-amplification

After the completion of required cycles of amplification, the samples were stored at 4℃ in a refrigerator and the contents were loaded on to agarose gels for electrophoresis.

3.3.1.7 Separation of amplified products by agarose gel electrophoresis

25 µl of the amplified products from each tube along with 2 µl of loading dye were separated on 1.5 per cent agarose gel using 1 X TAE buffer of pH 8.0 along with EcoR I/Hind III double digest as DNA molecular weight marker and photographed

using gel documentation system (Uvitec. Cambridge, England) at 5 V/cm for 3 h. All 37 primers producing repeatable amplicons pattern were considered for actual data analysis.

3.3.1.8 Analysis of PCR profiles

The mtDNA–PCR amplification patterns obtained were converted into a binary data matrix containing an array of 0 and 1. The presence of a band was scored as 1 and its absence as 0. The matrix values of binary data were calculated using standard procedure in NTsys-Pc-2.1 software package (Rohlf, 2000). The data were subjected to the SIMQUAL option to compute association coefficients using Jaccard's coefficient (Jaccard, 1908) of similarity to generate a similarity matrix. Clustering analysis was performed with the unweighted pairgroup method using arithmetic averages (UPGMA) in the SAHN (sequential, agglomerative, hierarchical and nested clustering method) module of NTsys- pc-2.0 software programme (Dice, 1945; Nei and Li, 1979). The binary data was subjected to bootstrapping (Felsenstein, 1985) (1000 times) using WINBOOT program (Yap and Nelson 1996).

3.4 To study the population dynamics of SFB in selected wild species of brinjal

3.4.1.1 Screening of selected wild species for resistance against BSFB

Roving survey was conducted to collect the wild brinjal from three representative locations of Karnataka state (i.e.Raichur and Dharwad). In this context based on the morphology of leaf, flower colour, fruit shape and colour, a sampling was made from selected forest and uncultivated barren land self sown wild brinjal plants. For identification care was taken to collect the ripened fruit as far as possible and the seedling was uprooted in case where fruit is lacking. Six species of brinjal were selected and their response was studied for BSFB infestation (Table 6). The collected species were sent to IIVR (Varanasi) for identification. Observations were made on shoot and fruit infestation under natural conditions at an interval of fifteen days for shoot infestation at the early stages of crop growth and fruit infestation from fruit development on wards. The per cent shoot and fruit infestation was recorded on number basis by counting the number of drooping shoots and infested fruits and the total number of healthy shoots and fruits using following formula.

$$\text{Per cent shoot infestation} = \frac{\text{Number of drooping shoots}}{\text{Total number of shoots}} \times 100$$

$$\text{Per cent fruit infestation} = \frac{\text{Number of infested fruits}}{\text{Total number of fruits}} \times 100$$

Table 6. Morphological characters of wild species of eggplant/aubergine

Traits/Characters	*S. torvum*	*S. indicum*	*S. viarum*	*S. incanum*	*S. virginianum*	*S. macrocarpon*
Common Name	Pea eggplant	Indian Nightshade	Tropical Soda Apple	Bitter Tomato	Bitter Brinjal	Gboma eggplant
Plant spread	Erect	Erect	Erect	Erect	Creeping	Erect
Plant growth/height	Indeterminate tall (2.0-5.0 m)	Determinate dwarf	Determinate dwarf	Determinate dwarf	Determinate dwarf	Determinate dwarf (1-1.5m)
Plant vigour	Very Strong	Strong	Strong	Strong	Weak	Weak
Plant prickliness on stem, petiole, leaf vein, flower calyx, fruit calyx	Large and hard Prickles on stem	Prickles on leaf, fruit calyx, stem and shoots	Very Large prickles on all parts	Prickles on leaf, fruit calyx and stem	Slender Prickles on leaf, fruit calyx, stem and shoots	No Prickles on On leaf.Only on midrib and lateral veins
Plant hairiness or Glabrous	On stem and fruit calyx	Glabrous	Hairyness on whole plant	Hairs on midrib, calyx and stem	Hairs on stem and shoot	Hairs on both sides of leaves with simple hairs
Leaf shape	Large lobed	Large simple	Large simple	Large lobed	Large lobed	Large lobed
Flower/Fruit number per inflorescence	12-18	5-6	3-4	5-6	2-3	1-2
Flower colour	White	Violet	White	Violet	Violet	Purple
Fruit furrowing	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Fruit shape	Obovoid	Oblong	Round	Round	Oblong	Round
Fruit colour	Green unstriped	Shiny Green striped	Green mottled	Green striped	Green mottled	Green
Fruit Clustering	Clustering	Clustering	Clustering	Clustering	Clustering	Solitary
Fruit position	Erect	Erect	Erect	Pendant	Pendant	Pendant
Fruit flesh colour	White	Greenish	White	White	Greenish	Greenish

3.5 Development and evaluation of IRM/IPM strategies for SFB management in brinjal

The field experiment were conducted during 2009-10 and 2010-11 (kharif season) to evaluate IPM modules against shoot and fruit borer on Brinjal hybrid MHBJ-99 at Horticultural garden, Main Agricultural Research Station, UAS, Raichur. Each module was separated by 5.0 m buffer area distance. Thirty days old healthy seedlings were transplanted in 25m x 10 m Plot sizes with a spacing of 90 x 60 cm between row- to -row and plant to plant respectively. Five modules having different components were designed and tested for their efficacy with respect to incidence of brinjal shoot and fruit borer. Thus modules served as treatment and blocks served as replication satisfying one way ANOVA requirement.The components included in each module revolved around management or suppression of pest population below ETL through integration of different techniques. Each module was divided into four equal blocks to serve as replication. In each module 10 plants were randomly selected in each replication and tagged for observation. In both the years, all the agronomic practices were followed to raise the crop as per the recommended package of practices (Anon., 2009). The plant protection measures for sucking pests were common for all the treatments. Three applications of acetamiprid 20 SP @ 10g ai/ha was given at 40, 80 and 110 DAT. Package of practices was followed and plant protection treatemnts were imposed for brinjal cultivation as per IPM modules (Plate 2).

3.6.1 Methodology for Preparation of indigenous spray solutions

1) Brahmasthra: 10 litres cow urine, 3kg cow dung, 5 kg g neem leaves and 3 kg pongamia leaves, 2 kg Castor leaves, 2 kg pomegranate leaves, 2 kg annona leaves, 2 kg papaya leaves, 2 kg Ipomia spp. Leaves, 2 kg garlic, 2 kg green chilli and 3 kg lantana leaves were used. All these ingredients were soaked in 200 litres of water and contents were stirred thrice a day and supernatant extracted was used for spraying.
2) Panchapatta: *vitex negundo* leaves, Eucalyptus leaves and Besharmi leaves were collected. These three types of leaves were crushed and kept in plastic barrel and water was poured up to 3 inches above all these ingredients in the barrel. The mixture was stirred twice a day for 30 days. The mixture was filtered through muslin cloth and used for spraying.

3.6.2 Details of IPM modules against *L. orbonalis*

<u>Module I</u>- Farmers practice

i. Application of conventional insecticides like endosulfan or monocrotphos or thiodicarb or cypermethrin from 10 DAT to till 30 DAT weekly 2 times under rainy season and 1 time under summer season.
ii. Application of spinosad and indoxacarb till flowering
iii. Spraying of newer chemicals like rynaxypyr, spinosad, flubendiamide and biological pesticides (spark, proton and neutron) as alternate sprays at weekly intervals from flowering to till final harvest.

<u>Module II</u>- IIHR +AVRDC recommendation

1. Sanitation of planting area to make sure eggplant residues from the previous crop are remained.
2. Excising and disposal of all ESFB-damaged shoots from 15 DAP when wilted shoots become visible and prompt disposal of damaged fruits at 15 days interval throughout the season.
3. 2-3 Soil application of neem and pongamia cake at sowing and 30-40 DAP and at 90-100 DAP @ the rate of 125 kg/acre.
4. Starting with the first flush of flowering (after 4weeks), installation of pheromone traps at every 10-m grid between 2 traps at the canopy level throughout the field baited with sex pheromone of ESFB. @ 5 traps/acre
5. Withholding of pesticide use as long as possible.

Field view of IPM plot

WOTA trap

Plate 2: Field view of IPM plot in Brinjal ecosystem

Module III- Bio- intensive module

1. Seven releases of egg parasite, *Trichograma chilonis* @1.0 lakh /ha at weekly intervals from 30 DAT.
2. 2-3 Soil application of neem and pongamia cake at transplanting, 30-40 DAP and at 90-100 DAP @ the rate of 125 kg/acre.
3. Installation of pheromone traps after 15 DAT @ 5 traps/acre
4. Three sprays of NSKE 5% + Application of neem oil 1% by mixing with detergent at the ratio of (2:1) at 15 days interval after 15 days of transplanting till the flower initiation.
5. Spraying of Panchapatti and Bhramasthra at the time of flowering @ 2ml/lt.
6. Need based application of spinosad from fruit initiation to till harvest.

Module IV- UAS module

1. Seedling root dip in imidacloprid @ 0.2ml/lt of water prior to transplanting.
2. Application of neem cake @2.5 q/ac at transplanting and 30 days after transplanting.
3. Need based application of Thiodicarb 75SP @ 1gm/lt of water at flowering and fruit formation stages.
4. Need based application of Spinosad 14.8SC @0.12ml/lt at 10 days interval at 80^{th} day.
5. Need based application of indoxicarb 48.2SC @0.3ml/lt at 90 DAT.
6. Spraying of new Bt product @1gm/lt developed by DOR Hyderabad.

Module V- Adoptable module

1. Sanitation of planting area to make sure eggplant residues from the previous crop, which can harbor ESFB are disposed off promptly.
2. Prompt excising and disposal of all ESFB-damaged shoots and fruits throughout the season.
3. Application of potassium @ 100 kg/ha as murate of potash (MOP) fertilizer in two splits at 20 DAT and at the flower initiation stage as additional dose.
4. Application of neem cake @2.5 q/acre in three splits at transplanting, 30 and 90 DAT.
5. Installation of leucinlure pheromone traps after 15 DAT @ 12 traps/acre just 25 cm above the plant canopy level and at the junction of a 10-m grid.
6. Application of Thiodicarb 75SP @ 1.0 g/l or Spinosad 45 SC @0.10 ml/l of water as alternate spray from 45 DAT till 90 DAT.
7. Need based application of Rynaxypyr 20 SC @ 0.2ml/l or flubendiamide 24 WG (0.012%) or Emamectin benzoate 5SG @ 0.2g/lt as alternate subsequent sprays at 5 % and 10% level of shoot & fruit infestation from 90 DAT to till final harvest.
8. Spraying of new Bt product @1gm/lt developed by DoR Hyderabad. If there is infestation at final harvest Bt product will be sprayed before picking if required.

3.6.3 Observations

Forty plants were selected randomly from each of the above mentioned modules and season long observations of insect pest population/damage and natural enemies population were made at ten days interval as follows.

3.6.3.1 Assessment of pest damage / population

3.6.3.1.2 Shoot and fruit borer

Adult moth population

Observations on moth activity were recorded by counting the number of moths trapped at weekly interval from 15 days after trap installation to till final harvest .The wota traps fitted with lucinlure were procured from PCI (Pest control India Ltd.), Bangalore.

Shoot Infestation

Observations on Shoot and fruit borer population was recorded by counting number of shoots showing drooping symptoms and total number of shoot on randomly selected 40 plants from each plot at ten days interval starting from 30 to 120 days after transplanting. In case of Modules which has shoot clipping as one of the component, the infested shoots were clipped, removed and destroyed after counting. The data on shoot damage was converted into per cent value and arc sin transformation before subjecting for statistical analysis. The cumulative per cent shoot damage was worked out using the formula.

$$\text{Per cent Shoot damage} = \frac{\text{Number of infested shoots}}{\text{Total number of shoots}} \times 100$$

Fruit infestation

Observations on fruit infestation were recorded at weekly interval at each harvest both on number and weight basis starting from fruit set to final harvest. At each harvest the weight of healthy and infested fruits were noted separately per plot per treatment. The percent fruit infestation was recorded on number basis by using following formula.

$$\text{\% Fruit infestation by number} = \frac{\text{Number of infested fruits}}{\text{Total number of fruits}} \times 100$$

The cumulative plot yield of healthy and infested fruits of all the harvests were transformed into healthy, infested and total yield per hectare in tons respectively. The data was further subjected to statistical analysis.

3.6.3.2 Natural enemies

Observation on predatory natural enemies population *viz., Coccinella septumpunctata* (grub and adults) and chrysoperla (grub) were recorded at ten days intervals on the randomly selected fourty tagged plants in each module from 30 to 110 DAT and average number per plant was worked out and data was subjected to statistical analysis

3.6.3.3 Yield and economics

The fruits were harvested at regular intervals. A total of eight pickings were done .At each harvest total yield of brinjal per plot for each treatment was recorded. The total fruit yield of all the harvests were averaged and converted to hectare basis for statistical analysis. The cost economics was worked out based on the average market price of brinjal.

3.7 Statistical analysis

The data averaged into respective parameter requisites was subjected to suitable transformation. After proper analysis, data was accommodated in the tables as per the needs of objectives for interpretation of results. Computer software packages M STATC and Dry soft were used for analysis. The standard procedures in agriculture statistics given by Gomez and Gomez (1976) were consulted throughout.

EXPERIMENTAL RESULTS

The results of the experiments conducted during 2009-10 and 2010-11 on the following objectives *viz*., to study the insecticide usage pattern in major brinjal growing regions of South India, to monitor the baseline susceptibility in SFB populations of South India, to different chemistries and Cry1Ac protein, assessment of genetic diversity of brinjal shoot and fruit borer (*Leucinodes orbonalis* G) populations occurring in south India using mitochondrial DNA markers, to study the population dynamics of SFB in selected wild species of brinjal and development and evaluation of IRM/IPM strategies for SFB management in brinjal obtained are envisaged hereunder.

4.1 Insecticide usage pattern in major brinjal growing regions of South India

It was evident from the survey of five different states comprising of fourteen different locations that, farmer's sprayed insecticide at an interval of 4-8 days. Farmers from Margoa, Vijaywada, Parbhani and Chennai sprayed the insecticides at an interval of 8 days which is highest among all the locations and lowest spray interval of 4 days was recorded from farmers of Bangalore and Raichur locations. The number of application of insecticides in the fourteen locations varied from 18 to 34 in brinjal against shoot and fruit borer. Maximum numbers of 36 sprays were recorded from the Raichur followed by 34 sprays from Hyderabad location .Whereas, lowest number of 18 sprays were recorded from Margoa and Chennai locations. Among the Maharashtra state, least number of 24 sprays was used by the farmers from parbhani with a spray interval of 8 days and highest numbers of sprays were recorded from the Kolhapur location with an spray interval of 6 days (Table 7).

Whereas, from Andhra Pradesh state, highest number of sprays were recorded from Hyerabad with an spray interval of 7 days and lowest number of sprays were recorded from Vijawada with an spray interval of 8 days. Maximum number of 22 sprays with an spray interval of 7 days in Aduthurai and least number of 18 sprays with an spray interval of 8 days from Chennai were recorded from locations of Tamilnadu state. Among the Karnataka state, more number of 34 sprays with a spray interval of 4 days was used by the farmers from Raichur followed by Bangalore with 32 sprays with an interval of 4 days. Lowest number of 24 sprays with an spray interval of 7 days were recorded from Dharwad location (Table 7).

From the fourteen locations surveyed across the brinjal ecosystems it was clear that, highest use of rynaxypyr with 92 per cent was observed from Raichur and lowest use of 56 per cent was observed from Margoa. In case of flubendiamide, highest use of (84 per cent) was observed in Raichur and lowest use of (40 per cent) was recorded in Margoa locations. Highest and lowest use of emamectin benzoate was recorded in Bangalore (76%) and Margoa (8%) locations.In case of spinosad highest use of 84 per cent was observed in Raichur, Banagalore and Hyderabad locations and lowest of 60 per cent was observed in Margoa and Chennai locations (Table 8).

Highest indoxacarb use of 68 per cent was observed in Raichur and the lowest use of 24 per cent in Margoa location. In case of Chlorpyriphos, Margoa farmers recorded maximum use of 12 per cent and lowest use of 4 per cent was observed in Coimbatore and Chennai Locations. In case of thiodicarb, highest per cent use of 44 per cent was observed in Hyderabad, whereas lowest use of 32 per cent was observed in Vijaywada, West Godavari and parbhani locations. Maximum Cypermethrin use of 52 per cent was observed in Raichur, Chennai, Coimbatore and Margoa locations. Lowest use of 40 per cent was observed in Dapoli, Dharwad and west Godavari locations. In case of quinalphos, Margoa recorded 16 per cent and 4 per cent use was recorded in Bijapur, West Godavari and Parbhani. Highest use rate of 20 per cent monocrotophos was recorded in Margoa and lowest of 4 per cent was observed in Parbhani, Kolhapur, Vijaywada, West Godavari and Raichur. In Carbaryl, Margoa recorded maximum use of 24 per cent and lowest use of 4 per cent was recorded in Dharwad and Raichur. Endosulfan with the highest use of 4 per cent was observed in Margoa, Chennai, Coimbatore and Dapoli and no usage was observed in remaining all other locations (Table 8).

Among the different states across the South india, Karnataka recorded the highest use of rynaxypyr (80 %), flubendiamide (72 %), emamectin benzoate (60%) spinosad (80%), indoxacarb (57.33%) and Thiodicarb (41.33 %). Whereas, lowest use of rynaxypyr (56 %), flubendiamide (40 %), emamectin benzoate (8 %), spinosad (60%), indoxacarb (24 %) and thiodicarb (12 %) was recorded in Goa state. Highest usage of cypermethrin (52 %), quinalphos (16 %), monocotrophos (20 %), carbaryl (24 %) and endosulfan (4%) in Goa. Among the different chemicals in Karnataka, highest use of rynaxypyr (80 %) and spinosad (80%) followed by flubendiamide (72%) and in Karnataka lowest.

Table 7: Type of insecticides used by brinjal growers against brinjal shoot and fruit borer, *Leucinodes orbonalis* in surveyed areas during two seasons of 2009-10 & 2010-11

State	Location	Pesticides used (Technical name)*			Spray Interval (Days)	Total No of sprays	Source of information
		Very frequently used	Commonly used	Rarely used			
Maharashtra	Parbhani	Emmamectin benzoate, Spinosad, Carbaryl, Acephate, Fenvalarate, Flubendiamide,Rynaxypyr, Cartap hydrochloride	Deltamethrin, Indoxacarb, Monocrotophos Cypermethrin, Quinalphos,	Methomyl, Deltamethrin+Triazophos Ethion+ chlorpyrifos and Cypermethrin –D, Profenophos+cypermethrin, Emmamectin benzoate	8	24	Neighbour, Dealers and company agents
	Dapoli	Emmamectin benzoate, Flubendiamide, Cypermethrin, Spinosad, Fenvalarate	Monocrotophos, Profenophos, Rynaxypyr, Deltamethrin+Triazophos, Indoxacarb, Alpha-cypermethrin, Ethion+Cypermethrin, Quinalphos	Lambda-cyhalothrin, Ethofenprox, Cypermethrin, Profenophos, Carbaryl, Endosulfan	7	28	Self, Neighbour, Dealers
	Kolhapur	Thiodicarb, cypermethrin, Flubendiamide, Fenvalarate,Coragen	Decamethrin, Lambda-cyhalothrin, Indoxacarb	Imidacloprid+Acephate, Clothidion, Proclaim, Quinalphos, Endosulfan, Monocrotophos	6	30	Neighbour, Dealers and company agents
Andhra Pradesh	Hyderabad	Emmamectin benzoate, Rynaxypyr	Spinosad, Profenophos	Flubendiamide, Deltamethrin+Triazophos Cypermethrin, Monocrotophos	7	34	Self, Dealers, Company agents Departments
	Vijayawada	Rynaxypyr, Spinosad, Carbosulfan, Methomyl	Lamda-cyhalothrin, Indoxacarb, Emmamectin benzoate	Flubendiamide, Endosulfan, Monocrotophos	8	24	Self, Neighbour and Dealers
	West Godavari	Emmamectin benzoate Carbosulfan, Carbaryl, Methomyl	Indoxacarb, Rynaxypyr, Quinalphos, Cypermethrin, Spinosad	Monocrotophos, Thiodicarb	7	26	Neighbour, dealers

Contd…

Goa	Margoa	Thiodicarb, Cypermethrin, Lambda- cyhalothrin, Endosulfan ,Neem oil	Spinosad,, Quinalphos	Rynaxypyr, Monocrotophos	8	18	Self and Neighbour
Tamilnadu	Chennai	Endosulfan, Monocrotophos, Chorpyriphos, Carbaryl, Cypermethrin	Indoxacarb, Lambda cyhalothrin	Rynaxypyr, Flubendiamide	8	18	Neighbour, dealers and company
	Coimbatore	Endosulfan,Fenvalarate Monocrotophos, Thiodicarb	Carbaryl	Spinosad, Rynaxypyr	5	20	Neighbour, dealers and company
	Aduthurai	Endosulfan, Cypermethrin, Monocrotophos, Thiodicarb	Thiodicarb	Rynaxypyr	7	22	Self, dealers and company
Karnataka	Raichur	Thiodicarb, Cypermethrin, Flubendiamide, Rynaxypyr, Spinosad.	Monocrotophos, Lambda cyhalothrin, Indoxacarb, , Spark, Emmamectin benzoate	Carbaryl, Cartap hydrochloride, Quinalphos	4	36	Neighbours, dealers and company agents
	Bijapur	Rynaxypyr,Cypermethrin, Fenvalarate,Spinosad	Monocrotophos, Thiodicarb	Monocrotophos, Endosulfan, Quinalphos, Deltamethrin+Triazopho s	6	28	Self, neighbour, dealers and company
	Dharwad	Chlorpyriphos,Carbaryl, Thiodicarb, Spinosad, Flubendiamide	Indoxacarb, Cypermethrin, Spinosad	Monocrotophos, Rynaxypyr	7	24	Neighbour, Dealers, SAU's and Departments
	Bangalore	Quinalphos, Carbaryl, Rynaxypyr	Flubendiamide, Monocrotophos	Lambda cyhalothrin, Emmamectin benzoate	4	32	Neighbour, dealers,SAU's Departments

*Average of 25 farmers

Table 8: Per cent of Insecticide usage pattern among brinjal growers against shoot and fruit borer in the surveyed area

Chemical	Per cent of farmers*														Mean
	PBN	DAP	KLP	HYD	VJA	WG	Margoa	MAA	CBE	ADT	RCR	BJP	DWD	BGL	
Rynaxypyr 20 SC	68.00	80.00	80.00	84.00	72.00	68.00	56.00	64.00	76.00	68.00	92.00	80.00	76.00	84.00	74.86
Flubendiamide 480 SC	68.00	68.00	72.00	80.00	60.00	64.00	40.00	48.00	52.00	56.00	84.00	72.00	64.00	80.00	64.86
Emmamectin Benzoate 5 SG	40.00	44.00	48.00	72.00	32.00	32.00	8.00	16.00	24.00	20.00	64.00	56.00	48.00	76.00	41.43
Spinosad 45 SC	76.00	76.00	80.00	84.00	76.00	76.00	60.00	60.00	64.00	64.00	84.00	80.00	76.00	84.00	74.29
Indoxacarb 14.8 SC	40.00	44.00	56.00	60.00	48.00	52.00	24.00	32.00	36.00	40.00	68.00	56.00	52.00	64.00	48.00
Chlorpyriphos 20 EC	4.00	0.00	0.00	0.00	0.00	0.00	12.00	8.00	4.00	8.00	0.00	0.00	0.00	0.00	2.57
Thiodicarb 75WP	32.00	36.00	40.00	44.00	32.00	32.00	40.00	36.00	36.00	40.00	40.00	40.00	40.00	44.00	38.00
Cypermethrin 25EC	44.00	40.00	44.00	48.00	44.00	40.00	52.00	52.00	52.00	48.00	52.00	44.00	40.00	48.00	46.29
Quinalphos 25 EC	4.00	0.00	0.00	0.00	0.00	4.00	16.00	12.00	8.00	8.00	0.00	4.00	0.00	0.00	4.00
Monocrotophos 36 SL	4.00	0.00	4.00	0.00	4.00	4.00	20.00	16.00	16.00	12.00	4.00	0.00	0.00	0.00	6.00
Carbaryl 50 WP	0.00	0.00	0.00	0.00	8.00	8.00	24.00	20.00	16.00	16.00	4.00	0.00	4.00	0.00	7.14
Endosulfan 35 EC	0.00	4.00	0.00	0.00	0.00	0.00	4.00	4.00	4.00	0.00	0.00	0.00	0.00	0.00	1.14

*Mean of 25 famers
PBN-Parbhani; DAP-Dapoli; KLP-Kolhapur; Hyd-Hyderabad; VJA-Vijaywada; W.G-West Godavari; MAA-Madurai
CBE-Coimbatore; ADT-Aduturai; RCR-Raichur; BJP-Bijapur; DWD-Dharwad; BGL-Banglaore.

Table 9: Per cent mean of Insecticides used by brinjal growers against shoot and fruit borer in the surveyed area

Chemicals	Per cent mean of farmers*				
	Karnataka	Andhra Pradesh	Tamilnadu	Maharashtra	Goa
Rynaxypyr 20 SC	80.00	74.67	69.33	76.00	56.00
Flubendiamide 480 SC	72.00	68.00	52.00	69.33	40.00
Emmamectin Benzoate 5SG	60.00	45.33	20.00	44.00	8.00
Spinosad 45 SC	80.00	78.67	62.67	77.33	60.00
Indoxacarb 14.8 SC	57.33	53.33	36.00	46.67	24.00
Chlorpyriphos 20 EC	0.00	0.00	6.67	1.33	12.00
Thiodicarb 75WP	41.33	36.00	37.33	36.00	40.00
Cypermethrin 25EC	44.00	44.00	50.67	42.67	52.00
Quinalphos 25 EC	1.33	1.33	9.33	1.33	16.00
Monocrotophos 36 SL	0.00	2.67	14.67	2.67	20.00
Carbaryl 50 WP	1.33	5.33	17.33	0.00	24.00
Endosulphan 35 EC	0.00	0.00	2.67	1.33	4.00

*Mean of 25 famers

Table 10. Baseline susceptibility of Cry1Ac (LC_{50},µg mL^{-1} diet) to brinjal shoot and fruit borer populations collected from brinjal growing districts of south India during 2009-10

Population	*n*	χ^2	Slope (± SE)	LC_{50} (95 % CI)	LC_{95} (95 % CI)
Dharwad, KA	630	6.12	1.10 (± 0.05)	0.031 (0.020-0.058)	1.052 (0.524-1.842)
Bijapur, KA	630	8.48	1.04 (± 0.08)	0.034 (0.025-0.046)	1.234 (0.724-1.045)
Bangalore, KA	630	7.93	1.12 (± 0.12)	0.038 (0.030- 0.060)	1.643 (0.776-2.365)
Raichur, KA	630	5.69	1.10 (± 0.10)	0.042 (0.024-0.048)	1.829 (0.627-2.127)
WestGodavari, AP	630	6.62	1.20 (± 0.08)	0.032 (0.032-0.076)	1.156 (0.825-2.628)
Hyderabad, AP	630	9.79	1.14 (± 0.10)	0.026 (0.016-0.040)	0.721 (0.442 -1.088)
Vijayawada, AP	630	6.76	1.16 (± 0.07)	0.030 (0.022-0.052)	0.823 (0.783-1.130)
Chennai, TN	630	7.40	1.18 (± 0.06)	0.036 (0.024-0.074)	1.476 (0.862-2.484)
Aduthurai, TN	630	8.24	1.10 (± 0.14)	0.028 (0.020-0.058)	0.883 (0.556-1.372)
Coimbatore, TN	630	6.65	1.12 (± 0.12)	0.038 (0.032-0.082)	1.620 (0.962-2.178)
Margoa, Goa	630	9.17	1.04 (± 0.10)	0.020 (0.018-0.042)	0.529 (0.324-0.984)
Kolhapur, MH	630	8.15	1.08 (± 0.04)	0.032 (0.022- 0.068)	1.142 (0.864-1.587)
Dapoli, MH	630	7.32	1.12 (± 0.06)	0.030 (0.022-0.048)	0.987 (0.265-1.478)
Parbhani,MH	630	7.41	1.00 (± 0.08)	0.029 (0.018-0.062)	0.868 (0.478-1.529)

LC_{50}: concentration of Cry1Ac that killed 50% of test larval population in the observation period of 7 days.
LC_{95}: concentration of Cry1Ac that killed 95% of test population. KA : Karnataka, AP: Andhra Pradesh,TN: TamilNadu, MH: Maharashtra

Table 11. Baseline susceptibility of Cry1Ac (LC_{50}, µg mL^{-1} diet) to brinjal shoot and fruit borer populations collected from brinjal growing districts of south India during 2010-11

Population	*n*	χ^2	Slope (± SE)	LC_{50} (95 % CI)	LC_{95} (95 % CI)
Dharwad, KA	630	7.13	1.04 (± 0.10)	0.028 (0.018-0.042)	0.872 (0.428-2.140)
Bijapur, KA	630	6.42	1.03 (± 0.06)	0.032 (0.022-0.068)	1.228 (0.720-2.240)
Bangalore, KA	630	8.23	1.14 (± 0.05)	0.035 (0.028-0.076)	1.360 (0.630-1.818)
Raichur, KA	630	9.28	1.18 (± 0.10)	0.040 (0.028-0.074)	1.742 (0.628-2.523)
West Godavari, AP	630	5.72	1.08 (± 0.12)	0.026 (0.020-0.046)	0.762 (0.452-1.244)
Hyderabad, AP	630	7.63	1.07 (± 0.07)	0.029 (0.024-0.064)	0.946 (0.710-1.950)
Vijayawada, AP	630	6.10	1.09 (± 0.08)	0.031 (0.020-0.052)	1. 146 (0.432-1.268)
Chennai, TN	630	8.21	1.18 (± 0.10)	0.034 (0.026-0.058)	1.386 (0.728-1.382)
Aduthurai, TN	630	9.10	1.09 (± 0.12)	0.030 (0.020-0.046)	1.046 (0.439-1.436)
Coimbatore, TN	630	8.73	1.16 (± 0.06)	0.036 (0.028-0.068)	1.543 (0.546-2.340)
Margoa, Goa	630	6.00	1.04 (± 0.08)	0.022 (0.018-0.042)	0.610 (0.373-0.852)
Kolhapur, MH	630	9.23	1.10 (± 0.14)	0.030 (0.024-0.065)	0.973 (0.428-1.342)
Dapoli, MH	630	6.73	1.00 (± 0.07)	0.027 (0.022-0.040)	0.764 (0.431-1.168)
Parbhani,MH	630	8.42	1.08 (± 0.08)	0.031 (0.026-0.069)	1.272 (0.563-1.136)

LC_{50}: concentration of Cry1Ac that killed 50% of test larval population in the observation period of 7 days.
LC_{95} : concentration of Cry1Ac that killed 95% of test population. KA : Karnataka, AP: Andhra Pradesh,TN: TamilNadu, MH: Maharashtra

use of carbaryl (1.33%) and quinalphos (1.33%) was observed with none of the farmers using chorpyriphos and endosulfan (Table 9). In Andhra Pradesh, maximum use of spinosad (78.67 %) was observed followed by rynaxypyr (74.67%) whereas, quinalphos recorded lowest of 1.33 per cent with no farmers using chorpyriphos and endosulfan. In Tamilnadu, more usage of rynaxypyr (69.33 %) was observed followed by spinosad (62.67%) and least of endosulfan. Maharashtra recorded the highest per cent (77.33) of spinosad followed by rynaxypyr (76 %) and whereas lowest use 1.33 per cent of chloropyriphos, quinalphos and endosulfan with none of the farmers using carbaryl. In Goa state, highest rate of spinosad (60 %) was recorded followed by rynaxypyr (56 %) with the lowest use of endosulfan (4%) (Table 9).

4.2 Baseline susceptibility studies in SFB populations of South India to different insecticide chemistries and Cry1Ac protein

4.2.1 Median lethal concentration (µg/ml diet LC_{50} and LC_{95}) of *Leucinodes orbonalis* neonates to Cry1 Ac protein

Susceptibility of *Leucinodes orbonalis* collected across the South Indian brinjal ecosystem was tested for Cry 1Ac protein for the period of two years, the results obtained during the course of study are presented here.

The 2009-10 Kharif results revealed that Cry 1Ac protein was found to be toxic to all fourteen geographic populations tested (Table 10). Median lethal concentrations (LC_{50}) for neonates ranged from 0.020 to 0.042 ppm (parts per million) of diet, with the population from Margoa having the lowest LC_{50} value of 0.020 µg/ml diet and that from Raichur having the highest LC_{50} value of 0.042 µg/ml diet . LC_{95} values ranged from 0.529 to 1.829 ppm of diet across the populations of which highest was found in Raichur (1.829 µg/ml diet) and lowest in Margoa (0.529 µg/ml diet) population. Among the geographic location of Karnataka, lowest LC_{50} value of 0.031 µg/ml diet was recorded in Dharwad population followed by LC_{50} values of Bijapur (0.034 µg/ml diet) and Bangalore (0.038 µg/ml diet). In case of Andhra populations, Lowest LC_{50} value (0.026 µg/ml diet) was recorded in Hyderabad followed by Vijaywada (0.030µg/ml diet) and West Godavari (0.032µg/ml diet). Similarly among the TamilNadu populations the lowest LC_{50} value (0.028 µg/ml diet) was noticed in Aduturai followed by Chennai (0.036µg/ml diet) and Coimbatore (0.038 µg/ml diet).In case of Maharashtra, the lowest LC_{50} value (0.029 µg/ml diet) was recorded in Parbhani followed by Dapoli (0.030 µg/ml diet) and Kolhapur (0.032 µg/ml diet). In 2010-11 Kharif season, the results also indicated that Cry 1Ac protein was found to be toxic to all fourteen geographic populations tested (Table 11). LC_{50} values of neonates among the different populations ranged from 0.022 to 0.040 µg/ml diet and LC_{95} values ranged from 0.610 to 1.742 µg/ml diet across the fourteen populations. Highest LC_{50} value of (0.040 µg/ml diet) was observed in Raichur population followed by Coimbatore (0.036 µg/ml diet), Bangalore (0.035 µg/ml diet), Chennai (0.034 µg/ml diet), Bijapur (0.032 µg/ml diet), Vijaywada (0.031 µg/ml diet) and Parbhani (µg/ml diet). Lowest LC_{50} value of 0.022 µg/ml diet was recorded in Margoa population followed by Dharwad (0.028 µg/ml diet), West Godavari (0.029 µg/ml diet), Dapoli (0.027 µg/ml diet), Kolhapur (0.030 µg/ml diet) and Aduthurai (0.030 µg/ml diet). Among the populations, Highest LC_{95} value of 1.742 µg/ml diet was recorded in Raichur population and Margoa recorded the lowest LC_{95} value of 0.610 µg/ml diet (Table 11).

4.2.2 Moult inhibitory concentration (µg/ml diet MIC_{50} and MIC_{95}) of Cry1 Ac protein to *Leucinodes orbonalis* neonates

During the year 2009-10, moult inhibitory concentration (MIC_{50}) values ranged from 0.003 to 0.014 µg/ml diet and the MIC_{95} values ranged from 0.028 to 0.145 µg/ml diet (Table 12). Raichur recorded Maximum MIC_{50} value of 0.014 µg/ml diet and Margoa recorded lowest MIC_{50} value of 0.03 µg/ml diet. Among the Karnataka populations, Dharwad showed highest MIC_{50} value of 0.011 µg/ml diet followed by MIC_{50} values of Bijapur (0.007 µg/ml diet) and Bangalore (0.07 µg/ml diet). Maximum MIC_{50} value of 0.009 µg/ml diet was noticed in Vijayawada population followed by MIC_{50} values of Hyderabad (0.007 µg/ml diet) and West Godavari (0.005 µg/ml diet) among the Andhra Pradesh Populations. In case of Tamilnadu populations, Coimbatore showed maximum MIC_{50} value of 0.006 µg/ml diet followed by MIC_{50} values of Aduthurai (0.04 µg/ml diet) and Chennai (0.005 µg/ml diet). Among the populations of Maharashtra, Kolhapur recorded the highest MIC_{50} value of 0.008 µg/ml diet followed by MIC_{50} values of Dapoli (0.008 µg/ml diet) and Parbhani (0.004 µg/ml diet).Highest MIC_{95} value of 0.145 µg/ml diet was recorded and lowest MIC_{95} value of 0.028 µg/ml diet (Table 12). In the 2010-11 cropping season, the results revealed that moult inhibitory concentration (MIC_{50})

values ranged from 0.003 to 0.012 µg/ml diet. The MIC_{95} values ranged from 0.055 to 0.130 µg/ml diet. Among the populations collected across the geography, highest MIC_{50} value of 0.012 µg/ml diet was reported in Raichur and the lowest value of 0.003 µg/ml diet was reported in Aduturai. Among the Karnataka populations, Bijapur showed lowest MIC_{50} value of 0.009 µg/ml diet followed by MIC_{50} values of Dharwad (0.010 µg/ml diet) and Bangalore (0.011 µg/ml diet). In case of Andhra Pradesh populations, the highest MIC_{50} value of (0.008 µg/ml diet) was reported in Vijaywada followed by Hyderabad (0.006 µg/ml diet) and West Godavari (0.004 µg/ml diet). Among populations of TamilNadu highest MIC_{50} value of 0.007 µg/ml diet was reported in Coimbatore followed by Chennai (0.005 µg/ml diet) .Kolhapur showed maximum MIC_{50} value of 0.009 µg/ml diet followed by Dapoli (0.007 µg/ml diet) and Parbhani (0.005 µg/ml diet). Margoa population showed the MIC_{50} value of 0.004 µg/ml diet .The Highest MIC_{95} value of 0.130 µg/ml diet was observed in Raichur and lowest MIC_{95} value of 0.032 µg/ml diet was noticed in Aduturai (Table 13).

4.2.3 Baseline susceptibility in SFB populations of South India to different insecticides

Log probit assay was carried out for rynaxypyr, flubendiamide, emamectin benzoate, spinosad, indoxacarb, carbaryl, thiodicarb, monocrotophos, quinalphos, chlorpyriphos, endosulfan and cypermethrin across 14 different geographic populations of *L. orbonalis* representing south Indian brinjal ecosystems. The assay was carried out on third instar larvae weighing 2.0-.3.0 mg. The results are presented in (Table 14-39) insecticide wise for the year 2009-10 and 2010-11. The resistance factors have been worked out by comparing the LC_{50} value of susceptible field strain. Among twelve insecticides, highest level of resistance development was noticed against endosulfan.

4.2.3.1 Rynaxypyr

The data on the LC_{50} values of rynaxypyr to fourteen different geographic populations of *L. orbonalis* for the two years are presented in the (Table14). The results indicate that there was no much difference in LC_{50} values among the different populations. During 2009-10, the LC_{50} values across the different geographic locations varied from 1.65 to 2.15 ppm. Among the populations, Raichur population recorded a maximum LC_{50} value of 2.15 ppm followed by the population from Hyderabad (2.10 ppm), Bangalore (2.05 ppm), Kolhapur (1.97ppm), and Bijapur (1.93 ppm). Lowest LC_{50} value was observed in population from Margoa (1.65ppm), followed by Chennai (1.69 ppm), Coimbatore (1.71ppm),West Godavari(1.72 ppm) and Aduthurai 1.75 ppm. The fruit and shoot borer from Raichur district had high degree of resistance (1.30 folds) followed by Hyderabad (1.27 folds), Bangalore (1.24 folds), Kolhapur (1.19 folds), Bijapur (1.17 folds) and Dapoli (1.14 folds) over Margoa strain. The least resistance ratio was observed in the population of Chennai (1.02 folds), followed by Coimbatore (1.04 folds) and West Godavari (1.04 folds) and Aduthurai (1.06 folds) (Table 14). *L. orbonalis* populations of other geographical areas such as Vijaywada, Parbhani and Dharwad developed resistance in the range of 1.08 to 1.12 folds to rynaxypyr. The highest LC_{95} value of 13.60 ppm was recorded in Raichur population whereas lowest LC_{95} value of 7.12 ppm in Chennai population (Table 14).Similar trend was noticed during the year, 2010-11.The population of Raichur recorded maximum LC_{50} value of 2.30 ppm to rynaxypyr followed by the population from Bangalore (2.18 ppm), Hyderabad (2.17 ppm), Kolhapur (2.10 ppm) and Bijapur (2.05 ppm). Lowest LC_{50} value was observed in population from Margoa (1.70 ppm) followed by Chennai (1.77 ppm), Parbhani (1.80 ppm) and West Godavari (1.82 ppm). Accordingly highest degree of resistance (1.35 folds) against susceptible field strain was recorded in Raichur followed by Hyderabad (1.28 folds), Bangalore (1.28 folds), Kolhapur (1.24 folds) and Bijapur (1.21 folds). The least resistance ratio was observed in the population of Chennai (1.04 folds) followed by West Godavari (1.06 folds), Coimbatore (1.06 folds) and Aduthurai (1.08 folds). Resistance levels *viz.,* Vijaywada, Parbhani, Dharwad and Dapoli varied between 1.11 to 1.19 folds. Similarly, highest LC_{95} value of 21.44ppm was recorded in Kolhapur population and lowest LC_{95} value of 7.16 ppm was recorded in Margoa (Table 15).

4.2.3.2 Emamectin benzoate

The LC_{50} values of emamectin benzoate differed strikingly among the fourteen geographic populations of *L. orbonalis*. A comparative analysis of LC_{50} values (Table 16) revealed that, Bangalore population recorded a maximum LC_{50} value to emamectin benzoate (4.20 ppm) followed by population from Hyderabad (4.11 ppm), Raichur (3.98 ppm), Bijapur (3.72 ppm), Kolhapur (3.53 ppm), Dharwad (3.48 ppm) and Dapoli (3.45 ppm) during 2009-10. Lowest LC_{50} value was observed in population from Margoa (2.15 ppm) followed by Chennai (2.34 ppm), Coimbatore (2.62 ppm), Aduthurai (2.81 ppm), Vijaywada (2.96 ppm), West Godavari (3.18 ppm) and Parbhani (3.30ppm). The resistance ratio (RR) at LC_{50} calculated against susceptible field strain (Margoa) to measure the level of resistance development was found to be highest for population of Bangalore (1.95 folds) followed by Hyderabad (1.91 folds), Raichur (1.85 folds), Bijapur (1.73 folds) Kolhapur (1.64 folds) and Dharwad (1.62 folds). Least resistance ratio was observed in the population of Chennai (1.09 folds) and Coimbatore (1.22 folds) (Table 16). *L. orbonalis* population of Aduthurai, Vijaywada, West Godavari, Parbhani and Dapoli developed resistance in the range of 1.31 to 1.60 folds. The results also revealed that, the value of LC_{95} ranged from 35.80 to 14.20 ppm. The highest LC_{95} value of 35.80 ppm was recorded in the population of Bangalore and lowest value of 14.20 ppm was recorded from Margoa population. During the year 2010-11 also, Bangalore population registered a maximum LC_{50} value to emamectin benzoate (4.41 ppm) followed by Hyderabad (4.28 ppm), Raichur (4.22 ppm), Bijapur (3.88 ppm) and Kolhapur (3.67 ppm), Dharwad (3.64 ppm) and Dapoli (3.58 ppm). Lowest LC_{50} value was observed in population from Margoa (2.24 ppm) followed by Chennai (2.44 ppm), Aduthurai (2.73 ppm) and Coimbatore (2.91 ppm) and Vijaywada (3.15 ppm). The computed resistance ratio at LC_{50} in comparison with susceptible field strain was highest for population of Bangalore (1.97 folds) followed by Hyderbad (1.91 folds), Raichur (1.88 folds), Bijapur (1.73 folds) and Dharwad (1.63 folds). The least resistance ratio was observed in the population of Chennai (1.09 folds) followed by Coimbatore (1.22 folds), Aduthurai (1.30 folds) and Vijayawada (1.41 folds). *Leucinodes orbonalis* population from West Godavari, Parbhani, Dapoli and Kolhapur developed resistance to emamectin benzoate in the range of 1.48 to 1.64 folds. The value of LC_{95} ranged from 39.16 ppm to 13.93. Maximum LC_{95} value was recorded from population of Bangalore (39.16 ppm) and lowest LC_{95}value of 13.93 ppm was observed in Margoa Population (Table 17).

4.2.3.2 Flubendiamide

The data on the LC_{50} values and resistance levels to flubendiamide in fourteen geographic populations of *L. orbonalis* in comparison with susceptible filed strain are presented in the (Table 18). The results indicated that there has been marked difference in LC_{50} values among the different populations to flubendiamide. A comparison of LC_{50} values during the year 2009-10 revealed that the Raichur population required highest quantity of insecticides to induce desired effect (50% kill) (2.80 ppm) followed by population from Bangalore (2.74 ppm), Hyderabad (2.70 ppm), Kolhapur (2.65 ppm), Bijapur (2.62 ppm) and Dapoli (2.61 ppm). Lowest LC_{50} value was observed in population from Margoa (2.10 ppm) and it has been considered as susceptible strain .It was followed by Chennai (2.18 ppm), Coimbatore (2.24 ppm), Aduthurai (2.32 ppm), Vijayawada (2.40 ppm) and West Godavari (2.45 ppm). The resistance ratio (RR) against susceptible field strain was found to be highest for population of Raichur (1.33 folds) followed by Bangalore (1.30 folds), Hyderabad (1.29 folds) and Kolhapur (1.26 folds). The least resistance ratio was observed in the population of Chennai (1.04 folds) followed by Coimbatore (1.07 folds) and Aduthurai (1.10 folds). *L. orbonalis* population of other geographic areas in the South Indian sub-continent such as Vijaywada, West Godavari, Dharwad, Parbhani, Dapoli and Bijapur developed resistance in the range of 1.14 to 1.25 folds. The data on LC_{95} revealed that, the values ranged from 11.02 to 26.14 ppm. Highest LC_{95} was reported in Bijapur (26.14 ppm) and the lowest was recorded in population of Coimbatore (11.02 ppm).Whereas, the results of 2010-11, revealed a maximum LC_{50} value of 2.94 ppm to flubendiamide in Raichur population followed by population from Bangalore (2.88 ppm), Hyderabad (2.84 ppm) and Kolhapur (2.76 ppm). Lowest LC_{50} value was observed in population from Margoa (2.14 ppm) followed by Chennai (2.28 ppm), Coimbatore (2.35 ppm), Aduthurai (2.42 ppm) and Vijaywada (2.51 ppm). Results revealed that, the LC_{95} values across the population ranged from 10.19 to 28.20 ppm. Maximum LC_{95} of 28.20 ppm was recorded from the population of Bijapur and lowest LC_{95} value of 10.19 ppm was reported in Aduthurai population. The resistance ratio (RR) against susceptible field strain at LC_{50} was found to be highest for population of Raichur (1.37 folds) followed by Bangalore (1.35 folds), Hyderabad (1.33 folds) and Kolhapur (1.29 folds). The least resistance ratio was observed in the population of Chennai (1.07 folds) followed by Coimbatore (1.10 folds) and Aduthurai (1.13 folds). Remaining locations like Vijaywada, West Godavari, Dharwad, Parbhani and Dapoli registered 1.17 to 1.27 folds of resistance (Table 19).

4.2.3.4 Spinosad

LC_{50} values obtained for spinosad among fourteen geographic populations of *L. orbonalis* are presented in (Table 20). The toxicity of spinosad varied among different strains. The relative toxicity of spinosad in comparison with susceptible field strain (Margoa) revealed that, in the year 2009-10, the Raichur population registered highest LC_{50} value (2.77 ppm) followed by Bangalore population (2.73 ppm),Hyderabad (2.67 ppm), Bijapur (2.65 ppm) and Kolhapur (2.64 ppm). Whereas, Margoa recorded the least LC_{50} value (2.30 ppm) followed by Chennai (2.36 ppm), Coimbatore (2.42 ppm), Aduthurai (2.48 ppm) and Vijaywada (2.52 ppm). The LC_{95} values across the geographic populations varied from 12.82 to 29.14 ppm. Maximum value of 29.14 ppm was recorded in Kolhapur population and least value of 12.82 ppm was recorded in Coimbatore population. The resistance development as measured from resistance ratio at LC_{50} value was highest in Raichur population (1.20 folds) followed by Bangalore (1.19 folds), Dharwad (1.13 folds) followed by Kolhapur and Bijapur populations which recorded 1.15 folds as against susceptible population (Table 20). Lowest resistance ratio was recorded by Chennai (1.03 folds) followed by Coimbatore (1.05 folds) and Aduthurai (1.08 folds). Populations from Vijayawada, Dharwad, West Godavari and Dapoli developed resistance in the range of 1.10 to 1.12 folds. During 2010-11, maximum resistance to spinosad was observed in Raichur population (2.93 ppm) followed by population from Bangalore (2.89 ppm), Hyderabad (2.85 ppm) followed by populations of Bijapur and Kolhapur (2.78 ppm). The least LC_{50} value was noticed in Margoa (2.42 ppm) followed by Chennai (2.44 ppm), Coimbatore (2.50 ppm), Aduthurai (2.55 ppm) and Vijaywada (2.66 ppm). The LC_{95} values ranged from 12.93 to 23.76 ppm. Maximum LC_{95} value of 23.76 was registered in Raichur population and least was recorded in Chennai (12.93 ppm). The resistance development as measured from resistance ratio at LC_{50} value was highest in Raichur population (1.21 folds) followed by Bangalore (1.19 folds), Hyderabad (1.18 folds) followed by Bijapur and Kolhapur (1.15 folds) as against susceptible field population. Whereas, lowest ratio was recorded by Chennai (1.01 folds) followed by Coimbatore (1.03 folds), Aduthurai (1.05 folds) and Vijaywada (1.10 folds) populations (Table 21).

4.2.3.5 Indoxacarb

During the year 2009-10, maximum LC_{50} value to indoxacarb was recorded in Raichur population (4.80 ppm) followed by Bangalore (4.72 ppm), Hyderabad (4.61 ppm), Kolhapur (4.52 ppm), Bijapur (4.45 ppm) and West Godavari (4.40ppm) .Minimum LC_{50} was observed in Margoa population (3.20 ppm) followed by Chennai (3.32 ppm), Coimbatore (3.45 ppm) and Aduthurai (3.61 ppm). The LC_{95} values ranged from 20.68 to 40.27 ppm. Highest LC_{95} was recorded in Bangalore (40.27) and the lowest LC_{95} value of 20.68 in Margoa population. The resistance ratio against susceptible Margoa strain was found to be highest for population of Raichur (1.50 folds) followed by Bangalore (1.48 folds), Hyderabad (1.44 folds) and Kolhapur (1.41 folds). Least resistance ratio was recorded in population from Chennai (1.04 folds) followed by Coimbatore (1.08 folds) and Aduthurai (1.13 folds). *L. orbonalis* population from Parbhani, Dapoli, Vijaywada, Dharwad, West godavari and Bijapur developed resistance in the range of 1.17 to 1.39 (Table 22). For the year 2010-11 also maximum LC_{50} value to indoxacarb was recorded in Raichur (4.97 ppm) followed by Bangalore (4.88 ppm), Hyderabad (4.72 ppm), Kolhapur (4.62 ppm), Bijapur (4.60 ppm) and West Godavari(4.50ppm).Minimum resistance was observed in Margoa (3.28 ppm) followed by Chennai (3.41 ppm), Coimbatore (3.58 ppm), Aduthurai (3,74 ppm) and Parbhani (3.87 ppm). In case of LC_{95}, Bangalore population recorded the highest value of 43.33 ppm and lowest LC_{95} value of 20.05 ppm was recorded in Chennai population. The resistance ratio against susceptible field strain was found to be highest for Raichur (1.52 folds) followed by Bangalore (1.49 folds), Hyderabad (1.44 folds), Kolhapur (1.41 folds), Bijapur (1.40 folds) (Table 23) and lowest ratio were recorded in Chennai (1.04 folds). A resistance level in the range of 1.04 to 1.37 was noticed in the remaining districts of Chennai, Coimbatore, Aduthurai, Dapoli, Vijaywada, West Godavari and Dharwad (Table 23).

4.2.3.6 Cypermethrin

The data on the LC_{50} values obtained to cypermethrin for fourteen different geographical populations of *L. orbonalis* for the two years are presented in (Table 24). The toxicity of cypermethrin varied among different populations. During the year 2009-10, Raichur population recorded a maximum LC_{50} value to cypermethrin (42.00 ppm) followed by population from Hyderabad (40.30 ppm), Bangalore (39.70 ppm) and Bijapur (38.00 ppm). Lowest LC_{50} value was observed in population from Margoa (35.00 ppm) followed by Chennai (35.10 ppm), Aduthurai (35.40 ppm),Coimbatore (35.80 ppm), Parbhani (35.90 ppm), Dharwad (36.00 ppm) and Dapoli (36.40 ppm). The LC_{95} of Hyderabad (141.62 ppm) was found to be highest and lowest LC_{95} value of 122.74 ppm was recorded in Coimbatore population. The resistance ratio (RR) against susceptible Margoa field strain was found to be highest for population of Raichur (1.20 folds) followed by Hyderabad (1.15 folds), Bangalore (1.13 folds), Kolhapur (1.10 folds) and Bijapur (1.09 folds). The least resistance ratio was observed in the population of Chennai (1.00 folds) followed by Aduthurai (1.01 folds), followed by Dharwad, Parbhani and Coimbatore (1.03 folds). *L. orbonalis* population from the districts of Dapoli, Vijaywada and West Godavari registered resistance ratio in the range of 1.04 to 1.08 folds (Table 24).

Table 12.Moult inhibitory concentration ($MIC_{50,}$ µg mL^{-1} diet) of Cry1Ac to brinjal shoot and fruit borer populations collected from brinjal growing districts of south India during 2009-10

Population	*n*	χ^2	Slope (± SE)	MIC_{50} (95 % CI)	MIC_{95}(95 % CI)
Dharwad, KA	630	9.14	1.27 (± 0.08)	0.011 (0.003-0.016)	0.102 (0.0823-0.1561)
Bijapur, KA	630	7.89	1.17 (± 0.10)	0.007 (0.004-0.009)	0.080 (0.0621-0.1268)
Bangalore, KA	630	8.32	1.21 (± 0.09)	0.010 (0.007-0.012)	0.095 (0.0812-0.4121)
Raichur, KA	630	9.36	1.36 (± 0.12)	0.014 (0.005-0.020)	0.145 (0.0908-0.1612)
West Godavari, AP	630	6.57	1.22 (± 0.06)	0.005 (0.003-0.008)	0.061 (0.0428-0.0891)
Hyderabad, AP	630	7.59	1.14 (± 0.09)	0.007 (0.005-0.010)	0.091 (0.0734-0.1382)
Vijayawada, AP	630	8.67	1.33 (± 0.07)	0.009 (0.005-0.011)	0.098 (0.0759-0.1469)
Chennai, TN	630	4.27	1.15 (± 0.08)	0.005 (0.004-0.007)	0.045 (0.0310-0.0789)
Aduthurai, TN	630	6.24	1.14 (± 0.06)	0.004(0.002-0.006)	0.037 (0.0218-0.0590)
Coimbatore, TN	630	7.28	1.13 (± 0.07)	0.006(0.004-0.007)	0.062 (0.0456-0.0872)
Margoa, Goa	630	5.33	1.06 (± 0.06)	0.003(0.001-0.005)	0.028 (0.0170-0.0428)
Kolhapur, MH	630	8.84	1.31 (± 0.10)	0.012 (0.006-0.025)	0.113 (0.0810-0.1561)
Dapoli, MH	630	7.52	1.12 (± 0.08)	0.008 (0.006-0.010)	0.084 (0.0632-0.1249)
Parbhani,MH	630	6.79	1.08 (± 0.06)	0.004 (0.003-0.006)	0.033 (0.0242-0.0572)

MIC_{50}: concentration of Cry1Ac that inhibited moulting of 50% of test larval population into the second instar in the observation period of 7 days.
MIC_{95}: concentration of Cry1Ac that inhibited moulting of 95% of test population.
KA : Karnataka,AP: Andhra Pradesh,TN: TamilNadu, MH: Maharashtra

Table 13. Moult inhibitory concentration (MIC_{50}, µg mL^{-1} diet) of Cry1Ac to brinjal shoot and fruit borer populations collected from brinjal growing districts of south India during 2010-11

Population	*n*	χ^2	Slope (± SE)	MIC_{50} (95 % CI)	MIC_{95} (95 % CI)
Dharwad, KA	630	9.18	1.19 (± 0.09)	0.010 (0.006-0.012)	0.098 (0.0765-0.1439)
Bijapur, KA	630	8.24	1.15 (± 0.07)	0.009 (0.006-0.010)	0.084 (0.0645-0.1292)
Bangalore, KA	630	9.27	1.28 (± 0.10)	0.011 (0.007-0.016)	0.110 (0.0767-0.1857)
Raichur, KA	630	9.33	1.33 (± 0.09)	0.012 (0.008-0.018)	0.130 (0.0942-0.1672)
West Godavari, AP	630	6.34	1.22 (± 0.06)	0.004 (0.002-0.007)	0.064 (0.0368-0.0721)
Hyderabad, AP	630	7.82	1.18 (± 0.08)	0.006 (0.004-0.009)	0.070 (0.0487-0.1074)
Vijayawada, AP	630	8.29	1.28 (± 0.09)	0.008 (0.006-0.010)	0.090 (0.0721-0.1352)
Chennai, TN	630	5.67	1.12 (± 0.06)	0.005 (0.004-0.008)	0.062 (0.0392-0.912)
Aduthurai, TN	630	6.54	1.16 (± 0.06)	0.003 (0.002-0.005)	0.032 (0.0194-0.0628)
Coimbatore, TN	630	7.28	1.19 (± 0.08)	0.007 (0.004-0.008)	0.084 (0.0608-0.1168)
Margoa, Goa	630	6.23	1.06 (± 0.06)	0.004 (0.002-0.006)	0.055 (0.0327-0.0789)
Kolhapur, MH	630	8.79	1.20 (± 0.10)	0.009 (0.006-0.014)	0.089 (0.0613-0.1240)
Dapoli, MH	630	6.67	1.12 (± 0.06)	0.007 (0.005-0.012)	0.079 (0.0542-0.0971)
Parbhani,MH	630	6.12	1.10 (± 0.07)	0.005 (0.003-0.008)	0.045 (0.0267-0.0632)

MIC_{50}: concentration of Cry1Ac that inhibited moulting of 50% of test larval population into the second instar in the observation period of 7 days.
MIC_{95}: concentration of Cry1Ac that inhibited moulting of 95% of test population.
KA : Karnataka,AP: Andhra Pradesh,TN: TamilNadu, MH: Maharashtra

Table 14. Susceptibility of geographic populations of *Leucinodes orbonalis* to Rynaxypyr during 2009-10

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	8.74	3.03 ± 0.35	2.15	(1.75-2.92)	13.60	(6.52-48.19)	1.30
Bangalore, KA	180	8.40	2.42 ± 0.33	2.05	(1.70-2.60)	11.86	(3.24-49.35)	1.24
Bijapur, KA	180	6.89	1.98 ± 0.31	1.93	(1.32-2.78)	14.72	(4.55-45.86)	1.17
Dharwad, KA	180	7.23	1.87 ± 0.25	1.85	(1.43-2.50)	9.72	(7.63-35.72)	1.12
Parbhani,MH	180	5.48	1.54 ± 0.27	1.82	(1.41-2.54)	10.21	(2.01-49.28)	1.10
Dapoli, MH	180	6.31	1.83 ± 0.30	1.88	(1.68-2.60)	15.35	(4.25-65.11)	1.14
Kolhapur, MH	180	7.87	2.01 ± 0.32	1.97	(1.64-2.82)	18.46	(5.42-54.66)	1.19
Chennai, TN	180	2.85	1.24 ± 0.18	1.69	(1.38-2.12)	7.12	(5.89-36.37)	1.02
Coimbatore, TN	180	3.91	1.30 ± 0.20	1.71	(1.35-2.27)	9.23	(7.26-37.43)	1.04
Aduthurai, TN	180	4.77	1.43 ± 0.21	1.75	(1.52-2.38)	10.64	(4.26-45.31)	1.06
Hyderabad, AP	180	8.53	2.79 ± 0.34	2.10	(1.68-2.77)	11.27	(2.41-51.63)	1.27
Vijayawada, AP	180	4.32	1.49 ± 0.24	1.78	(1.37-2.63)	11.47	(4.73-66.45)	1.08
West Godavari, AP	180	3.25	1.29 ± 0.31	1.72	(1.26-2.18)	9.34	(7.32-38.16)	1.04
Margoa, Goa	180	2.20	1.09 ± 0.13	1.65	(1.25-2.28)	8.15	(6.78-38.43)	---

* RR : Resistance ratio

Table 15. Susceptibility of geographic populations of *Leucinodes orbonalis* to Rynaxypyr 20SC during 2010-11

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	9.58	2.41 ± 0.24	2.30	(1.85-3.12)	15.97	(7.15-40.12)	1.35
Bangalore, KA	180	8.84	2.32 ± 0.15	2.18	(1.75-2.88)	13.08	(6.19-38.23)	1.28
Bijapur, KA	180	9.29	2.07 ± 0.20	2.05	(1.83-2.45)	18.66	(9.96-53.71)	1.21
Dharwad, KA	180	7.88	2.01 ± 0.36	1.97	(1.47-2.57)	8.29	(5.55-34.95)	1.16
Parbhani,MH	180	6.47	1.21 ± 0.13	1.80	(1.43-2.80)	9.38	(7.22-36.78)	1.14
Dapoli, MH	180	8.35	1.97± 0.21	2.03	(1.75-2.78)	17.15	(7.75-47.32)	1.19
Kolhapur, MH	180	8.99	2.11 ± 0.31	2.10	(1.65-2.93)	21.44	(10.51-57.83)	1.24
Chennai, TN	180	3.66	1.18 ± 0.11	1.77	(1.25-2.50)	7.79	(5.65-35.27)	1.04
Coimbatore, TN	180	7.30	1.78 ± 0.18	1.93	(1.35-2.53)	8.13	(6.95-36.85)	1.06
Aduthurai, TN	180	4.35	1.43 ± 0.17	1.84	(1.45-2.59)	11.43	(5.41-61.86)	1.08
Hyderabad, AP	180	6.13	1.83 ±0.27	2.17	(1.85-2.97)	12.85	(6.78-48.25)	1.28
Vijayawada, AP	180	5.70	1.72 ± 0.12	1.88	(1.53-2.70)	10.98	(4.55-65.12)	1.11
West Godavari, AP	180	3.78	1.32 ± 0.15	1.82	(1.50-2.45)	10.17	(3.69-34.26)	1.06
Margoa, Goa	180	2.48	1.09 ± 0.23	1.70	(1.22-2.56)	7.16	(5.25-25.86)	--

* RR : Resistance ratio

Table 16.Susceptibility of geographic populations of *Leucinodes orbonalis* to Emamectin benzoate during 2009-10

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.44	2. 83± 0.30	3.98	(3.43-4.62)	34.10	(18.31-89.53)	1.85
Bangalore, KA	180	7.84	2.75 ± 0.25	4.20	(3.95-5.12)	35.80	(21.86-78.63)	1.95
Bijapur, KA	180	6.91	2.37 ± 0.27	3.72	(3.22-4.35)	27.48	(11.28-70.43)	1.73
Dharwad, KA	180	6.32	1.83 ± 0.21	3.48	(3.18-4.28)	26.21	(14.27-64.40)	1.62
Parbhani,MH	180	5.27	1.64 ± 0.20	3.30	(2.87-4.10)	24.02	(11.34-59.70)	1.53
Dapoli, MH	180	5.64	1.76 ± 0.22	3.45	(2.95-4.31)	26.71	(13.78-76.27)	1.60
Kolhapur, MH	180	6.78	2.21 ± 0.18	3.53	(3.15-4.35)	28.25	(10.51-65.86)	1.64
Chennai, TN	180	2.76	1.24 ± 0.14	2.34	(1.98-3.14)	17.62	(5.29-72.45)	1.09
Coimbatore, TN	180	3.12	1.19 ± 0.17	2.62	(2.16-3.37)	16.20	(7.13-54.26)	1.22
Aduthurai, TN	180	3.67	1.34 ± 0.14	2.81	(2.27-3.60)	21.57	(9.34-61.83)	1.31
Hyderabad, AP	180	7.19	2.61 ± 0.23	4.11	(3.79-4.78)	28.91	(14.19-60.63)	1.91
Vijayawada, AP	180	4.16	1.43 ± 0.15	2.96	(2.46-3.81)	23.41	(10.34-69.39)	1.38
West Godavari, AP	180	4.93	1.59 ± 0.19	3.18	(2.88-3.97)	18.64	(4.37-58.30)	1.48
Margoa, Goa	180	2.34	1.17 ± 0.12	2.15	(1.75-2.95)	14.20	(5.26-64.55)	---

* RR : Resistance ratio

Table 17.Susceptibility of geographic populations of *Leucinodes orbonalis* to Emmamectin benzoate during 2010-11

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.18	2.81 ± 0.24	4.22	(3.82-5.02)	33.93	(17.34-68.28)	1.88
Bangalore, KA	180	7.13	3.04 ± 0.17	4.41	(4.05-5.20)	39.16	(23.23-79.26)	1.97
Bijapur, KA	180	6.75	2.73 ± 0.30	3.88	(3.08-4.63)	29.41	(15.26-69.38)	1.73
Dharwad, KA	180	6.33	2.91 ± 0.22	3.64	(3.14-4.35)	28.83	(14.28-66.74)	1.63
Parbhani,MH	180	5.62	2.45 ± 0.22	3.46	(3.16-4.27)	25.53	(18.47-61.85)	1.54
Dapoli, MH	180	5.13	2.50 ± 0.23	3.58	(3.13-4.39)	26.78	(15.47-76.85)	1.60
Kolhapur, MH	180	5.78	2.66 ± 0.20	3.67	(3.17-4.53)	22.68	(13.23-59.25)	1.64
Chennai, TN	180	3.37	1.17 ± 0.14	2.44	(2.04-3.30)	17.10	(6.52-54.25)	1.09
Coimbatore, TN	180	3.31	1.31 ± 0.15	2.91	(2.23-3.45)	21.18	(11.79-57.96)	1.22
Aduthurai, TN	180	4.17	1.49 ± 0.18	2.73	(2.46-3.62)	19.38	(33.59-57.63)	1.30
Hyderabad, AP	180	7.45	2.95 ± 0.21	4.28	(3.81-5.03)	35.05	(21.47-75.16)	1.91
Vijayawada, AP	180	4.39	1.88 ± 0.19	3.15	(2.74-4.05)	22.43	(10.34-58.84)	1.41
West Godavari, AP	180	5.34	2.22 ± 0.16	3.31	(2.91-4.17)	25.65	(16.55-80.39)	1.48
Margoa, Goa	180	2.76	1.08 ± 0.10	2.24	(1.82-2.99)	13.93	(7..39-52.96)	---

* RR : Resistance ratio

Table 18. Susceptibility of geographic populations of *Leucinodes orbonalis* to Flubendiamide 480SC during 2009-10

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	8.19	3.05 ± 0.33	2.80	(2.44-3.70)	22.32	(9.56-57.93)	1.33
Bangalore, KA	180	8.24	2.97 ± 0.32	2.74	(2.32-3.57)	18.10	(5.31-53.14)	1.30
Bijapur, KA	180	6.65	2.24 ± 0.31	2.62	(2.24-3.45)	26.14	(12.23-62.34)	1.25
Dharwad, KA	180	6.01	1. 43 ± 0.27	2.52	(2.17-3.16)	15.78	(4.79-42.33)	1.20
Parbhani,MH	180	5.83	1.39 ± 0.26	2.58	(2.12-3.23)	23.08	(8.11-61.25)	1.23
Dapoli, MH	180	7.36	1.94 ± 0.30	2.61	(2.23-3.10)	15.10	(6.05-48.12)	1.24
Kolhapur, MH	180	7.88	2.21 ± 0.29	2.65	(2.26-3.15)	23.22	(7.86-63.47)	1.26
Chennai, TN	180	2.86	1.10 ± 0.15	2.18	(1.68-2.71)	13.16	(4.57-49.31)	1.04
Coimbatore, TN	180	3.19	1.24 ± 0.17	2.24	(1.80-2.86)	11.02	(4.71-61.53)	1.07
Aduthurai, TN	180	4.01	1.31 ± 0.19	2.32	(1.98-3.10)	12.80	(3.48-51.99)	1.10
Hyderabad, AP	180	7.93	2.91 ± 0.32	2.70	(2.17-3.37)	21.13	(9.50-56.39)	1.29
Vijayawada, AP	180	4.59	1.38 ± 0.21	2.40	(2.12-3.37)	15.72	(5.13-53.27)	1.14
West Godavari, AP	180	5.34	2.01 ± 0.21	2.45	(2.07-3.47)	21.87	(7.91-59.38)	1.17
Margoa, Goa	180	2.21	1.09 ± 0.13	2.10	(1.91-3.17)	13.57	(6.78-49.63)	---

*RR-Resistance Ratio

Table 19. Susceptibility of geographic populations of *Leucinodes orbonalis* to Flubendiamide 480SC during 2010-11

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	8.10	3.04 ± 0.36	2.94	(2.42-3.64)	24.14	(11.36-79.32)	1.37
Bangalore, KA	180	7.73	2.55 ± 0.35	2.88	(2.47-3.67)	20.76	(7.56-56.84)	1.35
Bijapur, KA	180	6.40	2.01 ± 0.34	2.73	(2.35-3.45)	28.20	(12.31-68.15)	1.28
Dharwad, KA	180	4.01	1.37 ± 0.29	2.61	(2.30-3.31)	18.82	(14.75-50.25)	1.22
Parbhani,MH	180	4.24	1.35 ± 0.29	2.69	(2.19-3.40)	21.20	(10.23-56.86)	1.26
Dapoli, MH	180	5.48	1.40 ± 0.31	2.72	(2.35-3.52)	16.89	(7.85-45.62)	1.27
Kolhapur, MH	180	5.99	2.03 ± 0.32	2.76	(2.27-3.65)	25.42	(11.41-60.31)	1.29
Chennai, TN	180	2.57	1.19 ± 0.13	2.28	(1.85-3.02)	11.08	(3.12-36.56)	1.07
Coimbatore, TN	180	2.91	1.15 ± 0.17	2.35	(2.02-3.05)	12.24	(4.51-47.46)	1.10
Aduthurai, TN	180	3.33	1.23 ± 0.21	2.42	(2.05-3.13)	10.19	(3.18-46.29)	1.13
Hyderabad, AP	180	6.91	2.96 ± 0.36	2.84	(2.35-3.62)	23.32	(9.15-62.89)	1.33
Vijayawada, AP	180	3.22	1.27 ± 0.24	2.51	(2.21-3.21)	17.49	(6.78-57.26)	1.17
West Godavari, AP	180	3.93	1.30 ± 0.26	2.57	(2.07-2.67)	23.67	(9.96-48.31)	1.20
Margoa, Goa	180	2.16	1.08 ± 0.10	2.14	(1.74-3.04)	14.70	(7.96-50.26)	--

* RR : Resistance ratio

Table 20. Susceptibility of geographic populations of *Leucinodes orbonalis* to Spinosad 45 SC during 2009-10

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.52	3.01 ± 0.35	2.77	(2.33-3.37)	20.48	(7.20-60.23)	1.20
Bangalore, KA	180	7.36	2.93 ± 0.33	2.73	(1.98-4.56)	19.62	(6.49-56.28)	1.19
Bijapur, KA	180	6.89	2.49 ± 0.31	2.65	(2.05-3.50)	23.17	(9.85-59.16)	1.15
Dharwad, KA	180	5.52	1.83 ± 0.27	2.60	(1.87-2.50)	16.29	(5.26-66.23)	1.13
Parbhani,MH	180	4.73	1.53 ± 0.22	2.56	(2.10-3.36)	18.54	(6.28-54.79)	1.11
Dapoli, MH	180	4.65	1.77 ± 0.26	2.58	(2.08-3.41)	25.42	(9.37-70.12)	1.12
Kolhapur, MH	180	6.27	2.09 ± 0.29	2.64	(2.34-3.37)	29.14	(14.76-81.33)	1.15
Chennai, TN	180	2.86	1.19 ± 0.14	2.36	(1.89-3.30)	14.31	(6.31-49.16)	1.03
Coimbatore, TN	180	2.85	1.35 ± 0.19	2.42	(2.12-3.43)	12.82	(5.37-67.25)	1.05
Aduthurai, TN	180	3.17	1.24 ± 0.21	2.48	(2.05-3.10)	15.44	(4.29-56.44)	1.08
Hyderabad, AP	180	5.84	2.86 ± 0.30	2.67	(1.93-3.51)	17.62	(5.88-63.64)	1.16
Vijayawada, AP	180	3.41	1.41 ± 0.22	2.52	(2.15-3.23)	13.21	(4.16-59.43)	1.10
West Godavari, AP	180	4.61	1.61 ± 0.24	2.57	(2.12-3.40)	19.47	(6.37-55.93)	1.12
Margoa, Goa	180	2.13	1.16 ± 0.10	2.30	(1.98-3.15)	15.54	(3.43-70.29)	---

* RR : Resistance ratio

Table 21. Susceptibility of geographic populations of *Leucinodes orbonalis* to Spinosad 45 SC during 2010-11

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.88	3.05 ± 0.35	2.93	(2.44-3.75)	23.76	(11.26-55.34)	1.21
Bangalore, KA	180	7.57	2.98 ± 0.33	2.89	(2.50-3.61)	21.21	(12.56-71.89)	1.19
Bijapur, KA	180	6.29	2.57 ± 0.28	2.78	(2.39-3.59)	21.74	(8.86-56.36)	1.15
Dharwad, KA	180	5.33	2.35 ± 0.29	2.72	(2.35-3.55)	17.33	(5.25-46.18)	1.12
Parbhani,MH	180	3.94	1.81 ± 0.22	2.68	(2.33-3.45)	21.04	(10.34-59.46)	1.11
Dapoli, MH	180	4.12	2.29 ± 0.27	2.71	(2.22-3.56)	26.69	(13.93-61.89)	1.12
Kolhapur, MH	180	5.06	2.93 ± 0.31	2.78	(2.29-3.59)	32.94	(18.19-78.63)	1.15
Chennai, TN	180	3.01	1.29 ± 0.16	2.44	(2.04-3.24)	12.93	(5.46-42.36)	1.01
Coimbatore, TN	180	3.94	1.34 ± 0.20	2.50	(2.06-3.31)	14.13	(3.29-47.65)	1.03
Aduthurai, TN	180	3.67	1.53 ± 0.19	2.55	(2.02-3.35)	14.92	(5.86-51.55)	1.05
Hyderabad, AP	180	7.16	3.01 ± 0.34	2.85	(2.35-3.65)	20.66	(7.26-59.37)	1.18
Vijayawada, AP	180	4.01	1.97 ± 0.21	2.66	(2.17-3.41)	15.83	(2.56-70.33)	1.10
West Godavari, AP	180	4.78	2.10 ± 0.25	2.70	(2.35-3.45)	17.15	(6.89-53.26)	1.12
Margoa, Goa	180	2.22	1.21 ± 0.13	2.42	(2.01-3.23)	16.58	(5.86-52.16)	---

* RR : Resistance ratio

Table 22.Susceptibility of geographic populations of *Leucinodes orbonalis* to Indoxacarb 14.8SC during 2009-10

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.69	3.04 ± 0.34	4.80	(4.32-5.60)	36.14	(18.63-75.36)	1.50
Bangalore, KA	180	7.36	3.01 ± 0.33	4.72	(4.49-5.52)	40.27	(25.46-80.11)	1.48
Bijapur, KA	180	5.52	2.89 ± 0.30	4.45	(4.05-5.15)	28.40	(14.26-64.85)	1.39
Dharwad, KA	180	5.23	2.39 ± 0.25	4.36	(3.82-5.06)	31.57	(16.14-36.43)	1.36
Parbhani,MH	180	3.97	2.10 ± 0.22	3.75	(3.15-4.15)	25.37	(12.37-62.86)	1.17
Dapoli, MH	180	4.35	1.94 ± 0.24	3.88	(3.48-4.70)	29.41	(17.51-69.34)	1.21
Kolhapur, MH	180	6.37	2.66± 0.30	4.52	(4.12-5.22)	31.14	(17.26-79.77)	1.41
Chennai, TN	180	2.71	1.23± 0.15	3.32	(2.90-4.02)	23.17	(10.92-38.69)	1.04
Coimbatore, TN	180	2.69	1.47 ± 0.17	3.45	(3.05-4.26)	23.62	(5.34-61.30)	1.08
Aduthurai, TN	180	3.24	1.82 ± 0.19	3.61	(3.20-4.50)	28.24	(15.93-67.37)	1.13
Hyderabad, AP	180	6.81	2.91 ± 0.32	4.61	(4.19-5.41)	38.28	(23.15-82.55)	1.44
Vijayawada, AP	180	4.98	2.24 ± 0.26	4.30	(4.02-5.10)	33.42	(18.63-64.51)	1.34
West Godavari, AP	180	5.76	2.47 ± 0.28	4.40	(3.95-4.89)	35.12	(19.40-61.17)	1.38
Margoa, Goa	180	2.14	1.05 ± 0.10	3.20	(2.70-3.90)	20.68	(6.29-48.27)	---

* RR : Resistance ratio

Table 23. Susceptibility of geographic populations of *Leucinodes orbonalis* to Indoxacarb 14.8 SC during 2010-11

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.83	3.04 ± 0.35	4.97	(4.61-5.72)	39.16	(21.12-74.69)	1.52
Bangalore, KA	180	7.57	2.99 ± 0.33	4.88	(4.47-5.59)	43.33	(28.16-83.16)	1.49
Bijapur, KA	180	6.99	2.73 ± 0.31	4.60	(4.10-5.51)	31.65	(17.59-56.29)	1.40
Dharwad, KA	180	5.49	1.94 ± 0.26	4.48	(4.18-5.22)	27.19	(13.52-77.63)	1.37
Parbhani,MH	180	4.28	1..61 ± 0.21	3.87	(3.51-4.57)	23.92	(10.23-62.35)	1.18
Dapoli, MH	180	4.95	1.87 ± 0.21	4.21	(3.65-4.85)	20.77	(7.26-75.36)	1.22
Kolhapur, MH	180	7.37	2.86 ± 0.29	4.62	(4.15-5.31)	40.29	(27.58-55.23)	1.41
Chennai, TN	180	2.47	1.34 ± 0.16	3.41	(3.25-4.23)	20.05	(9.26-60.35)	1.04
Coimbatore, TN	180	3.73	1.53 ± 0.19	3.58	(3.12-4.33)	26.06	(12.29-62.16)	1.09
Aduthurai, TN	180	4.09	1.43 ± 0.15	3.74	(3.24-4.59)	21.32	(7.16-58.65)	1.14
Hyderabad, AP	180	7.19	2.86 ± 0.28	4.72	(4.42-5.36)	37.62	(29.15-77.89)	1.44
Vijayawada, AP	180	5.21	1.83 ± 0.27	4.42	(4.19-5.17)	31.47	(17.55-66.28)	1.35
West Godavari, AP	180	6.37	2.15 ± 0.30	4.50	(3.99-5.43)	41.18	(28.36-81.35)	1.37
Margoa, Goa	180	2.39	1.09 ± 0.12	3.28	(3.15-3.62)	26.73	(19.86-76.28)	---

* RR : Resistance ratio

Table 24. Susceptibility of geographic populations of *Leucinodes orbonalis* to Cypermethrin 25 EC during 2009-10

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	8.16	2.19 ± 0.24	42.00	(23.15-117.21)	141.36	(82.16-242.99)	1.20
Bangalore, KA	180	7.58	1.84 ± 0.17	39.70	(20.53-128.14)	137.42	(67.49-242.52)	1.13
Bijapur, KA	180	6.47	2.05 ± 0.21	38.00	(17.86-108.20)	130.64	(65.91-250.67)	1.09
Dharwad, KA	180	7.37	2.11 ± 0.18	36.00	(15.45-115.23)	126.33	(66.89-233.47)	1.03
Parbhani,MH	180	7.81	2.24 ± 0.14	35.90	(14.10-122.00)	133.14	(76.13-242.19)	1.03
Dapoli, MH	180	5.57	1.67± 0.11	36.40	(19.81-121.22)	136.92	(56.37-251.63)	1.04
Kolhapur, MH	180	7.68	1.77 ± 0.10	38.50	(20.60-118.90)	140.37	(75.34-247.01)	1.10
Chennai, TN	180	5.51	1.51 ± 0.26	35.10	(17.92-111.82)	135.63	(75.89-254.30)	1.00
Coimbatore, TN	180	4.81	1..36 ± 0.31	35.80	(19.63-123.50)	122.74	(50.71-227.43)	1.03
Aduthurai, TN	180	5.25	1.57 ± 0.21	35.40	(16.84-115.85)	137.80	(81.63-252.71)	1.01
Hyderabad, AP	180	3.88	1.22 ±0.24	40.30	(25.00-126.00)	146.51	(72.31-263.78)	1.15
Vijayawada, AP	180	4.51	1.33 ± 0.29	37.00	(24.00-119.50)	135.30	(96.87-254.52)	1.06
West Godavari, AP	180	5.71	1.46 ± 0.12	37.80	(21.99-112.20)	141.62	(71.63-257.69)	1.08
Margoa, Goa	180	3.68	1.14 ± 0.26	35.00	(15.10-120.56)	132.54	(89.51-237.44)	---

* RR : Resistance ratio

Table 25.Susceptibility of geographic populations of *Leucinodes orbonalis* to Cypermethrin 25 EC during 2010-11

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.10	2.27 ± 0.14	56.30	(21.52-135.55)	226.33	(164.84-345.99)	1.28
Bangalore, KA	180	7.88	2.50 ± 0.23	52.42	(27.14-125.34)	171.94	(140.26-294.61)	1.19
Bijapur, KA	180	5.57	2.25 ± 0.17	47.82	(30.99-129.25)	156.85	(94.22-261.55)	1.09
Dharwad, KA	180	8.14	2.32 ± 0.21	44.07	(24.89-134.17)	134.41	(106.26-250.57)	---
Parbhani,MH	180	7.17	2.34 ± 0.24	48.32	(20.21-128.94)	172.99	(97.93-289.55)	1.10
Dapoli, MH	180	6.35	1.56± 0.21	45.19	(29.47-130.10)	155.91	(95.11-235.16)	1.03
Kolhapur, MH	180	7.11	2.10 ± 0.11	47.23	(30.56-117.25)	150.19	(76.25-265.59)	1.07
Chennai, TN	180	4.34	2.21 ± 0.24	51.08	(25.08-136.41)	182.87	(91.36-284.80)	1.16
Coimbatore, TN	180	3.71	2.41 ± 0.31	53.14	(18.78-124.63)	190.24	(115.13-305.37)	1.21
Aduthurai, TN	180	5.75	1.83 ± 0.17	49.54	(27.12-129.88)	165.46	(90.28-275.16)	1.12
Hyderabad, AP	180	7.89	2.59 ±0.26	58.60	(36.13-138.22)	206.27	(139.22-186.84)	1.33
Vijayawada, AP	180	4.12	1.63 ± 0.26	46.30	(22.11-130.78)	161.12	(101.66-271.59)	1.05
West Godavari, AP	180	6.18	2.14 ± 0.18	45.20	(27.93-126.85)	144.64	(88.52-219.19)	1.03
Margoa, Goa	180	5.27	1.97 ± 0.21	52.26	(30.46-132.75)	201.20	(110.84-319.29)	1.19

* RR : Resistance ratio

Table 26. Susceptibility of geographic populations of *Leucinodes orbonalis* to Thiodicarb 75 WP during 2009-10

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.83	2.87 ± 0.34	63.40	(34.14-152.33)	281.30	(201.01-387.29)	1.27
Bangalore, KA	180	8.14	2.63 ± 0.23	65.00	(34.35-145.15)	253.71	(187.15-368.49)	1.30
Bijapur, KA	180	6.89	2.50 ± 0.21	58.23	(29.41-129.77)	213.20	(146.87-322.28)	1.16
Dharwad, KA	180	7.08	2.32 ± 0.27	60.00	(30.85-135.23)	231.62	(160.13-345.27)	1.20
Parbhani,MH	180	6.27	2.11 ± 0.18	55.60	(22.80-145.12)	210.17	(140.37-326.34)	1.11
Dapoli, MH	180	7.15	2.07± 0.21	57.14	(36.26-137.16)	261.40	(191.22-367.07)	1.14
Kolhapur, MH	180	8.21	2.27 ± 0.15	61.20	(34.30-136.40)	242.51	(168.49-357.16)	1.22
Chennai, TN	180	3.74	1.82 ± 0.11	50.00	(23.89-135.12)	238.24	(162.55-348.69)	---
Coimbatore, TN	180	4.30	1.97 ± 0.13	51.30	(29.32-126.14)	243.12	(165.09-350.74)	1.03
Aduthurai, TN	180	5.25	2.03 ± 0.11	56.38	(31.38-136.00)	221.52	(154.63-371.26)	1.13
Hyderabad, AP	180	6.99	2.23 ±0.27	63.82	(37.80-139.19)	251.23	(179.4-363.29)	1.28
Vijayawada, AP	180	6.12	1.91 ± 0.18	55.10	(20.14-120.26)	198.67	(118.01-317.24)	1.10
West Godavari, AP	180	5.28	1.77 ± 0.12	53.38	(25.10-128.50)	171.93	(101.85-286.34)	1.07
Margoa, Goa	180	4.88	1.65 ± 0.23	54.06	(30.23-142.00)	185.31	(135.28-294.67)	1.08

Table 27. Susceptibility of geographic populations of *Leucinodes orbonalis* to Thiodicarb 75 WP during 2010-11

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	8.05	2.92 ± 0.24	72.22	(42.11-162.01)	290.32	(222.15-391.48)	1.14
Bangalore, KA	180	7.73	3.05 ± 0.34	74.82	(34.12-155.24)	285.81	(205.46-375.19)	1.18
Bijapur, KA	180	7.52	2.71 ± 0.24	69.70	(42.70-148.86)	266.25	(201.27-281.45)	1.10
Dharwad, KA	180	6.95	2.52 ± 0.21	71.35	(32.87-149.85)	272.56	(197.32-377.44)	1.13
Parbhani,MH	180	6.43	2.34 ± 0.12	64.10	(36.19-136.46)	257.68	(187.66-359.42)	1.01
Dapoli, MH	180	6.84	2.21 ± 0.18	68.44	(29.33-138.99)	275.13	(199.17-382.03)	1.08
Kolhapur, MH	180	7.91	3.10 ± 0.26	72.60	(42.60-155.29)	299.84	(224.26-409.16)	1.15
Chennai, TN	180	6.42	2.62 ± 0.32	66.12	(37.25-143.53)	270.43	(195.86-381.69)	1.05
Coimbatore, TN	180	5.91	1.81 ± 0.22	63.18	(25.40-118.92)	245.14	(174.01-355.13)	---
Aduthurai, TN	180	6.78	2.47 ± 0.31	71.34	(31.10-142.34)	286.79	(204.59-390.78)	1.13
Hyderabad, AP	180	6.99	2.87 ±0.34	76.10	(41.86-155.27)	313.53	(226.12-432.16)	1.20
Vijayawada, AP	180	7.14	2.12 ± 0.11	64.23	(25.18-137.25)	249.21	(178.69-351.39)	1.02
West Godavari, AP	180	5.94	1.97 ± 0.17	64.10	(34.01-144.29)	224.35	(129.10-341.76)	1.02
Margoa, Goa	180	7.47	2.05 ± 0.24	70.42	(47.10-149.12)	283.09	(198.64-394.89)	1.11

* RR : Resistance ratio

Table 28. Susceptibility of geographic populations of *Leucinodes orbonalis* to Carbaryl 50 WP during 2009-10

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.55	2.94 ± 0.29	150.00	(105.32-240.53)	1135.67	(1075.11-1315.64)	1.25
Bangalore, KA	180	7.43	281. ± 0.31	147.64	(107.22-227.36)	1088.40	(1015.27-1273.66)	1.23
Bijapur, KA	180	5.79	2.49 ± 0.28	137.00	(101.00-212.15)	887.60	(817.31-989.29)	1.14
Dharwad, KA	180	6.14	2.11 ± 0.23	139.17	(109.00-219.00)	931.00	(854.13-1036.43)	1.16
Parbhani,MH	180	4.46	1.91 ± 0.20	135.00	(99.45-210.11)	851.26	(769.10-962.39)	1.12
Dapoli, MH	180	5.10	2.63 ± 0.21	138.00	(98.00-218.00)	905.53	(840.90-1025.86)	1.15
Kolhapur, MH	180	6.73	2.79 ± 0.24	142.20	(100.82-227.32)	961.27	(891.45-1066.89)	1.18
Chennai, TN	180	2.44	1.09 ± 0.14	120.08	(86.08-190.45)	782.60	(702.13-897.96)	---
Coimbatore, TN	180	3.38	1.27 ± 0.16	127.60	(97.62-207.17)	843.18	(770.26-958.63)	1.06
Aduthurai, TN	180	3.49	1.46 ± 0.19	130.10	(89.18-205.14)	827.56	(757.59-933.53)	1.08
Hyderabad, AP	180	7.21	2.76 ± 0.21	144.32	(115.20-229.00)	1042.39	(966.86-1245.17)	1.20
Vijayawada, AP	180	5.37	1.87 ± 0.15	137.00	(104.50-202.14)	893.42	(813.11-998.56)	1.14
West Godavari, AP	180	4.13	1.72 ± 0.18	134.26	(99.90-199.25)	877.45	(799.63-987.45)	1.12
Margoa, Goa	180	2.52	1.18 ± 0.13	122.00	(72.00-202.00)	804.45	(731.15-913.84)	1.02

* RR : Resistance ratio

Table 29.Susceptibility of geographic populations of *Leucinodes orbonalis* to carbaryl 50 WP during 2010-11

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.81	3.04 ± 0.28	158.23	(110.65-228.29)	1072.80	(998.85-1263.37)	1.13
Bangalore, KA	180	7.53	2.84 ± 0.30	156.72	(125.46-226.56)	1125.25	(1045.01-1330.52)	1.12
Bijapur, KA	180	4.13	1.63 ± 0.20	145.20	(107.82-238.69)	998.98	(920.11-1109.74)	1.04
Dharwad, KA	180	4.62	1.79 ± 0.21	147.61	(105.63-218.66)	1030.32	(964.74-220.75)	1.06
Parbhani,MH	180	3.14	1.33 ± 0.17	143.41	(125.56-220.35)	975.19	(895.11-1090.79)	1.03
Dapoli, MH	180	4.83	1.59 ± 0.21	146.31	(126.68-227.76)	1038.80	(969.99-1239.79)	1.05
Kolhapur, MH	180	6.90	2.26 ± 0.24	150.26	(112.26-190.00)	1104.41	(1010.63-1289.58)	1.08
Chennai, TN	180	2.66	1.07 ± 0.12	138.16	(103.86-205.77)	909.09	(829.09-1010.38)	0.99
Coimbatore, TN	180	3.67	1.24 ± 0.16	143.49	(110.11-219.34)	964.25	(892.01-1079.91)	1.03
Aduthurai, TN	180	5.74	1.96 ± 0.23	148.20	(108.11-228.48)	1089.27	(1015.11-1274.38)	1.06
Hyderabad, AP	180	7.42	2.51 ± 0.26	153.45	(102.15-240.96)	1193.84	(1120.33-1380.8)	1.10
Vijayawada, AP	180	6.39	2.30 ± 0.25	152.00	(106.87-235.82)	1170.40	(1090.27-1375.17)	1.09
West Godavari, AP	180	5.63	2.17 ± 0.27	148.24	(124.31-210.56)	1064.36	(984.99-1253.44)	1.06
Margoa, Goa	180	2.71	1.17 ± 0.14	139.61	(103.28-204.96)	932.59	(844.09-1037.36)	---

* RR : Resistance ratio

During 2010-11 also, Hyderabad population registered a maximum LC_{50} value to cypermethrin (58.60 ppm) followed by population from Raichur (56.30 ppm), Coimbatore (53.14 ppm), Bangalore (52.42), Margoa (52.26), Chennai (51.08), Parbhani (48.32 ppm) and Bijapur (47.82 ppm). Lowest LC_{50} value was observed in population from Dharwad (44.07 ppm) followed by Dapoli (45.19 ppm), West Godavari (45.20 ppm) and Vijaywada (46.30 ppm). Highest LC_{95} value was recorded in Raichur population (226.33 ppm) and lowest LC_{95} value of 134.41ppm was recorded from Dharwad population. The resistance ratio (RR) against susceptible strain was again highest for Hyderabad population (1.33 folds) followed by Raichur (1.28 folds), Coimbatore (1.21 folds) and Bangalore (1.19 folds). The least resistance ratio was observed in West Godavari and Dapoli population (1.03 folds) followed by Vijayawada (1.07 folds) (Table 23). Resistance levels in the *L. orbonalis* population of other geographical areas *viz.*, Bijapur, Parbhani, Aduthurai and Chennai varied between 1.09 to 1.16 folds (Table 25).

4.2.3.7 Thiodicarb

The data on the LC_{50} values of thiodicarb to fourteen different geographic populations of *L. orbonalis* for the two years are presented in the (Table 26). The results indicate that there has been marked difference in LC_{50} values among the different populations. During 2009-10, Bangalore population recorded a maximum LC_{50} value of 65.00 ppm followed by population from Hyderabad (63.82 ppm), Raichur (63.40 ppm), Kolhapur (61.20 ppm), Dharwad (60.00 ppm) and Bijapur (58.23 ppm). Lowest LC_{50} value was observed in population from Chennai (50.00 ppm) followed by Coimbatore (51.30 ppm), west Godavari (53.38 ppm), Margoa (54.06 ppm) and Vijaywada (55.10 ppm). Highest LC_{95} value was recorded in population from Raichur (281.30 ppm), whereas lowest value of LC_{95} recorded from West Godavari population (171.93 ppm). The *L. orbonalis* population of Bangalore district developed higher degree of resistance (1.27 folds) at LC_{50} against susceptible field strain followed by Bangalore (1.30 folds), Hyderabad (1.28 folds) and Kolhapur (1.22 folds). The least resistance ratio was observed in the population of Coimbatore (1.03 folds) followed by West Godavari (1.07 folds), Margoa (1.08 folds) and Parbhani (1.11 folds). *L. orbonalis* population of other geographical areas such as Aduthurai, Dapoli, Bijapur and Dharwad developed resistance in the range of 1.13 to 1.20 folds. Similar trend was noticed during the year, 2010-11. Bangalore population recorded a maximum LC_{50} value to thiodicarb (74.82 ppm) followed by population from Hyderabad (76.10 ppm), Kolhapur (72.60 ppm), Raichur (72.22 ppm), Dharwad (71.35 ppm) and Aduthurai (71.34 ppm). Lowest LC_{50} value was observed in population from Coimbatore (63.18 ppm) followed by West Godavari and Parbhani (64.10 ppm) followed by Vijaywada (64.23 ppm), Chennai (66.12 ppm) and Dapoli (68.44 ppm). Highest LC_{95} value of 313.53 ppm was recorded in Hyderbad population and lowest LC_{95} value of 224.35 ppm was observed from West Godavari population. Accordingly the highest degree of resistance (1.20 folds) against susceptible strain was recorded in Hyderabad followed by Bangalore (1.18 folds), Kolhapur (1.15 folds) and Raichur (1.14 folds). The least resistance ratio was observed in the population of Parbhani (1.01folds) followed by Vijaywada and West Godavari (1.02 folds) (Table 25). Resistance levels in other locations *viz.,* Chennai, Dapoli, Bijapur, Margoa and Dharwad varied between 1.05 to 1.13 folds (Table 27).

4.2.3.8 Carbaryl

The LC_{50} values of carbaryl differed strikingly among fourteen geographic populations of *L. orbonalis*. A comparative analysis of LC_{50} values presented in (Table 28) revealed that, Raichur population recorded a maximum LC_{50} value to carbaryl (150.00 ppm) followed by population from Bangalore (147.64 ppm), Hyderabad (144.32 ppm), Kolhapur (142.20 ppm) and Dharwad (139.17 ppm). Lowest LC_{50} value was observed in population from Chennai (120.08 ppm) followed by Margoa (122.00 ppm), Coimbatore (127.60 ppm) and Aduthurai (130.10 ppm). Raichur population recorded maximum LC_{95} value of 1135.67 ppm and lowest was observed in Chennai (782.60 ppm) population. Resistance ratio (RR) at LC_{50} calculated against susceptible strain to measure the level of resistance development was found to be highest for population of Raichur (1.25 folds) followed by Bangalore (1.23 folds), Hyderabad (1.20 folds) and Kolhapur (1.18 folds). Lowest resistance ratio was observed in Margoa (1.02 folds) followed by Coimbatore (1.06 folds), west Godavari and Parbhani populations (1.12 folds). Populations of Vijayawada, Bijapur, Dapoli, and Dharwad developed resistance in the range of 1.14 to 1.16. During the year 2010-11 also, Raichur population registered a maximum LC_{50} value to carbaryl (158.23 ppm) followed by population from Bangalore (156.72 ppm), Hyderabad (153.45 ppm), Vijaywada (152.00 ppm) and Kolhapur (150.26 ppm). Lowest value was observed in population from Chennai (138.16 ppm) followed by Margoa (139.61 ppm), Coimbatore (143.49 ppm), Dapoli (146.31ppm) and Dharwad (147.61 ppm). Highest LC_{95} value was recorded in Hyderabad (1193.84 ppm) and lowest was observed in Chennai (909.09 ppm) populations. The computed resistance ratio at LC_{50} in comparison with susceptible strain was highest for population of Raichur (1.13 folds) followed by Bangalore (1.12 folds), Hyderabad (1.10 folds) and Vijaywada (1.09 folds). The least resistance ratio was observed in the population of Chennai (0.99 folds) followed by Coimbatore and Parbhani (1.03 folds) followed by Bijapur (1.04 folds). *L. orbonalis* of Dapoli, Aduthurai, West Godavari, Kolhapur resistance ratios ranged from 1.05 to 1.08 folds (Table 29).

4.2.3.9 Quinalphos

LC_{50} values obtained to quinalphos for fourteen different geographic populations of *L. orbonalis* are presented in (Table 30). The toxicity of quinalphos varied among different strains. The relative toxicity of quinalphos in comparison with susceptible strain revealed that, in the year 2009-10, Hyderabad population registered highest LC_{50} value (190.00 ppm) followed by Raichur (188.67 ppm), Bangalore (182.32 ppm) Bangalore (182.32 ppm) and Bijapur (175.00 ppm). Whereas, least resistance was recorded by Margoa (100.00 ppm) followed by Chennai (110.23 ppm), Coimbatore (118.00 ppm) and Aduthurai (127.60 ppm). Whereas, highest LC_{95} was recorded in population of Hyderabad (1294.42 ppm) and lowest LC_{95} value of 532.27 ppm was observed in Margao population. The resistance development with respect to susceptible Margoa strain as measured from resistance ratio at LC_{50} value was highest in Hyderabad (1.90 folds) followed by Raichur (1.89 folds), Bijapur (1.75 folds) and Dharwad (1.68 folds). Lowest ratio was recorded by Chennai (1.10 folds) followed by Coimbatore (1.18 folds), Aduthurai (1.28 folds) and Vijaywada (1.40 folds). Populations from West Godavari, Dapoli, Parbhani and Kolhapur developed resistance in the range of 1.46 to 1.60 folds.Whereas, during 2010-11, maximum resistance to quinalphos was observed in Hyderabad population (197.16 ppm) followed by Raichur (195.23 ppm), Bangalore (188.61 ppm), Bijapur (181.00 ppm) and Dharwad (174.12 ppm). Least LC_{50} value was noticed in Margoa (121.60 ppm) followed by Chennai (124.27 ppm), Coimbatore (130.00 ppm) and Aduthurai (136.10 ppm). Whereas, highest LC_{95} value was recorded in Hyderabad (1382.09 ppm) and lowest was recorded in Margoa (629.89 ppm). Highest resistance ratio to quinalphos was recorded by Hyderabad (1.62 folds) followed by Raichur (1.61 folds) and Bangalore (1.55 folds) populations. Lowest ratio was recorded by Chennai (1.02 folds) followed by Coimbatore (1.07 folds) and Aduthurai (1.12 folds) (Table 29). Moderate level of resistance in the range of 1.12 to 1.39 folds was noticed in the populations of Aduthurai, Vijaywada, West Godavari, Dapoli, Parbhani and Kolhapur (Table 31).

4.2.3.10 Monocrotophos

During the year 2009-10, Maximum LC_{50} value to monocrotophos was recorded in Bangalore (180.00 ppm) followed by Raichur (177.90 ppm), Hyderabad (176.54 ppm), Vijaywada (168.32 ppm) and West Godavari (165.41 ppm). Least LC_{50} value of 140.00 ppm was observed in Margoa population followed by Chennai (147.22 ppm), Coimbatore (152.16 ppm), Aduthurai (156.27 ppm) and Dapoli (159.20 ppm). The value of LC_{95} was highest in population of Raichur (1322.45 ppm) and the lowest value of 941.28 ppm was recorded in population of Margoa (Table 32).The resistance ratio against susceptible Margoa strain was found to be highest for population of Bangalore (1.29 folds) followed by Raichur (1.27 folds), Hyderabad (1.26 folds), and Vijaywada (1.20 folds). Least ratio was recorded in population from Chennai (1.05 folds) followed by Coimbatore (1.09 folds) and Aduthurai (1.12 folds). *L. orbonalis* population from Parbhani, Dapoli, Dharwad, Kolhapur and West Godavari developed resistance in the range of 1.14 to 1.18 folds (Table 32). For the year 2010-11, also maximum LC_{50} value to monocrotophos was recorded in Bangalore (187.48 ppm) followed by Raichur (183.27 ppm), Hyderabad (182.13 ppm), Vijaywada (175.21 ppm) and Kolhapur (174.10 ppm). Minimum resistance was observed in Margoa (155.23 ppm) followed by Chennai (161.38 ppm), Coimbatore (165.62 ppm) Bijapur (167.07 ppm) and Dapoli (167.25 ppm). The value of LC_{95} was highest in population of Hyderabad (1329.55 ppm) and whereas, lowest was in population of Margoa (828.93 ppm). The resistance ratio was found to be highest for Bangalore (1.21 folds) followed by Raichur (1.18 ppm) and Hyderabad (1.17 folds). Least ratio was recorded in population from Chennai (1.04 folds) followed by Coimbatore (1.07 folds) followed by Bijapur and Dapoli (1.08 folds). A resistance level in the range of 1.09 to 1.13 folds was noticed in the remaining populations of Dharwad, Aduthurai, Parbhani, and West Godavari (Table 33).

4.2.3.11 Chlorpyriphos

The data on LC_{50} values of chlorpyriphos to fourteen different geographic populations of *L. orbonalis* for the two years are presented in the (Table 34). The results indicate that there has been marked difference in LC_{50} values among the different populations. During 2010-11, Bangalore population recorded a maximum LC_{50} value of 240.00 ppm followed by population from Raichur (238.04 ppm), Kolhapur (234.00 ppm), Parbhani (230.10 ppm) and Hyderabad (230.00 ppm). Lowest

LC_{50} value was observed in population from Margoa (210.12 ppm) followed by Aduthurai (212.52 ppm), Dharwad (221.32 ppm) and West Godavari (225.80 ppm). The value of LC_{95} was highest in population of Bangalore (1670.25 ppm) and least value was recorded in population of Chennai (1028.37 ppm). The Higher degree of resistance ratio was observed in Bangalore (1.20 folds) followed by Raichur (1.19 folds) and Kolhapur (1.17 folds) with respect to Chennai strain. Least resistance ratio was recorded in population of Coimbatore 91.03 folds) followed by Margoa (1.05 folds), Aduthurai (1.06 folds). Remaining populations of Dharwad, West Godavari, Bijapur, Vijaywada, Dapoli, Hyderabad, Parbhani ratio ranged from 1.11 to 1.15 folds (Table 34). Similar trend was noticed during the year 2010-11, where in Bangalore population recorded a maximum LC_{50} value to chlorpyriphos (249.83 ppm) followed by Kolhapur (248.24 ppm), Raichur (247.75 ppm) and Parbhani (242.41 ppm). Lowest LC_{50} value was observed in population from Chennai (212.40 ppm) followed by Coimbatore (217.36 ppm), Aduthurai (224.52 ppm) and Margoa (227.05 ppm). Highest LC_{95} value was recorded in Kolhapur (1809.67 ppm) and lowest value of 1295.64 ppm was observed in Chennai population. Accordingly the highest degree of resistance (1.18 folds) against susceptible strain was recorded in Bangalore followed by Raichur and Kolhapur (1.17 folds) and Parbhani (1.14 folds). The least resistance ratio was observed in the population of Coimbatore (1.02 folds) followed by Aduthurai (1.06 folds) and Margoa (1.07 folds). Resistance levels in other locations *viz*., Dharwad, Vijaywada, West Godavari, Hyderabad and Dapoli varied from 1.08 to 1.13 folds (Table 35).

4.2.3.12 Endosulfan

The data from the Table revealed that during the year 2009-10, maximum LC_{50} value to endosulfan was recorded in Raichur (240.00 ppm) followed by Bangalore (237.47 ppm), Hyderabad (234.18 ppm), Bijapur (232.34) and West Godavari (231.07 ppm). Minimum LC_{50} was observed in Margoa (180.00 ppm) followed by Chennai (182.00 ppm), Coimbatore (184.60 ppm) and Aduthurai (186.00 ppm). Maximum value of LC_{95} was observed in Raichur population (1651.00 ppm) and least LC_{95} value was recorded in Margoa (1229.46 ppm). The resistance ratio against Margoa (susceptible) strain was found to be highest in Raichur (1.33 folds) followed by Bangalore (1.32 folds), Hyderabad (1.30 folds) and Bijapur (1.29 folds). Least ratio was recorded in population from Chennai (1.01 folds) followed by Coimbatore and Aduthurai (1.03 folds). *L. orbonalis* population from Parbhani, Dapoli, Dharwad, Kolhapur, Vijaywada and West Godavari developed resistance in the range of 1.23 to 1.28 folds (Table 36). For the year 2010-11, also maximum LC_{50} value to endosulfan was recorded in Raichur
(247.42 ppm) followed by Bangalore (244.72 ppm), Hyderabad (242.67 ppm), Bijapur (240.61) and West Godavari (240.58 ppm). Minimum resistance was observed in Aduthurai (194.39 ppm) followed by Chennai (196.27 ppm), Coimbatore (198.12 ppm) and Margoa (198.25 ppm). Highest LC_{95} of 1774.00 ppm was recorded in Raichur population and lowest value of LC_{95} was recorded in Aduthurai (1162.45 ppm). The resistance ratio against susceptible strain was found to be highest for Raichur (1.27 folds) followed by Bangalore (1.26 folds), Hyderabad (1.25 folds) and Bijapur (1.24 folds). Least resistance ratio was recorded in population from Chennai (1.01 folds) followed by Margoa and Coimbatore (1.02 folds). Resistance level in the range of to 1.19 to 1.25 folds was noticed in the remaining locations of Parbhani, Dapoli, Kolhapur, Vijaywada and West Godavari (Table 37).

Contingent table showing LC_{50} values for all the twelve insecticides bioassayed during 2009-10 (Table 38). Contingent table showing LC_{50} values for all the twelve insecticides bioassayed during 2010-11 (Table 39).

4.3 Assessment of genetic diversity of SFB (*Leucinodes orbonalis*.G*)* populations occurring in south India using mitochondrial DNA markers

All the 15 gels resulting from short listed primers had maximum number of clear and scorable amplicons in each DNA sample with few ghost or minor bands, which were ignored. Sample gels resulting from mtd primers used across individually pooled organelle DNA of all the 14 geographical populations is presented in Plate 3 and 4.

A total of 158 amplicon levels resulting from 15 primers were available for analysis. The highest number of 18 amplicon levels was produced by the primer mtd 14, followed by 15 levels by mtd 16. The lowest of one marker levels was noticed with mtd 5 primer. On an average there were 16.75 amplicon levels per primer, of which 12.26 were polymorphic, indicating high variability among *L. orbonalis* populations.

Table 30.Susceptibility of geographic populations of *Leucinodes orbonalis* to Quinalphos 25 EC during 2009-10

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.86	2.91 ± 0.33	188.67	(153.61-269.62)	1187.23	(1109.41-1376.37)	1.89
Bangalore, KA	180	7.38	3.01 ± 0.21	182.32	(160.32-250.31)	1088.10	(1011.20-1293.75)	1.82
Bijapur, KA	180	6.91	2.85± 0.28	175.00	(133.00-264.00)	972.61	(901.02-1193.37)	1.75
Dharwad, KA	180	6.55	2.73 ± 0.29	167.72	(137.00-247.18)	892.13	(820.16-1007.26)	1.68
Parbhani,MH	180	6.23	2.31 ± 0.24	154.04	(114.04-232.06)	761.62	(690.37-870.41)	1.54
Dapoli, MH	180	5.96	2.17 ± 0.17	148.28	(112.72-218.52)	721.32	(655.13-831.56)	1.48
Kolhapur, MH	180	6.87	2.65 ± 0.25	160.10	(125.00-240.00)	823.21	(745.97-939.54)	1.60
Chennai, TN	180	3.45	1.32 ± 0.12	110.23	(74.00-180.00)	605.68	(572.34-714.43)	1.10
Coimbatore, TN	180	3.94	1.43 ± 0.18	118.00	(81.00-195.00)	618.34	(552.31-730.95)	1.18
Aduthurai, TN	180	4.31	1.59 ± 0.19	127.60	(82.00-212.40)	645.61	(571.26-750.09)	1.28
Hyderabad, AP	180	7.95	3.06 ±0.34	190.00	(157.00-280.00)	1294.42	(1223.59-1314.90)	1.90
Vijayawada, AP	180	5.09	1.71 ± 0.22	140.21	(100.00-229.79)	654.57	(579.87-793.84)	1.40
West Godavari, AP	180	4.93	1.94 ± 0.20	146.48	(102.00-226.00)	703.24	(637.21-809.65)	1.46
Margoa, Goa	180	2.86	1.08 ± 0.13	100.00	(73.00-175.00)	532.27	(460.86-652.96)	---

* RR : Resistance ratio

Table 31. Susceptibility of geographic populations of *Leucinodes orbonalis* to Quinalphos 25 EC during 2010-11

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.57	2.96 ± 0.34	195.23	(145.23-285.43)	1368.56	(1282.12-1541.84)	1.61
Bangalore, KA	180	7.39	2.85 ± 0.33	188.61	(143.11-255.35)	1278.78	(1199.11-1509.89)	1.55
Bijapur, KA	180	6.74	2.41 ± 0.31	181.00	(129.66-367.00)	1062.47	(997.26-1243.87)	1.49
Dharwad, KA	180	6.51	2.74 ± 0.32	174.12	(134.21-266.10)	912.39	(849.83-1021.41)	1.43
Parbhani,MH	180	6.10	2.26 ± 0.21	166.00	(136.00-345.35)	1163.66	(1085.59-1353.36)	1.37
Dapoli, MH	180	5.76	1.92 ± 0.22	157.20	(107.20-235.31)	756.13	(695.40-891.26)	1.29
Kolhapur, MH	180	6.49	2.38 ± 0.28	168.42	(128.24-239.55)	860.63	(795.46-981.28)	1.39
Chennai, TN	180	3.16	1.1 3 ± 0.14	124.27	(96.42-204.24)	585.31	(542.15-702.33)	1.02
Coimbatore, TN	180	3.93	1.19 ± 0.18	130.00	(100.01-205.31)	639.60	(598.81-758.84)	1.07
Aduthurai, TN	180	4.17	1.64 ± 0.17	136.10	(195.09-217.58)	812.52	(747.28-917.99)	1.12
Hyderabad, AP	180	7.96	3.06 ± 0.35	197.16	(148.81-275.15)	1382.09	(1301.42-1473.48)	1.62
Vijayawada, AP	180	4.81	2.33 ± 0.24	149.34	(100.55-218.56)	689.95	(617.46-804.35)	1.23
West Godavari, AP	180	5.32	1.77 ± 0.19	155.49	(105.14-234.00)	794.55	(691.84-801.63)	1.28
Margoa, Goa	180	2.45	1.09 ± 0.12	121.60	(175.89-192.31)	629.89	(535.3-746.26)	---

* RR : Resistance ratio

Table 32.Susceptibility of geographic populations of *Leucinodes orbonalis* to Monocrotophos 36 SL during 2009-10

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.51	6.92 ± 0.24	177.90	(142.24-259.53)	1322.45	(1241.26-1513.21)	1.27
Bangalore, KA	180	7.11	7.21 ± 0.32	180.00	(151.51-250.12)	1287.61	(1207.41-1492.34)	1.29
Bijapur, KA	180	6.82	6.61. ± 0.32	162.62	(124.24-232.38)	1115.37	(1050.96-1320.85)	1.16
Dharwad, KA	180	6.27	6.73 ± 0.14	163.74	(128.11-208.31)	1157.41	(1081.91-1337.15)	1.17
Parbhani,MH	180	5.88	5.98 ± 0.28	160.02	(110.61-240.37)	1173.62	(1095.30-1359.52)	1.14
Dapoli, MH	180	6.09	6.10 ± 0.13	159.20	(124.11-240.29)	1108.17	(1041.6-1299.64)	1.14
Kolhapur, MH	180	6.47	6.38 ± 0.12	165.20	(125.21-255.32)	1194.82	(1134.21-1395.07)	1.18
Chennai, TN	180	6.18	5.27 ± 0.34	147.22	(123.78-227.14)	971.62	(894.63-1176.10)	1.05
Coimbatore, TN	180	5.69	4.74 ± 0.32	152.16	(113.50-232.00)	1013.12	(941.91-1203.25)	1.09
Aduthurai, TN	180	4.93	5.10 ± 0.28	156.27	(116.19-236.20)	1067.51	(998.08-1276.59)	1.12
Hyderabad, AP	180	6.98	6.59 ± 0.11	176.54	(149.26-246.30)	1310.00	(1250.36-1505.29)	1.26
Vijayawada, AP	180	5.42	5.72 ± 0.26	168.32	(141.92-238.50)	1183.32	(1103.27-1379.03)	1.20
West Godavari, AP	180	5.10	5.92 ± 0.22	165.41	(135.74-136.65)	1145.00	(1069.56-1327.86)	1.18
Margoa, Goa	180	4.47	4.28 ± 0.27	140.00	(119.10-205.00)	941.28	(870.36-1147.83)	---

* RR : Resistance ratio

Table 33. Susceptibility of geographic populations of *Leucinodes orbonalis* to Monocrotophos 36 SL during 2010-11

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	8.66	2.62 ± 0.14	183.27	(153.27-264.45)	1242.57	(1153.15-1433.35)	1.18
Bangalore, KA	180	7.71	2.47 ± 0.17	187.48	(157.34-257.89)	1287.99	(1201.63-1477.10)	1.21
Bijapur, KA	180	6.99	1.98. ± 0.32	167.07	(127.34-339.55)	1186.20	(1096.99-1387.81)	1.08
Dharwad, KA	180	6.73	2.06 ± 0.17	169.21	(134.31-249.86)	1213.24	(1148.30-1423.58)	1.09
Parbhani,MH	180	5.94	1.75 ± 0.28	171.56	(137.67-255.67)	1178.62	(1098.83-1383.46)	1.11
Dapoli, MH	180	6.45	1.50 ± 0.22	167.25	(122.34-238.56)	1187.48	(1107.22-1365.14)	1.08
Kolhapur, MH	180	7.14	1.68 ± 0.12	174.10	(140.95-263.12)	1283.12	(1199.39-1492.86)	1.12
Chennai, TN	180	6.68	1.33 ± 0.27	161.38	(125.32-243.25)	1081.25	(1001.78-1273.35)	1.04
Coimbatore, TN	180	6.10	1.18 ± 0.34	165.62	(126.34-238.65)	1059.97	(995.25-1248.82)	1.07
Aduthurai, TN	180	7.33	1.89 ± 0.14	171.42	(129.35-254.67)	1306.22	(1225.11-1501.74)	1.10
Hyderabad, AP	180	8.11	2.03 ± 0.21	182.13	(132.10-274.23)	1329.55	(1256.00-1530.41)	1.17
Vijayawada, AP	180	7.02	2.22 ± 0.16	175.21	(140.46-257.69)	1103.82	(1025.88-1290.28)	1.13
West Godavari, AP	180	5.90	2.10 ± 0.28	172.54	(129.19-249.82)	983.48	(903.19-1095.28)	1.11
Margoa, Goa	180	4.85	1.08 ± 0.34	155.23	(118.82-235.00)	828.93	(761.86-929.69)	--

* RR : Resistance ratio

Table 34. Susceptibility of geographic populations of *Leucinodes orbonalis* to Chlorpyriphos 20 EC during 2009-10

Population	*N*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.51	2.93 ± 0.29	238.04	(206.16-286.19)	1528.14	(1468.17-1709.31)	1.19
Bangalore, KA	180	7.83	2.86 ± 0.32	240.00	(190.64-302.39)	1670.25	(1595.87-1860.29)	1.20
Bijapur, KA	180	5.92	1.69 ± 0.24	226.20	(185.24-295.13)	1497.36	(1430.10-1677.23)	1.13
Dharwad, KA	180	4.57	1.59 ± 0.19	221.32	(174.32-290.81)	1382.37	(1308.63-1574.87)	1.11
Parbhani,MH	180	7.10	2.25 ± 0.21	230.10	(198.19-310.00)	1575.30	(1500.02-1770.39)	1.15
Dapoli, MH	180	6.37	1.84 ± 0.21	229.62	(201.36-312.00)	1541.42	(1475.93-1727.51)	1.15
Kolhapur, MH	180	7.38	2.43 ± 0.30	234.00	(189.19-305.42)	1664.18	(1590.36-1854.97)	1.17
Chennai, TN	180	2.99	1.07 ± 0.14	200.00	(150.61-270.00)	1028.37	(950.12-1230.28)	---
Coimbatore, TN	180	3.34	1.24 ± 0.13	205.40	(174.89-285.14)	1267.10	(1195.29-1357.46)	1.03
Aduthurai, TN	180	3.67	1.76 ± 0.15	212.52	(185.26-301.14)	1405.10	(1375.12-1610.39)	1.06
Hyderabad, AP	180	6.43	1.97 ± 0.25	230.00	(195.00-320.00)	1541.40	(1467.89-1739.56)	1.15
Vijayawada, AP	180	5.83	1.78 ± 0.23	227.08	(177.00-295.23)	1560.12	(1500.97-1750.39)	1.14
West Godavari, AP	180	5.48	1.63 ± 0.20	225.80	(180.00-291.20)	1514.62	(1436.06-1720.35)	1.13
Margoa, Goa	180	4.01	1.61 ± 0.17	210.12	(165.62-282.40)	1354.00	(1273.6-1534.73)	1.05

* RR : Resistance ratio

Table 35.Susceptibility of geographic populations of *Leucinodes orbonalis* to chlorpyriphos 20 EC during 2010-11

Population	*N*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.66	2.94 ± 0.30	247.75	(207.75-228.32)	1687.18	(1604.18-1775.46)	1.17
Bangalore, KA	180	8.14	3.01 ± 0.32	249.83	(201.84-338.14)	1746.31	(1648.36-1935.91)	1.18
Bijapur, KA	180	4.37	1.39 ± 0.24	235.19	(208.92-320.59)	1526.38	(1435.14-1735.28)	1.11
Dharwad, KA	180	3.95	1.58 ± 0.18	230.21	(200.21-300.89)	1540.10	(1461.68-1732.35)	1.08
Parbhani,MH	180	7.17	2.55 ± 0.27	242.41	(210.98-342.18)	1645.96	(1556.19-1835.61)	1.14
Dapoli, MH	180	6.34	1.97± 0.18	240.72	(205.31-333.12)	1610.42	(1541.88-1795.25)	1.13
Kolhapur, MH	180	7.81	2.14 ± 0.23	248.24	(218.24-323.11)	1809.67	(1734.35-1994.26)	1.17
Chennai, TN	180	2.46	1.12 ± 0.13	212.40	(184.74-295.11)	1295.64	(1198.84-1475.35)	---
Coimbatore, TN	180	2.83	1.17 ± 0.11	217.36	(177.25-299.05)	1369.37	(1296.84-1462.34)	1.02
Aduthurai, TN	180	3.07	1.37 ± 0.15	224.52	(194.00-296.99)	1425.70	(1341.36-1606.55)	1.06
Hyderabad, AP	180	5.99	1.63 ± 0.17	238.47	(205.11-315.78)	1576.29	(1478.15-1785.75)	1.12
Vijayawada, AP	180	4.91	1.46 ± 0.21	235.69	(201.42-317.50)	1543.77	(1458.87-1733.46)	1.11
West Godavari, AP	180	5.79	1.85 ± 0.25	234.71	(196.89-279.89)	1666.44	(1595.42-1854.48)	1.11
Margoa, Goa	180	2.65	1.59 ± 0.14	227.05	(177.05-312.46)	1464.47	(1389.22-1666.28)	1.07

* RR : Resistance ratio

Table 36.Susceptibility of geographic populations of *Leucinodes orbonalis* to Endosulfan 35 EC during 2009-10

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	8.27	2.17 ± 0.26	240.00	(190.24-320.45)	1651.00	(1576.43-1842.37)	1.33
Bangalore, KA	180	6.91	1.93 ± 0.17	237.47	(198.37-301.80)	1504.43	(1429.71-1705.05)	1.32
Bijapur, KA	180	7.19	2.10. ± 0.23	232.34	(189.00-307.90)	1591.60	(1525.13-1781.39)	1.29
Dharwad, KA	180	7.04	1.81 ± 0.12	227.42	(178.31-305.21)	1474.18	(1400.23-1683.56)	1.26
Parbhani,MH	180	5.89	1.64 ± 0.11	221.42	(189.63-307.25)	1395.71	(1320.02-1605.07)	1.23
Dapoli, MH	180	6.74	1.52 ± 0.21	224.30	(186.00-304.00)	1439.27	(1364.23-1621.49)	1.25
Kolhapur, MH	180	7.37	1.32 ± 0.24	228.21	(179.00-293.62)	1326.31	(1251.93-1516.46)	1.27
Chennai, TN	180	5.71	1.17 ± 0.18	182.00	(145.14-271.32)	1257.00	(1191.14-1447.06)	1.01
Coimbatore, TN	180	6.08	1..41 ± 26	184.60	(139.28-279.00)	1292.35	(1222.73-1493.49)	1.03
Aduthurai, TN	180	5.94	1.10 ± 0.14	186.00	(142.00-260.00)	1308.69	(1228.51-1509.78)	1.03
Hyderabad, AP	180	7.54	1.97 ±0.32	234.18	(199.20-304.00)	1610.04	(1534.89-1795.76)	1.30
Vijayawada, AP	180	5.43	2.09 ± 0.12	230.14	(192.86-295.00)	1538.62	(1473.59-1744.27)	1.28
West Godavari, AP	180	4.72	1.88 ± 0.21	231.07	(182.00-301.70)	1569.21	(1494.04-1779.65)	1.28
Margoa, Goa	180	3.99	1.28 ± 0.24	180.00	(135.55-247.26)	1229.46	(1153.11-1418.27)	---

* RR : Resistance ratio

Table 37. Susceptibility of geographic populations of *Leucinodes orbonalis* to Endosulfan 35 EC during 2010-11

Population	*n*	χ^2	Slope ± S.E.	LC_{50} (ppm)	(95 % CI)	LC_{95} (ppm)	(95 % CI)	RR*
Raichur, KA	180	7.88	3.06 ± 0.21	247.42	(210.56-328.82)	1774.00	(1681.83-1962.85)	1.27
Bangalore, KA	180	7.64	2.81 ± 0.24	244.72	(199.12-319.42)	1708.15	(1637.77-1893.28)	1.26
Bijapur, KA	180	6.89	2.41 ± 0.14	240.61	(210.61-320.56)	1624.12	(1568.26-1830.86)	1.24
Dharwad, KA	180	7.24	2.67 ± 0.12	234.09	(194.99-315.46)	1685.45	(1607.22-1880.44)	1.20
Parbhani,MH	180	6.91	2.34 ± 0.17	231.60	(181.01-322.75)	1563.30	(1483.11-1754.22)	1.19
Dapoli, MH	180	5.87	1.87± 0.26	235.30	(195.28-315.45)	1517.69	(1446.13-1708.26)	1.21
Kolhapur, MH	180	7.09	2.10 ± 0.13	237.52	(183.25-312.78)	1546.26	(1457.25-1727.33)	1.22
Chennai, TN	180	6.21	1.51 ± 0.26	196.27	(146.27-267.43)	1197.25	(1119.47-1289.99)	1.01
Coimbatore, TN	180	6.05	1..36 ± 0.31	198.12	(153.62-269.63)	1347.22	(1265.22-1550.56)	1.02
Aduthurai, TN	180	5.73	1.57 ± 0.21	194.39	(156.00-275.31)	1162.45	(1092.63-1343.86)	---
Hyderabad, AP	180	6.77	1.99 ±0.32	242.67	(202.47-312.58)	1669.57	(1594.23-1870.26)	1.25
Vijayawada, AP	180	4.93	1.63 ± 0.26	238.22	(205.34-327.71)	1536.52	(1456.01-1737.99)	1.23
West Godavari, AP	180	3.48	1.47 ± 0.12	240.58	(195.85-320.04)	1712.93	(1667.31-1917.16)	1.24
Margoa, Goa	180	3.83	1.74 ± 0.17	198.25	(148.96-278.28)	1288.63	(1197.25-1444.71)	1.02

* RR : Resistance ratio

Table 38. Contingent table showing LC_{50} values for all the twelve insecticides bioassayed during 2009-10

Locations	LC_{50} (ppm)													
	RCR	BGL	BJP	DWD	PBN	DAP	KLP	MAA	CBE	ADT	HYD	VJA	W.G	Margoa
Rynaxypyr	2.15	2.05	1.93	1.85	1.82	1.88	1.97	1.69	1.71	1.75	2.10	1.78	1.72	1.65
Flubendiamide	2.80	2.74	2.62	2.52	2.58	2.61	2.65	2.18	2.24	2.32	2.70	2.40	2.45	2.10
Spinosad	2.77	2.73	2.65	2.60	2.56	2.58	2.64	2.36	2.42	2.48	2.67	2.52	2.57	2.30
Indoxacarb	4.80	4.72	4.45	4.36	3.75	3.88	4.52	3.32	3.45	3.61	4.61	4.30	4.40	3.20
Quinalphos	188.67	182.32	175.00	167.72	154.04	148.28	160.10	110.23	118.00	127.60	190.00	140.21	146.48	100.00
Chlorpyriphos	238.04	240.00	226.20	221.32	230.10	229.62	234.00	200.00	205.40	212.52	230.00	227.08	225.80	210.12
Thiodicarb	63.40	65.00	58.23	60.00	55.60	57.14	61.20	50.00	51.30	56.38	63.82	55.10	53.38	54.06
Cypermethrin	42.00	39.70	38.00	36.00	35.90	36.40	38.50	35.10	35.80	35.40	40.30	37.00	37.80	35.00
Endosulfan	240.00	237.47	232.34	227.42	221.42	224.30	228.21	182.00	184.60	186.00	234.18	230.14	231.07	180.00
Monocrotophos	177.90	180.00	162.62	163.74	160.02	159.20	165.20	147.22	152.16	156.27	176.54	168.32	165.41	140.00
Carbaryl	150.00	147.64	137.00	139.17	135.00	138.00	142.20	120.08	127.60	130.10	144.32	137.00	134.26	122.00
Emmamectin Benzoate	3.98	4.20	3.72	3.48	3.30	3.45	3.53	2.34	2.62	2.81	4.11	2.96	3.18	2.15

PBN-Parbhani; DAP-Dapoli; KLP-Kolhapur; Hyd-Hyderabad; VJA-Vijaywada; W.G-West Godavari; Margoa; MAA-Madurai; CBE-Coimbatore; ADT-Aduturai; RCR-Raichur; BJP-Bijapur; DWD-Dharwad; BGL-Banglaore.

Table 39. Contingent table showing LC_{50} values for all the twelve insecticides bioassayed during 2010-11

Locations	LC_{50} (ppm)													
	RCR	**BGL**	**BJP**	**DWD**	**PBN**	**DAP**	**KLP**	**MAA**	**CBE**	**ADT**	**HYD**	**VJA**	**W.G**	**Margoa**
Rynaxypyr	2.30	2.18	2.05	1.97	1.80	2.03	2.10	1.77	1.93	1.84	2.17	1.88	1.82	1.70
Flubendiamide	2.94	2.88	2.73	2.61	2.69	2.72	2.76	2.28	2.35	2.42	2.84	2.51	2.57	2.14
Spinosad	2.93	2.89	2.78	2.72	2.68	2.71	2.78	2.44	2.5	2.55	2.85	2.66	2.70	2.42
Indoxacarb	4.97	4.88	4.60	4.48	3.87	4.21	4.62	3.41	3.58	3.74	4.72	4.42	4.50	3.28
Quinalphos	195.23	188.61	181.00	174.12	166.00	157.20	168.42	124.27	130.00	136.10	197.16	149.34	155.49	121.60
Chlorpyriphos	247.75	249.83	235.19	230.21	242.41	240.72	248.24	212.4	217.36	224.52	238.47	235.69	234.71	227.05
Thiodicarb	72.22	74.82	69.70	71.35	64.10	68.44	72.60	66.12	63.18	71.34	76.10	64.23	64.10	70.42
Cypermethrin	56.30	52.42	47.82	44.07	48.32	45.19	47.23	51.08	53.14	49.54	58.60	46.30	45.20	52.26
Endosulfan	247.42	244.72	240.61	234.09	231.6	235.30	237.52	196.27	198.12	194.39	242.67	238.22	240.58	198.25
Monocrotophos	183.27	187.48	167.07	169.21	171.56	167.25	174.1	161.38	165.62	171.42	182.13	175.21	172.54	155.23
Carbaryl	158.23	156.72	145.20	147.61	143.41	146.31	150.26	138.16	143.49	148.20	153.45	152.00	148.24	139.61
Emmamectin Benzoate	4.22	4.41	3.88	3.64	3.46	3.58	3.67	2.44	2.91	2.73	4.28	3.15	3.31	2.24

PBN-Parbhani; DAP-Dapoli; KLP-Kolhapur; Hyd-Hyderabad; VJA-Vijaywada; W.G-West Godavari; Margoa; MAA-Madurai; CBE-Coimbatore; ADT-Aduturai; RCR-Raichur; BJP-Bijapur; DWD-Dharwad; BGL-Banglaore.

LEGEND

Lane-1 : Parbhani population

Lane-2 : Dapoli population

Lane-3 : Kolhapur population

Lane-4 : Hyderabad population

Lane-5 : Vijaywada population

Lane-6 : West Godavari population

Lane-7 : Margoa population

Lane-8 : Madurai population

Lane-9 : Coimbatore population

Lane-10: Aduturai population

Lane-11: Raichur population

Lane-12: Bijapur population

Lane-13: Dharwad population

Lane-14: Bangalore population

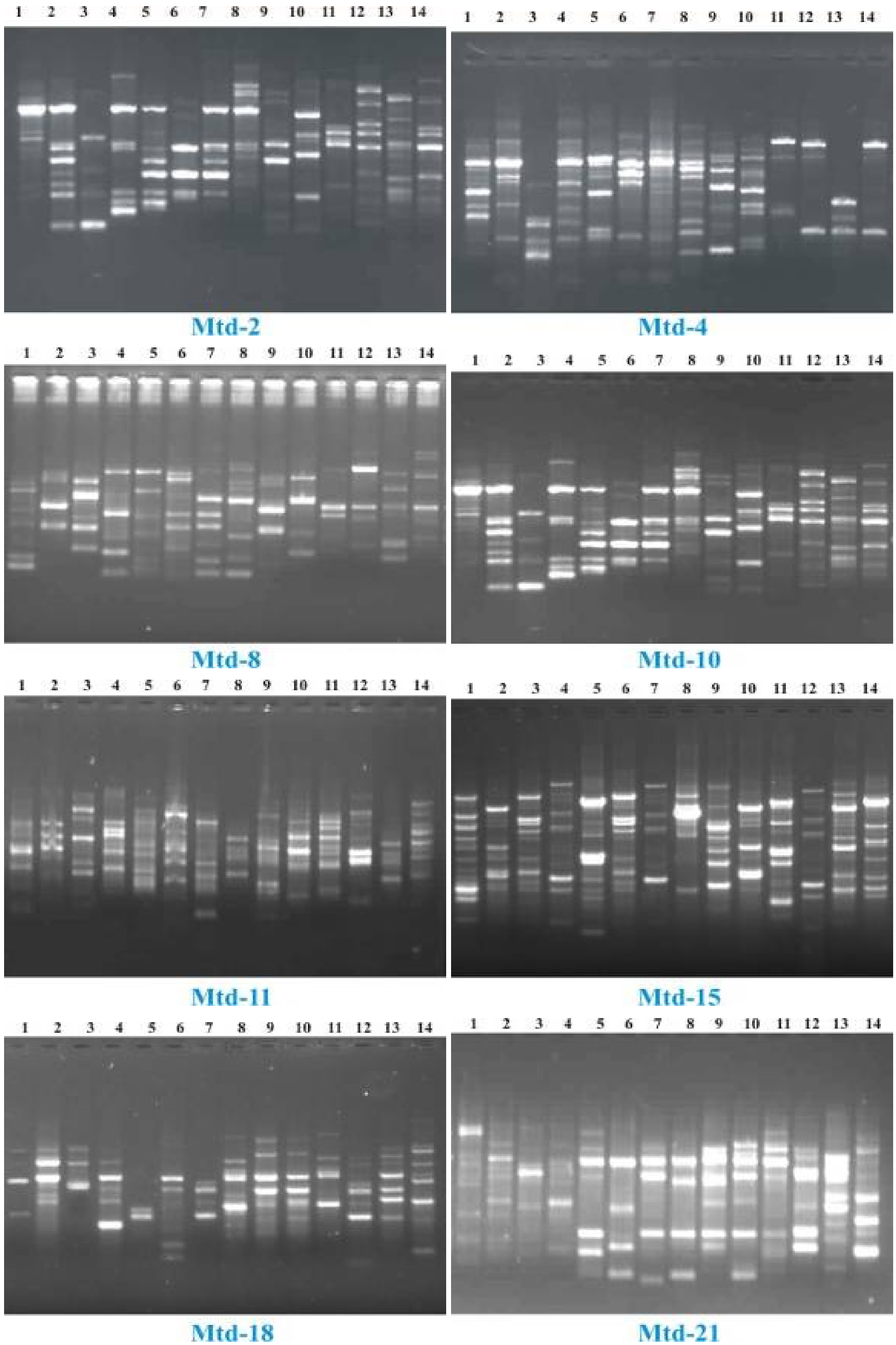


Plate 3: DNA profiles of the primers Mtd 2, Mtd 4, Mtd 8, Mtd 10, Mtd 11, Mtd 15, Mtd 18 and Mtd 21

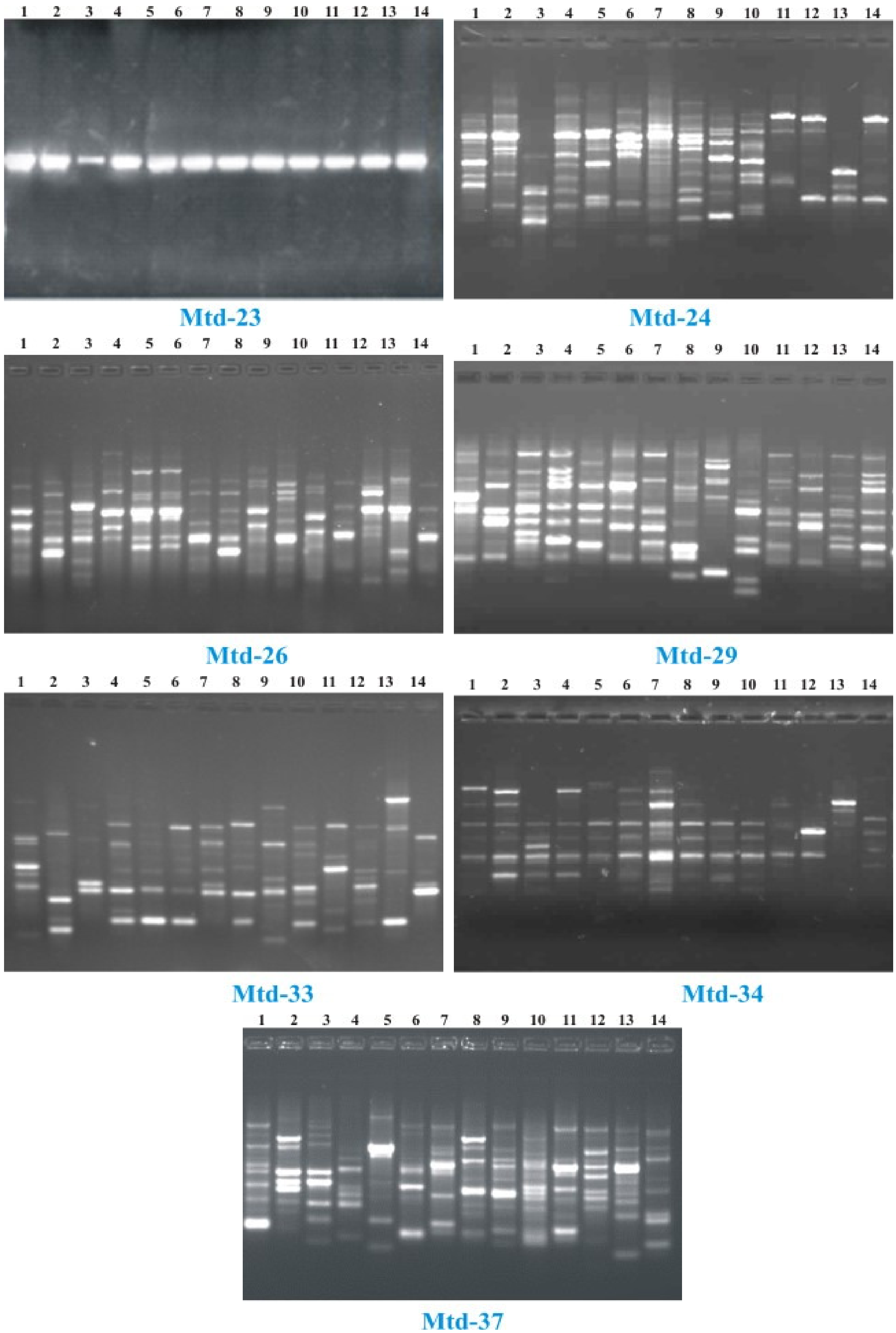


Plate 4: DNA profiles of the primers Mtd 23, Mtd 24, Mtd 26, Mtd 29, Mtd 33, Mtd 34 and Mtd 37

All the 15 primers selected for the study produced unique banding patterns that could differentiate all the 14 geographic populations. Based on simple matching co-efficients a genetic similarity matrix was constructed using mtd marker data, to assess the genetic relatedness among selected populations. Similarity co-efficients ranged from 0.38 to 0.90 among populations.

The minimum genetic relatedness was 18 per cent between Bangalore and Hyderabad populations. The highest genetic similarity of 90 per cent was evident between the populations of Aduthurai and Coimbatore. Genetic similarity coefficients indicating the extent of relatedness among geographic populations are furnished in (Table 40).

Clustering and principal component analysis (PCA) clearly showed two major groups X and Y in geographical populations of *L. orbonalis* (Fig.2). In PCA, the first two components accounted for 10% of the variation. The first group (X) comprised nine populations while the distinct second group (Y) consisted of only five populations (Goa, Bangalore, Raichur, Bijapur and Dharwad). The X group is subdivided into X1 and X2 at a similarity coefficient of 0.52, where The X1 group comprising three geographical populations. X2 comprised six populations included two distinct groups (at a similarity coefficient of 0.72) X2.1 and X2.2; X2.1 group consisting of from Hyderabad, Vijaywada, West Godavari, while X2.2 comprised population from Aduthurai, Chennai and Coimbatore.

The Y group is subdivided into Y1 and Y2 at a similarity co-efficient of 0.62,where Y1 consisting of single population of Goa and the Y2 group comprising four geographical populations consisting of Bangalore, Raichur, Bijapur and Dharwad.

On the basis of simple matching coefficients all the selected populations were grouped into 5 clusters. Cluster 5 had maximum of four populations followed by cluster 1, 2 and 3 with three populations each and cluster 4 with a single population.

4.4 Population dynamics of SFB in selected wild species of brinjal

The data on the number of shoots and fruits affected by shoot and fruit borer *L. orbonalis* was recorded at fortnightly interval is presented in Table 41. Totally six wild species *viz.*, *Solanum torvum*, *Solanum indicum*, *Solanum viarum*, *Solanum incanum*, *Solanum virginianum* and *S. macrocarpon* were selected. Among all the species *S. torvum* and *S.viarum* were found to be dominating species at all the surveyed locations. The differences of shoot and fruit damage were found to be highly significant among the species. The data revealed that, the shoot and fruit damage in *S.torvum* (Plate 5) varied from 1.93 to 16.51 and 15.62 to 46.45 per cent and differed significantly during different months in both the seasons of 2009 and 2010 (Table 41). Maximum infestation was found to be during the months of October, November, December and January in both the seasons of 2009 and 2010. Over all mean shoot and fruit infestation was to found to be 7.16 and 27.29 per cent. According to the fruit damage (21-30 %) it is classified as tolerant (Table 41). During both the seasons 2009 and 2010, the wild species of *S. indicum* (Plate 6) recorded highest shoot and fruit infestation, which varied from 2.50 to 29.20 per cent and 10.00 to 44.24 per cent (Table 41). The shoot and fruit infestation differed variedly during the different months. Similarly maximum shoot and fruit damage was found to be from September to march during both the seasons. The mean shoot and fruit infestation was recorded as 15.45 and 26.78 per cent. Based on the level of fruit infestation the species is classified as tolerant (Table 42).

Data revealed that, there was no shoot infestation throughout the period in *S. viarum* (Plate 7) species. Whereas, fruit damage was very minimum and varied from 2.10 to 7.28 per cent. The maximum fruit damage (7.28 %) was noticed in the month of 1st fortnight of October 2010. The least damage (2.10 %) was in the month of August 2nd fortnight (Table 41).The mean fruit damage was found to be 1.72 per cent, which falls under the category of highly resistant (Table 42).

The level of shoot and fruit infestation in *S .incanum* (Plate 8) species varied from 1.10 to 5.58 per cent from both the seasons of 2009 and 2010. Whereas, fruit infestation was found to be varied from 1.00 to 8.30 which differed significantly during the various months (Table 41). Over all mean shoot and fruit infestation was found to be 1.92 and 3.63 per cent. Based on the mean fruit infestation the species is classified under highly resistant category (Table 42).

The data from the table revealed that, no shoot infestation was recorded in *S. virginianum* (Plate 9) throughout the seasons of 2009 and 2010. The fruit damage differed significantly during the different months and ranged from 10.30 to 30.24 per cent. The fruit damage was maximum during September to January months of both the seasons. The mean fruit infestation of 13.55 per cent was noticed and belongs to the category of fairly resistant (Table 42).

Table 40. Similarity co-efficients of geographic populations of *L.orbonalis* obtained by mtd conserved primer PCR analysis

	PBN	DAP	KLP	HYD	VJA	W.G	Margoa	MAA	CBE	ADT	BGL	RCR	BJP	DWD
PBN	1.00													
DAP	0.87	1.00												
KLP	0.81	0.85	1.00											
HYD	0.56	0.56	0.56	1.00										
VJA	0.52	0.54	0.54	0.89	1.00									
W.G	0.52	0.51	0.52	0.82	0.88	1.00								
Margoa	0.41	0.43	0.43	0.24	0.32	0.35	1.00							
MAA	0.50	0.52	0.48	0.74	0.70	0.70	0.50	1.00						
CBE	0.52	0.51	0.49	0.69	0.68	0.71	0.45	0.87	1.00					
ADT	0.50	0.52	0.48	0.68	0.68	0.69	0.43	0.83	0.90	1.00				
BGL	0.46	0.46	0.47	0.18	0.25	0.27	0.69	0.26	0.32	0.34	1.00			
RCR	0.49	0.49	0.48	0.23	0.25	0.26	0.64	0.29	0.33	0.38	0.88	1.00		
BJP	0.54	0.50	0.51	0.30	0.30	0.32	0.59	0.35	0.35	0.38	0.82	0.88	1.00	
DWD	0.51	0.48	0.48	0.32	0.34	0.33	0.57	0.39	0.40	0.41	0.76	0.83	0.89	1.00

PBN-Parbhani; DAP-Dapoli; KLP-Kolhapur; Hyd-Hyderabad; VJA-Vijaywada; W.G-West Godavari; Margoa; MAA-Madurai; CBE-Coimbatore; ADT-Aduturai; RCR-Raichur; BJP-Bijapur; DWD-Dharwad; BGL-Banglaore.

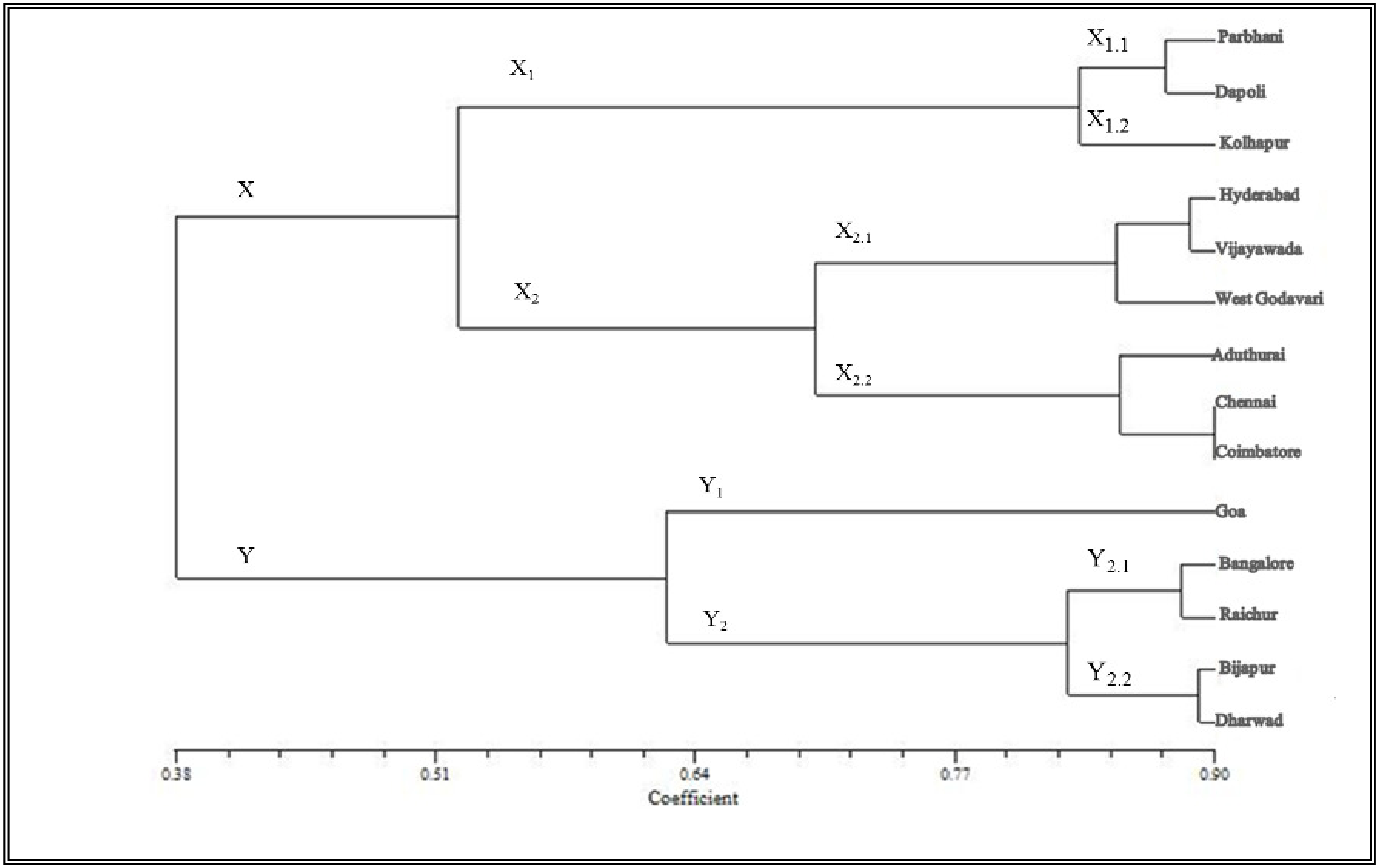


Fig 2. Dendrogram of Brinjal shoot and fruit borer, *L.orbonalis* populations constructed based on co-efficients with UPGMA-SAHN clustering method

Table 41. Per cent Infestation of *Leucinodes orbonalis* in wild species of brinjal in surveyed areas of North Karnataka region during 2009-10 and 2010-11 season

Month		Per cent shoot and fruit damage*											
		S. torvum		*S. indicum*		*S. viarum*		*S. incanum*		*S. virginianum*		*S. macrocarpon*	
		Shoot	Fruit	Shoot	Fruit	Shoot	Fruit	Shoot	Fruit	Shoot	Fruit	Shoot	Fruit
July 09	1st fortnight	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2nd fortnight	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August 09	1st fortnight	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2nd fortnight	4.33	0.00	3.10	0.00	0.00	0.00	0.00	1.28	0.00	0.00	0.00	0.00
September 09	1st fortnight	5.51	0.00	4.38	10.00	0.00	0.00	1.20	3.28	0.00	0.00	0.00	0.00
	2nd fortnight	6.10	20.30	6.23	16.66	0.00	0.00	1.00	3.86	0.00	0.00	0.00	0.00
October 09	1st fortnight	8.20	24.80	7.14	20.00	0.00	0.00	1.60	4.47	0.00	0.00	20.00	0.00
	2nd fortnight	10.83	25.45	10.33	26.80	0.00	0.00	2.40	5.72	0.00	11.11	0.00	20.00
November 09	1st fortnight	12.10	29.51	12.50	32.40	0.00	3.23	2.92	6.6	0.00	13.1	0.00	33.33
	2nd fortnight	14.42	33.88	14.32	36.22	0.00	4.51	3.24	5.94	0.00	0.00	33.33	0.00
December 09	1st fortnight	12.20	38.70	18.10	40.20	0.00	6.00	3.60	6.28	0.00	17.21	0.00	40.00
	2nd fortnight	16.51	43.82	21.42	43.72	0.00	6.88	4.12	5.10	0.00	20.24	16.66	0.00
January 10	1st fortnight	13.41	40.63	23.20	41.60	0.00	0.00	3.40	4.20	0.00	21.32	0.00	50.00
	2nd fortnight	10.78	37.84	26.82	40.28	0.00	5.61	2.42	3.50	0.00	0.00	20.00	0.00
February 10	1st fortnight	5.12	35.32	22.34	38.33	0.00	3.42	1.88	2.34	0.00	14.60	0.00	36.00
	2nd fortnight	4.32	32.10	20.60	35.32	0.00	0.00	1.10	1.68	0.00	15.10	0.00	0.00
March 10	1st fortnight	5.60	30.12	18.30	32.36	0.00	0.00	0.00	1.00	0.00	13.45	0.00	25.00
	2nd fortnight	4.37	26.90	16.21	30.00	0.00	0.00	0.00	0.00	0.00	10.30	0.00	0.00
April 10	1st fortnight	3.92	22.34	13.24	27.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2nd fortnight	2.35	19.43	12.16	24.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May10	1st fortnight	2.42	18.71	8.72	21.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2nd fortnight	1.93	17.57	5.41	19.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June 10	1st fortnight	3.41	23.68	7.36	17.23	0.00	0.00	2.35	2.88	0.00	16.28	0.00	0.00
	2nd fortnight	3.62	25.80	8.10	16.40	0.00	3.41	3.48	3.62	0.00	0.00	0.00	16.66

Contd….

Month		Per cent shoot and fruit damage*											
		S. torvum		***S. indicum***		***S. viarum***		***S. incanum***		***S. virginianum***		***S. macrocarpon***	
		Shoot	**Fruit**	**Shoot**	**Fruit**	**Shoot**	**Fruit**	**Shoot**	**Fruit**	**Shoot**	**Fruit**	**Shoot**	**Fruit**
July 10	1st fortnight	4.10	26.41	10.00	18.42	0.00	0.00	0.00	4.18	0.00	20.3	0.00	20.00
	2nd fortnight	4.38	28.23	14.00	19.60	0.00	3.88	1.80	3.88	0.00	0.00	0.00	25.00
August 10	1st fortnight	6.61	32.10	15.70	21.20	0.00	6.14	2.30	4.92	0.00	24.42	33.33	20.80
	2nd fortnight	8.21	35.42	15.90	23.52	0.00	2.10	0.00	5.64	0.00	21.60	0.00	33.33
September 10	1st fortnight	10.35	39.67	17.40	26.80	0.00	0.00	3.68	6.10	0.00	26.20	0.00	38.00
	2nd fortnight	11.14	42.20	18.90	29.40	0.00	5.32	4.60	7.23	0.00	27.14	50.00	42.00
October 10	1st fortnight	13.57	44.21	21.47	32.80	0.00	7.28	4.88	8.30	0.00	28.26	0.00	48.20
	2nd fortnight	12.60	45.60	24.82	36.50	0.00	0.00	5.18	6.68	0.00	24.86	20.00	56.00
November 10	1st fortnight	14.78	46.45	27.68	38.41	0.00	5.23	5.58	7.40	0.00	28.90	0.00	64.50
	2nd fortnight	13.14	43.00	28.21	41.10	0.00	0.00	3.65	8.28	0.00	29.40	16.66	75.00
December 10	1st fortnight	10.63	38.12	26.32	42.18	0.00	3.10	4.10	6.94	0.00	30.24	0.00	84.00
	2nd fortnight	8.11	34.35	29.20	44.24	0.00	0.00	3.70	5.72	0.00	27.62	0.00	75.00
January 11	1st fortnight	9.30	32.22	26.48	39.95	0.00	3.60	3.12	4.36	0.00	24.30	12.00	35.00
	2nd fortnight	6.27	29.80	24.12	35.27	0.00	0.00	2.42	3.78	0.00	25.64	0.00	20.60
February 11	1st fortnight	5.33	25.42	20.18	31.30	0.00	0.00	1.00	3.10	0.00	23.18	0.00	16.66
	2nd fortnight	4.57	21.08	17.30	27.62	0.00	2.40	0.00	2.60	0.00	20.36	0.00	12.50
March 11	2nd fortnight	3.82	19.20	14.74	24.20	0.00	0.00	0.00	1.64	0.00	17.20	5.00	10.00
	2nd fortnight	2.30	15.62	13.80	21.60	0.00	0.00	0.00	0.00	0.00	16.72	0.00	0.00
Mean		7.16	27.29	15.45	26.78	0.00	1.72	1.92	3.63	0.00	13.55	5.40	21.37
S.D.		4.49	13.10	8.15	12.40	0.00	2.42	1.78	2.61	0.00	11.27	11.50	24.45

* Mean of five plants

S.D = standard deviation

Table 42. Susceptibility of wild solanum spp. to shoot and fruit borer *L.orbonalis*

Sl. No	Reaction	Fruit Damage (%)	No. of species	Solanum spp.
1.	Immune	0	Nil	---
2.	Highly Resistant	1-10	2	*Solanum viarum* *Solanum incanum*
3.	Fairly Resistant	11-20	1	*Solanum virginianum*
4.	Tolerant	21-30	3	*Solanum torvum* *Solanum indicum* *Solanum macrocarpon*
5.	Susceptible	31-40	Nil	----
6.	Highly susceptible	41 and above	Nil	----

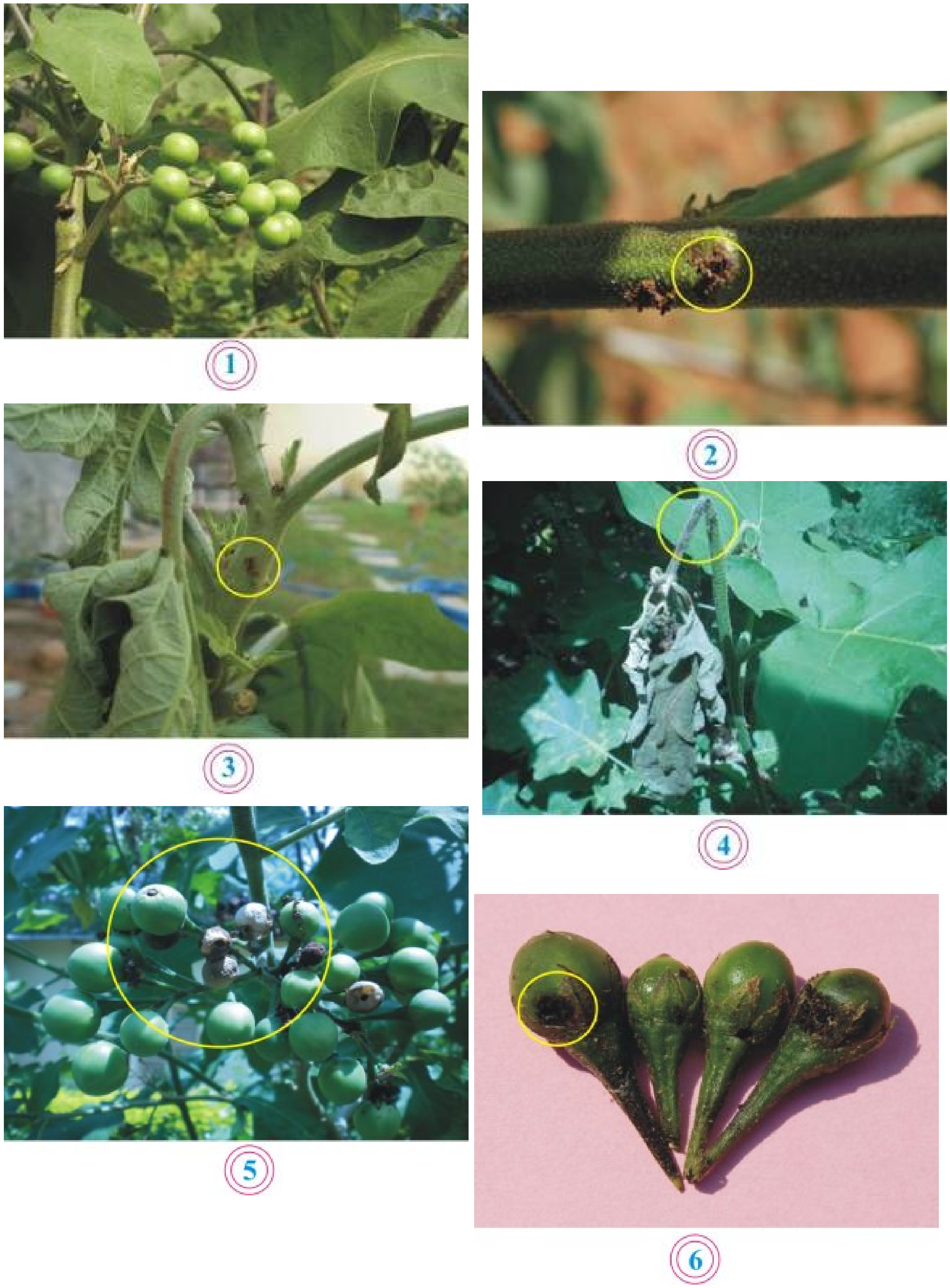


Plate 5: Damage symptoms due to *L. orbonalis* in *Solanum torvum*

Plate 6: Damage symptoms due to *L. orbonalis* in *Solanum indicum*

1

2

Plate 7: Damage symptoms due to *L. orbonalis* in *Solanum viarum*

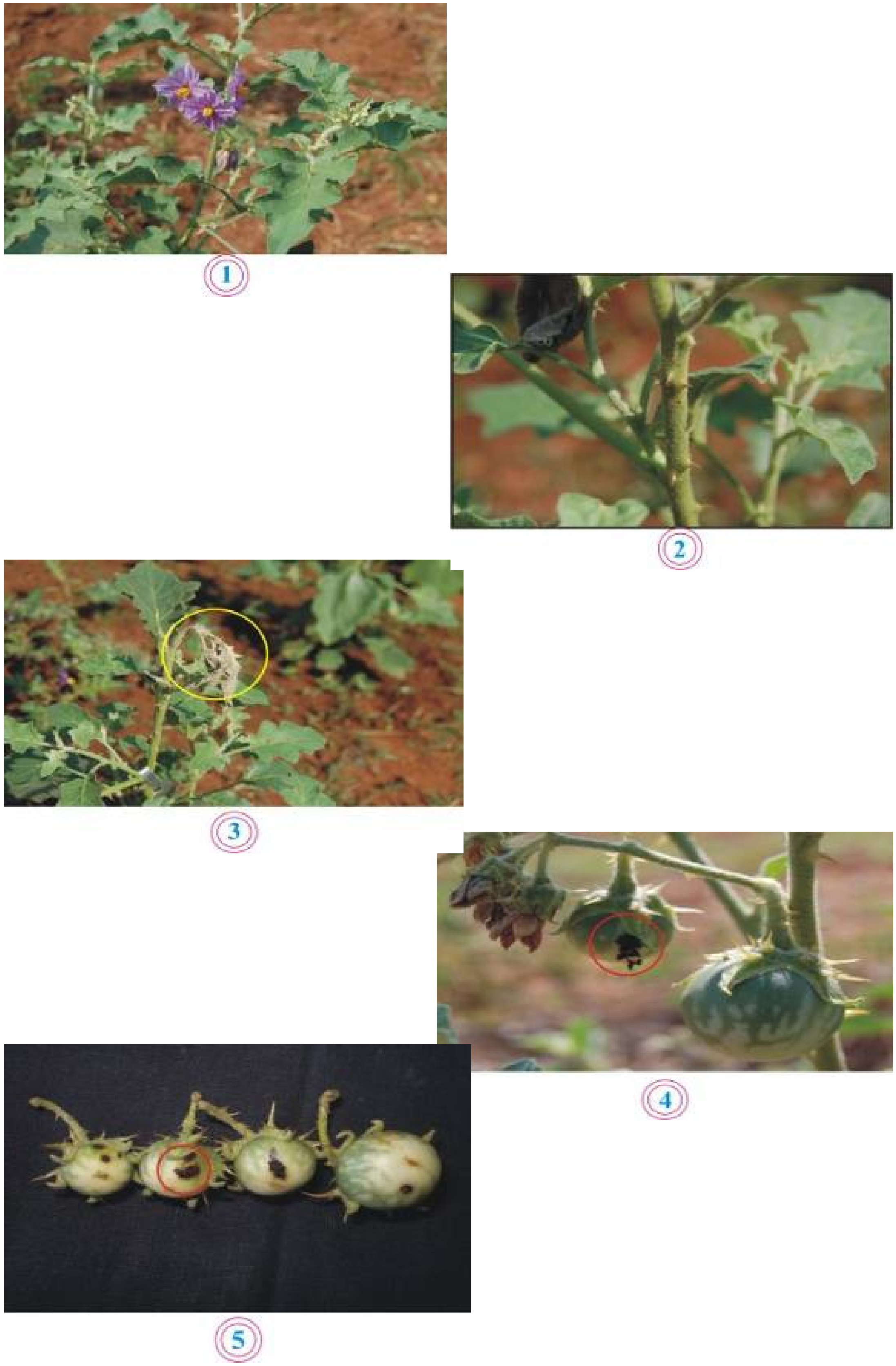


Plate 8: Damage symptoms due to *L. orbonalis* in *Solanum incanum*

1

2

3

4

Plate 9: Damage symptoms due to *L. orbonalis* in *Solanum virginianum*

The species *S. macrocarpon* (Plate 10) recorded both the shoot and fruit damage. The shoot infestation varied from 5.00 to 50.00 per cent and the extent of fruit damage ranged from 16.66 to 56.00 per cent, which differed significantly during the various months. The mean shoot and fruit damage was found to be 5.40 to 21.37 per cent (Table 41). Based on the fruit damage, the species is classified as tolerant (Table 42).

Among the six wild species surveyed, three species have been classified under tolerant category followed by two species under highly resistant category. Only one species was found to be susceptible (Table 42).

4.5 Development and evaluation of IRM/IPM strategies for SFB management in brinjal

4.5.1 Incidence of shoot damage in different modules

The incidence of shoot borer among the different modules differed significantly at different stages of crop growth. The results obtained are presented in the Table 43 .It was observed that there was a significant difference between the treatments at 30 Days after Transplanting (DAT). The incidence of shoot damage ranged from 24.10 to 27.62 per cent. Significantly lowest incidence of shoot damage of 24.10 per cent was observed in Module-I (Farmers practice) which differed significantly with all other modules. The Module-II (IHR+AVRDC) (25.88%) and Module-V (Adoptable) (25.68 %) were on par with each other and differed significantly with other modules. The Module-IV (UAS Raichur) (26.54 %) and Module-III (Biointensive) (27.62 %) differed significantly with each other. Similar trend was noticed at 40 and 50 Days after transplanting (DAT) during 2009-10 crop season (Table 44).

At 60 Days after transplanting (DAT) the lowest incidence of shoot damage was noticed in Module-I (Farmers practice) (18.31 %) followed by Module-V (Adoptable module) (18.80 %) which were on par with each other and differed significantly with all other modules. Module -II (IIHR+AVRDC) recorded shoot damage of 21.40 per cent followed by Module –IV (UAS,Raichur) (22.88 %) and Module-III (Bioitensive) (24.18%) which differed significantly with each other .Similar trend was observed at 70 and 80 Days after transplanting (DAT) (Table 43).

At 90 days after transplanting (DAT), Module-V (Adoptable) recorded lowest incidence of shoot damage (12.08 %) followed by Module I (Farmers Practice) (13.82%), Module-II (IIHR+ AVRDC) (14.72 %), Module-IV (UAS Raichur) (17.35%) and Module –III (Bio-intensive) which recorded shoot damage of 16.47 per cent. All the modules differed significantly with each other. Similar trend was observed at 100, 110 and 120 days after transplanting (DAT) (Table 43).

The data from cumulative mean revealed that, all the modules differed significantly with each other. Significantly lowest incidence of shoot damage was observed in Adoptable module (Module V) (15.52 %) followed by Module-I (farmers practice) (15.80 %), Module -II (IIHR+AVRDC) (17.60 %), Module-V (UAS Raichur) (19.03 %) and Module- III (Bio-intensive) which recorded shoot damage of 20.55 per cent .All the modules differed significantly with each other (Table 43).

In the year 2010-11, similar observations were recorded with reference to shoot damage in all the modules (Table 44). At 30 days after transplanting (DAT), Module- I (farmers practice) registered significantly lowest fruit damage of 19.23 % followed by Module-V (Adoptable) (21.24 %) and Module-II (IIHR+AVRDC) (21.87 %) which were on par with each other and differed significantly with rest of the treatments. The Module- IV (UAS, Raichur) recorded the shoot damage of 23.72 per cent and differed with Module- III (Bio-intensive) which recorded shoot damage of 25.81 per cent.

Similar trend was observed at 40 and 50 days after transplanting (DAT).At 60 DAT, the lowest shoot damage was registered in Module- I (farmers practice) (16.10) followed by Module -V (Adoptable module) (16.34 %) which were on par with each other and differed significantly with rest of the treatments. Whereas, Module- II (IIHR+AVRDC) recorded shoot damage of 18.00 per cent followed by Module -IV (UAS Raichur) (20.72 %) and Module -III (Bio-intensive) (22.72 %) which differed significantly with each other. Similar observations were noticed at 70 and 80 days after transplanting (DAT) (Table 44).

At 90 DAT, module-V (Adoptable) registered least shoot damage of 9.60 percent followed by module-I (farmers practice) (11.00 %), Module-II (IIHR+AVRDC) (12.82 %), Module- IV (UAS Raichur) (9.60 %) and Module- III (Bio- intensive) (15.72%), where in all the modules differed significantly from each other. Similar trend was noticed at 100, 110 and 120 days after transplanting (DAT).

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Plate 10: Damage symptoms due to *L. orbonalis* in *Solanum macrocarpon*

The data from cumulative mean revealed that, all the modules differed significantly with respect to shoot damage. Least shoot damage of 12.95 per cent was noticed in case of Module-V (Adoptable module) followed by Module- I (farmers practice) (13.42 %), Module- II (IIHR+AVRDC) (15.24 %), Module IV (UAS Raichur) (17.30 %) and Module III (Bio-intensive) (11.14 %) which differed significantly from each other (Table 44).

The Pooled mean data from 2009-10 and 2010-11 clearly indicated that, at 30 DAT, Module-II (IIHR+AVRDC) and Module-V (Adoptable module) recorded shoot damage of 23.88 and 23.46 per cent, where both were on par with each other and differed significantly with rest of the treatments. Similar trend was followed at 40 and 50 DAT. At 60 DAT, Module -I (farmers practice) recorded shoot damage of 17.21 per cent and Module -V (Adoptable module) (17.57 %) were on par with each other and differed significantly compared to rest of the treatments. Similar observations were noticed at 70 and 80 DAT. At 90 DAT, Module-V (Adoptable) recorded lowest shoot damage of 10.84 per cent followed by Module-I (farmers practice) (12.41 %), which were found to be on par with each other and differed significantly with other treatments. Similar observations were also recorded at 100, 110 and 120 DAT (Table 45).

4.5.2 Incidence of fruit damage in different modules

The fruit damage due to shoot and fruit borer incidence was recorded at each picking during 2009-10 cropping season and the per cent fruit damage was worked out picking wise and the cumulative mean per cent fruit damage was worked out and presented in Table 46.

That data on per cent fruit damage revealed that, during first picking, the mean per cent fruit damage was significantly less in Module- V (Adoptable) (19.12 %) followed by Module- I (farmers practice) (19.72 %) which were on par with each other and differed significantly with rest of the treatments . Module -II (IIHR +AVRDC) recorded mean fruit damage of 21.34 per cent followed by Module -IV (UAS Raichur) (22.68 %) and Module- III (Bio-intensive) (24.52) which differed significantly with each other. Similar observations were recorded at second, third and fourth pickings. Whereas, at fifth picking, least mean fruit damage (14.21%) was recorded in Module-V (Adoptable module) followed by Module-I (farmers practice) (15.61 %), Module-II (IIHR+AVRDC) (17.20 %), Module-IV (UAS Raichur) (18.78 %) and Module- III (Bio-inetnsive) which recorded the mean fruit damage of 20.10 per cent. All the modules differed significantly with respect to each other. Similar trend was also observed at sixth, seventh and eighth pickings (Table 46).

The data on cumulative mean per cent fruit damage revealed that, lowest mean fruit damage of 14.68 per cent was recorded in Adoptable module (Module V) (14.68 %) followed by Module-I (farmers practice) (15.47 %), IIHR+ AVRDC (Module II) (17.38 %), Module-IV (UAS Raichur) (18.77 %) and Module- III (Bio-intensive) (19.74%) where in all the modules differed significantly with each other with respect to fruit damage (Table 46).

During the year 2010-11, the data on per cent mean fruit damage at different pickings are presented in Table 47. In case of first picking, lowest mean fruit damage was observed in Module-V (Adoptable module) (18.35 %) and Module-I (farmers practice) (18.67 %) which were on par with each other and differed over rest of the modules. Similar trend was noticed at second, third and fourth pickings. Whereas, at fifth picking significantly least fruit damage was recorded in Module-V (Adoptable module) (13.10 %) followed by Module- I (farmers practice) (14.10 %) which were on par with each other and differed significantly over rest of the treatments. Similar observations of fruit damage were recorded in case of sixth, seventh and eighth pickings (Table 47).

The data from the cumulative mean revealed that, all the modules differed significantly with respect to fruit damage. The lowest fruit damage of 13.60 per cent was recorded in Module-V (Adoptable) followed by Module-I (farmers practice) (14.20 %), Module -II (IIHR+AVRDC) (15.95 %), Module -IV (UAS Raichur) (17.35 %) and Module -III (Bio-intensive) (18.82 %), which differed significantly with each other (Table 47).

The pooled mean data from 2009-10 and 2010-11 cropping seasons showed that, in case of first four pickings, lowest fruit damage was recorded in Module-V (Adoptable module) (18.74 to 16.79 %) and Module- I (farmers practice) (19.20 to 16.50 %) which were on par with each other and differed significantly with each other. Whereas, in remaining pickings of fifth, sixth, seventh and eighth pickings, significantly lowest fruit damage was recorded in Module-V (Adoptable module) (13.66 to 7.46 %) followed by Module-I (farmers practice) (14.86 to 8.77 %), Module- II (IIHR+ AVRDC) (16.14 to 10.29 %), Module- IV (UAS Raichur) (17.65 to 11.72 %) and Module- III (Bio-intensive) (19.21 to 13.24 %) which differed significantly with each other (Table 48).

Table 43. Per cent shoot damage by *Leucinodes orbonalis* in different IPM modules during 2009-10 season

Treatments	Shoot damage (%)*										Cumulative Mean
	30 DAT*	40 DAT	50 DAT	60 DAT	70 DAT	80 DAT	90 DAT	100 DAT	110 DAT	120 DAT	
T_1- Module I (Farmers practice)	24.10 (29.40)a	22.72 (28.47)a	21.60 (27.69)a	18.31 (25.33)a	16.14 (23.69)a	15.61 (23.27)a	13.82 (21.82)b	11.18 (19.53)b	8.71 (17.17)b	6.28 (14.51)b	15.80 (23.45)b
T_2- Module II (IIHR+AVRDC)	25.88 (30.58)b	24.42 (29.61)b	22.70 (28.45)b	21.40 (27.42)b	17.50 (24.73)b	16.88 (24.26)b	14.72 (22.56)c	13.83 (20.99)c	10.46 (18.87)c	8.23 (16.67)c	17.60 (24.81)c
T_3- Module III (Bio-itensive)	27.62 (31.71)d	26.60 (31.05)d	25.36 (30.24)d	24.18 (29.45)d	23.10 (28.73)d	19.78 (26.41)d	17.35 (24.62)e	15.70 (23.34)e	14.21 (22.15)e	11.59 (19.90)e	20.55 (26.96)e
T4- Module IV (UAS, Raichur)	26.54 (31.01)c	25.68 (30.45)c	23.68 (29.12)c	22.88 (28.58)c	20.32 (26.79)c	18.45 (25.44)c	16.47 (23.94)d	14.35 (22.26)d	12.00 (20.27)d	9.88 (18.32)d	19.03 (25.86)d
T5- Module V (Adoptable)	25.68 (30.45)b	24.14 (29.43)b	22.62 (28.40)b	18.80 (25.70)a	15.10 (22.87)a	14.30 (22.22)a	12.08 (20.34)a	9.72 (18.17)a	7.36 (15.74)a	5.42 (13.46)a	15.52 (23.20)a
SEm$\pm$	0.18	0.20	0.23	0.56	0.31	0.29	0.22	0.34	0.44	0.33	0.07
CD at 5%	0.53	0.58	0.70	1.67	0.92	0.86	0.64	1.03	1.32	0.98	0.22
CV (%)	9.64	10.61	13.32	12.64	10.23	13.18	14.62	16.24	9.31	8.61	10.42

*Mean of 40 plants
DAT – Days after Transplanting
Figures in parentheses are arc sin transformed values
Means followed by same alphabet do not differ significantly by DMRT at 5%

Table 44. Per cent shoot damage by *Leucinodes orbonalis* in different IPM modules during 2010-11 season

Treatments	Shoot damage (%)*										Cumulative Mean
	30 DAT*	40 DAT	50 DAT	60 DAT	70 DAT	80 DAT	90 DAT	100 DAT	110 DAT	120 DAT	
T_1- Module I (Farmers practice)	19.23 (26.01)a	18.85 (25.73)a	17.27 (24.56)a	16.10 (23.66)a	14.67 (22.52)a	12.23 (20.47)a	11.00 (19.28)b	9.50 (17.95)b	8.14 (16.58)b	7.23 (15.60)b	13.42 (21.49)b
T_2- Module II (IIHR+AVRDC)	21.87 (27.88)b	20.52 (26.94)b	19.51 (26.21)b	18.00 (25.10)b	16.67 (24.10)b	14.28 (22.20)b	12.82 (20.79)c	11.08 (19.44)c	9.45 (17.90)c	8.18 (16.62)c	15.24 (22.98)c
T_3- Module III (Bio-itensive)	25.81 (30.53)d	24.52 (29.68)d	24.90 (29.93)d	22.72 (28.47)d	20.24 (26.74)d	18.20 (25.25)d	15.72 (23.36)e	13.75 (21.77)e	12.22 (20.46)e	11.14 (19.50)e	18.92 (25.78)e
T4- Module IV (UAS, Raichur)	23.72 (29.15)c	22.76 (28.49)c	23.06 (28.70)c	20.72 (27.08)c	18.59 (25.54)c	16.71 (24.13)c	13.92 (21.91)d	12.18 (20.43)d	11.31 (19.65)d	10.03 (18.46)d	17.30 (24.58)d
T5- Module V (Adoptable)	21.24 (27.44)b	20.21 (26.72)b	19 .36 (26.10)b	16.34 (23.84)a	14.88 (22.69)a	12.57 (20.77)a	9.60 (18.05)a	8.20 (16.64)a	7.27 (15.64)a	6.21 (14.43)a	12.95 (21.09)a
SE m±	0.44	0.31	0.39	0.44	0.38	0.35	0.35	0.31	0.26	0.32	0.12
CD at 5%	1.31	0.94	1.18	1.32	1.13	1.06	1.05	0.92	0.77	0.96	0.35
CV (%)	10.44	13.21	12.42	9.34	11.23	10.28	9.12	11.64	10.18	11.41	8.74

*Mean of 40 plants
DAT – Days after Transplanting
Figures in parentheses are arc sin transformed values
Means followed by same alphabet do not differ significantly by DMRT at 5%

Table 45: Pooled data of Per cent shoot damage by *Leucinodes orbonalis* in different IPM modules for two seasons

Treatments	Shoot damage (%)*										Cumulative Mean
	30 DAT*	40 DAT	50 DAT	60 DAT	70 DAT	80 DAT	90 DAT	100 DAT	110 DAT	120 DAT	
T_1- Module I (Farmers practice)	21.67 (27.74)a	20.79 (27.12)a	19.44 (26.16)a	17.21 (24.51)a	15.41 (23.11)a	13.92 (21.91)a	12.41 (20.63)b	10.34 (18.76)b	8.43 (16.87)b	6.76 (15.06)b	14.61 (22.47)b
T_2- Module II (IIHR+AVRDC)	23.88 (29.25)b	22.47 (28.30)b	21.11 (27.35)b	19.70 (26.35)b	17.09 (24.41)b	15.58 (23.25)b	13.77 (21.78)c	12.46 (20.67)c	9.96 (18.39)c	8.21 (16.65)c	16.42 (23.90)c
T_3- Module III (Bio-intensive)	26.72 (31.12)d	25.56 (30.37)d	25.13 (30.09)d	23.45 (28.96)d	21.67 (27.74)d	18.99 (25.83)d	16.54 (23.99)e	14.73 (22.57)e	13.22 (21.32)e	11.37 (19.70)e	19.74 (26.38)e
T4- Module IV (UAS, Raichur)	25.13 (30.09)c	24.22 (29.48)c	23.37 (28.91)c	21.80 (27.83)c	19.46 (26.17)c	17.58 (24.79)c	15.20 (22.94)d	13.27 (21.36)d	11.66 (19.96)d	9.96 (18.39)d	18.16 (25.23)d
T5- Module V (Adoptable)	23.46 (28.79)b	22.18 (28.09)b	20.99 (27.27)b	17.57 (24.78)a	14.99 (22.78)a	13.44 (21.50)a	10.84 (19.22)a	8.96 (17.42)a	7.32 (15.69)a	5.82 (13.95)a	14.23 (22.16)a
SE m±	0.27	0.29	0.36	0.34	0.42	0.33	0.32	0.22	0.44	0.36	0.09
CD at 5%	0.80	0.86	1.07	1.03	1.25	0.99	0.96	0.65	1.31	1.07	0.28
CV (%)	10.20	9.42	13.21	8.68	12.10	10.31	11.42	12.43	13.25	9.61	8.41

*Mean of 40 plants
DAT – Days after Transplanting
Figures in parentheses are arc sin transformed values
Means followed by same alphabet do not differ significantly by DMRT at 5%

Table 46 .Per cent fruit damage by *Leucinodes orbonalis* in different IPM modules during 2009-10 season

Treatments	Mean per cent fruit infestation by *L. orbonalis* at different pickings								Cumulative Mean
	I picking	II picking	III picking	IV picking	V picking	VI picking	VII picking	VIII picking	
T_1- Module I (Farmers practice)	19.72 (26.36)a	17.54 (24.76)a	18.10 (25.18)a	17.51 (24.74)a	15.61 (23.27)b	13.80 (21.81)b	11.55 (19.87)b	9.53 (17.98)b	15.47 (23.16)b
T_2- Module II (IIHR+AVRDC)	21.34 (27.51)b	19.88 (26.48)b	20.72 (27.08)b	19.65 (26.31)b	17.20 (24.50)c	15.47 (23.16)c	13.67 (21.70)c	11.10 (19.46)c	17.38 (24.64)c
T_3- Module III (Bio-itensive)	24.52 (29.68)d	22.78 (28.51)d	23.88 (29.25)d	22.42 (28.26)d	20.10 (26.64)e	18.34 (25.36)e	16.27 (23.79)e	13.78 (21.79)e	19.74 (26.38)e
T4- Module IV (UAS, Raichur)	22.68 (28.44)c	21.32 (27.50)c	22.28 (28.17)c	20.84 (27.16)c	18.78 (25.68)d	16.89 (24.27)d	14.94 (22.74)d	12.44 (20.65)d	18.77 (25.67)d
T5- Module V (Adoptable)	19.12 (25.93)a	17.26 (24.55)a	18.43 (25.42)a	17.86 (25.00)a	14.21 (22.15)a	12.32 (20.55)a	10.18 (18.61)a	8.05 (16.48)a	14.68 (22.53)a
SE m$\pm$	0.29	0.30	0.34	0.26	0.30	0.33	0.32	0.36	0.19
CD at 5%	0.88	0.88	1.03	0.78	0.89	1.01	0.95	1.07	0.56
CV (%)	8.23	10.34	9.27	6.74	11.10	9.43	12.37	13.61	12.23

*Mean of 40 plants
Figures in parentheses are arc sin transformed values
Means followed by same alphabet do not differ significantly by DMRT at 5%

Table 47.Per cent fruit damage by *Leucinodes orbonalis* in different IPM modules during 2010-11 season

Treatments	Mean per cent fruit infestation by *L. orbonalis* at different pickings								
	I picking	II picking	III picking	IV picking	V picking	VI picking	VII picking	VIII picking	Cumulative mean
T_1- Module I (Farmers practice)	18.67 (25.60)a	16.21 (23.74)a	17.75 (24.92)a	15.48 (23.17)a	14.10 (22.06)b	13.03 (21.16)b	10.38 (18.79)b	8.00 (16.43)b	14.20 (22.14)b
T_2- Module II (IIHR+AVRDC)	20.59 (26.99)b	18.77 (25.67)b	19.55 (26.24)b	18.04 (25.13)b	15.08 (22.85)c	14.40 (22.30)c	11.72 (20.02)c	9.47 (17.92)c	15.95 (23.54)c
T_3- Module III (Bio-itensive)	23.36 (28.90)d	21.82 (27.85)d	22.82 (28.54)d	20.48 (26.91)d	18.31 (25.33)e	16.65 (24.08)e	14.45 (22.34)e	12.70 (20.88)e	18.82 (25.71)e
T4- Module IV (UAS, Raichur)	21.77 (28.04)c	20.32 (26.79)c	21.41 (27.56)c	19.39 (26.13)c	16.52 (23.98)d	15.25 (22.99)d	13.10 (21.22)d	11.00 (19.37)d	17.35 (24.61)d
T5- Module V (Adoptable)	18.35 (25.36)a	16.47 (23.94)a	17.34 (24.61)a	15.72 (23.36)a	13.10 (21.22)a	11.90 (20.18)a	9.07 (17.53)a	6.87 (15.20)a	13.60 (21.64)a
SE m±	0.27	0.32	0.30	0.24	0.26	0.30	0.35	0.40	0.15
CD at 5%	0.80	0.96	0.89	0.71	0.78	0.91	1.04	1.19	0.45
CV (%)	7.64	9.21	8.32	10.27	9.45	11.13	11.10	10.12	10.17

*Mean of 40 plants
Figures in parentheses are arc sin transformed values
Means followed by same alphabet do not differ significantly by DMRT at 5%

Table 48. Pooled data of Per cent fruit damage by *Leucinodes orbonalis* in different IPM modules for two seasons

Treatments	Mean per cent fruit infestation by *L. orbonalis* at different pickings								
	I picking	II picking	III picking	IV picking	V picking	VI picking	VII picking	VIII picking	Cumulative mean
T_1- Module I (Farmers practice)	19.20 (25.98)a	16.88 (24.25)a	17.93 (25.05)a	16.50 (23.96)a	14.86 (22.67)b	13.42 (21.49)b	10.97 (19.34)b	8.77 (17.22)b	14.81 (22.63)b
T_2- Module II (IIHR+AVRDC)	20.97 (27.25)b	19.33 (26.08)b	20.14 (26.66)b	18.85 (25.73)b	16.14 (23.69)c	14.94 (22.73)c	12.70 (20.87)c	10.29 (18.71)c	16.67 (24.09)c
T_3- Module III (Bio-itensive)	23.94 (29.29)d	22.30 (28.18)d	22.82 (28.54)d	21.45 (27.59)d	19.21 (25.99)d	17.50 (24.73)d	15.36 (23.07)d	13.24 (21.34)d	19.48 (26.19)d
T4- Module IV (UAS, Raichur)	22.23 (28.13)c	20.82 (27.15)c	21.85 (27.86)c	20.12 (26.65)c	17.65 (24.84)e	16.07 (23.63)e	14.02 (21.99)e	11.72 (20.02)e	18.06 (25.15)e
T5- Module V (Adoptable)	18.74 (25.65)a	16.87 (24.25)a	17.89 (25.02)a	16.79 (24.19)a	13.66 (21.69)a	12.11 (20.36)a	9.63 (18.07)a	7.46 (15.85)a	14.14 (22.09)a
SE m±	0.28	0.33	0.21	0.29	0.32	0.23	0.35	0.42	0.16
CD at 5%	0.83	0.98	0.64	0.87	0.95	0.85	1.04	1.25	0.49
CV (%)	9.62	11.21	12.34	10.61	8.23	12.18	13.08	10.37	11.10

*Mean of 40 plants
Figures in parentheses are arc sin transformed values
Means followed by same alphabet do not differ significantly by DMRT at 5%

Cumulative mean data (Table 48) showed that, all the modules differed significantly with respect to fruit damage. The lowest fruit damage of 14.14 per cent was recorded in Module-V (Adopatble) (14.14 %) followed by Module- I (farmers practice) (14.81%), Module-II (IIHR+AVRDC)(16.67%), Module-IV (UAS Raichur) (18.06 %) and Module- III (Bio-itensive) (19.48 %) .

4.5.3 Natural enemies

4.5.3.1 Coccinellids

Population of coccinellids was recorded at 10 days interval starting from 30 days after transplanting to 110 DAT (2009-10) (Table 49.). At 30 DAT, population of coccinellids ranged from 0.64 to 1.25. Highest population was recorded in Module V (Adoptable) (1.25/plant) followed by Module III (1.21/plant), Module II (1.19/plant) and Module-I (1.09/plant) which were on par with each other, whereas least population was in Module-I (Farmers practice) (0.64 /plant). Similar trend was observed even at 40, 50 and 60 DAT.

At 70 DAS, observation in different treatments the population of coccinellids ranged from 0.50 to 1.57 per plant. The modules *viz.,* Module-III, Module-II recorded 1.65 and 1.60 per plant respectively and were on par with each other. The lowest population was observed in the Module-I (0.50/plant) which differed significantly with rest of modules. At 80 DAT, population of coccinellids ranged from 0.45 - 1.42. The Module-V, Module-IV and Module-I recorded population of 1.351.10 and 0.50 per plant and differed significantly with each other. The Module II (1.60 per plant) and Module-III (1.65) were on par with each other (Table 49.).

Highest coccinellid population at 80 DAT observation was recorded in Module-III (1.42 per plant) followed by Module-II (1.36 per plant) and were on par with each other. The modules-V, IV and I recorded the coccinellid population of 1.02, 0.80 and 0.45 per plant and differed significantly with each other. At 90 DAT, observation among different treatments highest coccinellid population was recorded in Module-III (1.35/ plant) followed by Module-II (1.20/plant) which were on par with each other but differed significantly with rest of the Modules in the study. Similar trend was observed at 100 and 110 DAT wherein, the modules II and II remained par with each other (Table 49).

In the consecutive year (2010-11) Coccinellids population at 30 DAT ranged from 0.68 to 1.23. Highest population was recorded in Module V (Adoptable) (1.23/plant) followed by Module II (1.21/plant), Module III (1.18/plant) and Module (1.09/plant) which were on par with each other. At 40 DAT, highest population of coccinellids was observed in Module-III (1.34/plant) followed by Module-II (1.32/ plant), Module-V (1.30/plant) and Module-IV (1.24/plant) which were on par with each other and least was recorded in Module-I (0.60/plant). The trend remained same even at 50 and 60 DAT observations (Table 50).

At 70 DAT, highest coccinellid population was recorded in Module-III (1.60/plant) followed by Module-II (1.52/plant) and were on par with each other, but differed with rest of the modules *viz.,* Module-V, Module-IV and Module-I which recorded coccinellid population of 1.30, 1.05 and 0.39 per plant respectively and differed significantly with each other. The population of coccinellid at 80 DAT in different modules ranged from 0.32 to 1.68 in which highest was in the Module-III and least in Module-I. The modules Ii and III were on par with each other which recorded 1.68 and 1.62 coccinellids per plant (Table 50).

Coccinellid population at 90 DAT was highest in the Module-III (1.43/plant) and least in Module-I (0.27/plant) which were on par with each other. Coccinellid population of 1.40, 1.05 and 0.78 per plant recorded in the modules-II, V and IV respectively. Similar trend was observed even at both 100 and 110 DAT where the Modules II and II were on par with each other and differed significantly with other modules (Table 50).

Pooled mean data for two years (2009-10 and 2010-11) revealed that, Module-I (Farmers practice) recorded lowest population and differed significantly with rest of the modules at all days of observations. Whereas, Module II, III, IV and V recorded the population of (1.20, 1.20, 1.11 and 1.24/plant) and were on par with eachother. Similar trend was observed at 40, 50 and 60 DAT. At 70 DAT, highest population of 1.63/plant was recorded in Module II and Module III (1.56/plant) which were on par with each other and differed significantly over rest of the modules. MModules IV and module V recorded 1.08 and 1.33/plant and differed significantly with each other. Similar trend was noticed at 80, 90, 100 and 110 DAT (Table 51).

Table 49: Mean population of coccinellids in different IPM modules during 2009-10 season

Treatments	No of coccinellids/plant*								
	30 DAT*	40 DAT	50 DAT	60 DAT	70 DAT	80 DAT	90 DAT	100 DAT	110 DAT
T_1- Module I (Farmers practice)	0.64 (1.07)a	0.58 (1.04)a	0.52 (1.01)a	0. 56 (1.03)a	0.50 (1.00)a	0.45 (0.97)a	0.38 (0.94)a	0.30 (0.89)a	0.22 (0.85)a
T_2- Module II (IIHR+AVRDC)	1.19 (1.30)b	1.30 (1.34)b	1.40 (1.38)b	1.50 (1.41)b	1.60 (1.45)d	1.36 (1.34)d	1.20 (1.30)d	1.10 (1.26)d	1.00 (1.22)d
T_3- Module III (Bio-itensive)	1.21 (1.31)b	1.38 (1.37)b	1.45 (1.40)b	1.57 (1.44)b	1.65 (1.47)d	1.42 (1.39)d	1.35 (1.36)d	1.25 (1.32)d	1.15 (1.28)d
T4- Module IV (UAS, Raichur)	1.09 (1.26)b	1.19 (1.30)b	1.27 (1.33)b	1.35 (1.36)b	1.10 (1.26)b	0.80 (1.14)b	0.68 (1.09)b	0.52 (1.01)b	0.42 (0.96)b
T5- Module V (Adoptable)	1.25 (1.32)b	1.32 (1.35)b	1.48 (1.41)b	1.55 (1.43)b	1.35 (1.36)c	1.02 (1.23)c	0.96 (1.20)c	0.85 (1.16)c	0.72 (1.10)c
SEm±	0.06	0.08	0.10	0.11	0.03	0.02	0.03	0.05	0.04
CD at 5%	0.17	0.24	0.29	0.31	0.08	0.07	0.09	0. 14	0.11
CV (%)	10.61	11.32	13.11	8.69	9.13	10.24	12.52	11.45	13.27

*Mean of 40 plants
DAT – Days after transplanting
Means followed by same alphabet do not differ significantly by DMRT at 5%
Figures in the parentheses are $\sqrt{(x + 0.5)}$ values

Table 50: Mean population of coccinellids in different IPM modules during 2010-11 season

Treatments	No of coccinellids/plant*								
	30 DAT*	40 DAT	50 DAT	60 DAT	70 DAT	80 DAT	90 DAT	100 DAT	110 DAT
T_1- Module I (Farmers practice)	0.68 (1.09)a	0.60 (1.05)a	0.52 (1.01)a	0.46 (0.98)a	0.39 (0.94)a	0.32 (0.91)a	0.27 (0.88)a	0.24 (0.86)a	0.18 (0.82)a
T_2- Module II (IIHR+AVRDC)	1.21 (1.31)b	1.32 (1.35)b	1.40 (1.38)b	1.48 (1.41)b	1.52 (1.42)d	1.62 (1.46)d	1.40 (1.38)d	1.25 (1.32)d	1.13 (1.28)d
T_3- Module III (Bio-itensive)	1.18 (1.30)b	1.34 (1.36)b	1.43 (1.39)b	1.53 (1.42)b	1.60 (1.45)d	1.68 (1.48)d	1.43 (1.39)d	1.28 (1.33)d	1.22 (1.31)d
T4- Module IV (UAS, Raichur)	1.12 (1.27)b	1.24 (1.32)b	1.32 (1.35)b	1.40 (1.38)b	1.05 (1.24)b	1.10 (1.26)b	0.78 (1.13)b	0.55 (1.02)b	0.45 (0.97)b
T5- Module V (Adoptable)	1.23 (1.32)b	1.30 (1.34)b	1.45 (1.40)b	1.51 (1.42)b	1.30 (1.34)c	1.35 (1.36)c	1.05 (1.24)c	0.88 (1.17)c	0.80 (1.14)c
SEm$\pm$	0.05	0.09	0.12	0.13	0.02	0.03	0.04	0.05	0.04
CD at 5%	0.15	0.26	0.35	0.38	0.07	0.09	0.11	0.14	0.13
CV (%)	9.32	10.39	14.10	7.20	10.22	8.13	11.28	12.10	9.47

*Mean of 40 plants
DAT – Days after transplanting
Means followed by same alphabet do not differ significantly by DMRT at 5%
Figures in the parentheses are $\sqrt{(x + 0.5)}$ values

Table 51: Pooled data of mean population of coccinellids in different IPM modules for two seasons

Treatments	No of coccinellids/plant*								
	30 DAT*	**40 DAT**	**50 DAT**	**60 DAT**	**70 DAT**	**80 DAT**	**90 DAT**	**100 DAT**	**110 DAT**
T_1- Module I (Farmers practice)	0.66 (1.08)a	0.59 (1.04)a	0.52 (1.01)a	0.51 (1.00)a	0.45 (0.97)a	0.39 (0.94)a	0.33 (0.91)a	0.27 (0.88)a	0.20 (0.84)a
T_2- Module II (IIHR+AVRDC)	1.20 (1.30)b	1.31 (1.35)b	1.40 (1.38)b	1.49 (1.41)b	1.56 (1.44)d	1.49 (1.41)d	1.30 (1.34)d	1.18 (1.29)d	1.07 (1.25)d
T_3- Module III (Bio-itensive)	1.20 (1.30)b	1.36 (1.36)b	1.44 (1.39)b	1.55 (1.43)b	1.63 (1.46)d	1.55 (1.43)d	1.39 (1.37)d	1.27 (1.33)d	1.19 (1.30)d
T4- Module IV (UAS, Raichur)	1.11 (1.27)b	1.22 (1.31)b	1.30 (1.34)b	1.38 (1.37)b	1.08 (1.25)b	0.95 (1.20)b	0.73 (1.11)b	0.54 (1.02)b	0.44 (0.97)b
T5- Module V (Adoptable)	1.24 (1.32)b	1.31 (1.35)b	1.47 (1.40)b	1.53 (1.42)b	1.33 (1.35)c	1.19 (1.30)c	1.01 (1.23)c	0.87 (1.17)c	0.76 (1.12)c
SEm$\pm$	0.06	0.08	0.11	0.12	0.03	0.03	0.04	0.04	0.04
CD at 5%	0.17	0.25	0.32	0.35	0.08	0.09	0.10	0.11	0.12
CV (%)	7.61	11.13	10.07	8.10	12.16	9.27	10.22	8.57	10.18

*Mean of 40 plants

DAT – Days after transplanting

Means followed by same alphabet do not differ significantly by DMRT at 5%

Figures in the parentheses are $\sqrt{(x + 0.5)}$ values

Table 52: Mean population of chrysoperla in different IPM modules during 2009-10 season

Treatments	No of chrysoperla/plant*								
	30 DAT*	**40 DAT**	**50 DAT**	**60 DAT**	**70 DAT**	**80 DAT**	**90 DAT**	**100 DAT**	**110 DAT**
T_1- Module I (Farmers practice)	0.52 (1.01)a	0.58 (1.04)a	0.62 (1.06)a	0.55 (1.02)a	0.43 (0.96)a	0.36 (0.93)a	0.30 (0.89)a	0.18 (0.82)a	0.10 (0.77)a
T_2- Module II (IIHR+AVRDC)	0.88 (1.17)b	0.92 (1.19)b	0.98 (1.22)b	1.10 (1.26)b	1.45 (1.40)d	1.29 (1.34)d	1.20 (1.30)d	1.10 (1.26)d	0.97 (1.21)d
T_3- Module III (Bio-itensive)	0.92 (1.19)b	0.96 (1.21)b	1.05 (1.24)b	1.18 (1.30)b	1.49 (1.41)d	1.33 (1.35)d	1.27 (1.33)d	1.16 (1.29)d	1.04 (1.24)d
T4- Module IV (UAS, Raichur)	0.80 (1.14)b	0.85 (1.16)b	0.92 (1.19)b	0.98 (1.22)b	1.05 (1.24)b	0.65 (1.07)b	0.50 (1.00)b	0.45 (0.97)b	0.37 (0.93)b
T5- Module V (Adoptable)	0.85 (1.16)b	0.92 (1.19)b	1.00 (1.22)b	1.05 (1.24)b	1.20 (1.30)c	1.00 (1.22)c	0.82 (1.15)c	0.80 (1.14)c	0.65 (1.07)c
SEm$\pm$	0.04	0.03	0.04	0.06	0.03	0.04	0.05	0.04	0.05
CD at 5%	0.11	0.10	0.12	0.18	0.09	0.11	0.14	0.11	0.13
CV (%)	8.21	11.20	10.60	9.27	8.43	10.20	9.17	11.34	12.18

*Mean of 40 plants
DAT – Days after transplanting
Means followed by same alphabet do not differ significantly by DMRT at 5%
Figures in the parentheses are $\sqrt{(x + 0.5)}$ values

4.5.3.2 Chrysoperla

The chrysoperla population recorded at 10 days interval starting from 30 days after transplanting till 110 DAT. The population at 30 DAT, in different modules was in the range of 0.52 to 0.92 per plant. Highest chrysoperla population was observed in the Module-III (0.92/plant) followed by the modules-II, V, IV which recorded 0.88, 0.85 and 0.80 per plant respectively and were on par with each other. The least coccinellid population of 0.52 was recorded in Module-I (Table 52).At 40 DAT observation highest chrysoperla population was recorded in Module-III (0.96/plant) and least in Module-I (0.58/plant). The modules *viz.,* II, V and IV recorded 0.92, 0.92 and 0.85 per plant and were on par with each other. The trend remained same even at 50 and 60 days after transplanting.

At 70 DAT, Module-III and Module-II recorded chrysoperla of 1.49, 1.45 per plant and were on par with each other. Other modules namely Module-V, IV and I recorded 1.20, 1.05 and 0.43 chrysoperla per plant which differed statistically with each other. At 80 DAT, the modules- V, IV and I recorded the population of 1.00, 0.65 and 0.36 per plant which differed with each other significantly. The Module-III and Module-II were on par with each other which recorded chrysoperla of 1.33 and 1.29 per plant which were on par with each other (Table 52).Similar trend was observed at 90 and 100 days after transplanting where module-II and III were on par with each other and rest of the treatments differed significantly with each other.Highest population at 110 DAT was recorded in Module-III (1.04/plant) followed by Module-II (0.97/plant) and were on par with each other. The Module- V, Module-IV and Module-I recorded the population of 0.65, 0.37 and 0.10 per plant and these three modules differed statistically with each other (Table 52).

During the year 2010-11 the population of chrysoperla were slightly higher compared to previous year (Table 53).At 30 days after transplanting the population of chrysoperla ranged from 0.58 to 0.94 per plant. Highest chrysoperla per plant was recorded in the Module-III (0.94) followed Module-II (0.95/plant), Module-V (0.86/plant) and Module IV (0.82/plant) which were on par with each other. At 40 DAT, observation the highest population of chrysoperla was recorded in the module-III (0.98/plant) and least in module-I (0.52/plant). Similarly at 50 DAT, the modules-III, II, V and IV were on par with other which recorded 1.06, 1.02, 0.98 and 0.93 per plant which were on par with each other. The trend remained same even at 60 Days after transplanting.

At 70 DAT, the modules V, IV and I were on par with each other which recorded the population of chrysoperla of 1.05, 0.92 and 0.46 per plant respectively and differed significantly with each other, but the module-III and II were on par with each other which recorded the population of 1.35 and 1.32 per plant respectively. At 80 days after transplanting the population was highest in Module-III (1.17/plant) and least in the module-I (0.35/plant) and these two treatments differed statistically with each other (Table 53).

The population of chrysoperla at 90 DAT in different modules ranged from 0.28-1.08 per plant of which highest was in the module-III and lowest was in the module-I. The modules V, IV and I differed significantly with each other which recorded 0.77, 0.50 and 0.28 per plant. The trend remained same even at 100 and 110 days after transplanting wherein the highest population of chrysoperla was recorded in the module-III which was on apr with module-II which differed significantly with rest of the modules (Table 53).

Pooled analysis of 2009-10 and 2010-11 revealed that the population, significantly lowest population was reorded in module-I (Farmers practice) at all observations.At 30 DAT, module-I (Farmer practice) recorded lowest population 0.55/plant followed by module-V(0.86/plant), module-IV(0.81/plant), module-II(0.90/plant) and module –III (0.93/plant) which were on par with each other. Similar trend was noticed at 40, 50 and 60 DAT. At 70 DAT, module-II and module-III recorded 1.39 and 1.42/plant which were on par with each other and differed significantly with module-IV and module-V which recorded 0.99 and 1.13/plant and were on par with each other. At 80 DAT, module-III recorded 1.25/plant which was on par with module-II (1.21/plant) and differed significantly with module-IV (0.63/plant) and module-V (0.93/plant) and both the modules differed significantly. Similar trend was observed at 90,100 and 110 DAT (Table 54).

4.5.4 Trap catches

Trap catches of *Leucinodes orbonalis* was recorded at weekly interval from 34th standard week to 51st standard week in all the three modules in both the years of experimentation. During the period of 2009-10 peak moth trap catches was observed in the 42nd standard week (18.10 moths/trap/week) followed by 41st and 43rd week which recorded 14.30 and 13.33 moths per trap per week in Module-II and lowest number of moths trapped during the 51st standard week. In module-III the number of moths trapped per trap was highest in 42nd standard week, 41st (17.10 moths/trap/week) and 43rd week (16.67 moths/trap/week) and lowest number of trap catches was during 51st standard week. Whereas, in module-V peak trap catches of moths was recorded during 42nd standard week (14.67 moths/trap/week) and lowest during 50th standard week (0.33 moths/trap/week) (Table 55).

Overall mean adult moths per trap over 18 weeks was recorded higher in Module-III (133.29 adults/trap) followed by module-II and module-IV which recorded 123.86 and 114.73 mean adults moths per trap over the same period and differed significantly from each other (Table 55).

During the second year of study (2010-2011), moths trapped were less compared to previous year. Peak moth trap catches of 20.40 was observed at 42nd standard week followed by 43rd (14.83 moths/trap/week) and mean trap catches of 147.35 was recorded in module-III which was higher compared to module-II wherein number of moths trapped was 127.14. The peak trap catches (17.00 moths/trap/week) was observed in the module-II during 42nd standard week. Similarly in module-V number of moths trapped was low compared to other modules. Lowest number of trap catches was observed during 51st standard week in module –II and module-III with 1.09/traps/week (Table 55).

Data of pooled analysis indicates that mean number of adult moth trap catches was highest in the Module-III (142.53 adults/trap) followed by other two modules with 125.55 and 116.56 adults per trap in Module-II and Module-V respectively. In all the modules the peak trap catches of moths was noticed in the 42nd standard week (Table 55).

4.5.5 Yield and cost economics

IPM modules developed for brinjal shoot and fruit borer with different components during 2009-10 revealed that, all the modules differed significantly in terms of yield (Table 56). Among the modules significantly highest yield of 54.24 q/ha was recorded in Module- V (Adoptable) with highest net returns (Rs.258058/ha) and C: B ratio of 1:3.83 followed by Module -I (farmers practice) with yield of 49.80 q/ha with net returns of (Rs.229680) and C:B ratio of 1:3.32.Similarly, Module-II (IIHR+AVRDC) recorded 45.81 q/ha with net returns (Rs.204800/ha) and C:B ratio of 1:3.20 respectively. Module –IV (UAS Raichur) recorded yield of 40.18q/ha with net returns of (Rs.176080) and C:B ratio of 1:2.71 and lowest yield of 33.32 q/ha was recorded in Module-III (Bio-intensive) with net returns of Rs.137120/ha and C:B ratio of 1:2.18 respectively (Table 56).

Similarly during 2010-11, maximum yield of 50.17q/ha was recorded in Module-V (Adoptable) with net profit of Rs.333978/ha with C:B ratio of 1:4.96 followed by Module-I (farmers practice) which recorded yield of 47.60 q/ha with net returns of Rs.311680/ha and C:B ratio of 1:4.52. Module –II (IIHR+AVRDC) recorded a yield of 43.24 q/ha with net returns of Rs.281920/ha followed by Module – IV (UAS Raichur) with yield of 39.74q/ha with net profit of Rs.252920 with C:B ratio of 1:3.89 and lowest yield of Module-III (Bio-intensive) which recorded 35.80 q/ha with C:B ratio of 1:3.56 (Table 57).

Table 53: Mean population of chrysoperla in different IPM modules during 2010-11 season

Treatments	No of chrysoperla/plant*								
	30 DAT*	40 DAT	50 DAT	60 DAT	70 DAT	80 DAT	90 DAT	100 DAT	110 DAT
T_1- Module I (Farmers practice)	0.58 (1.04)a	0.52 (1.01)a	0.60 (1.05)a	0.53 (1.01)a	0.46 (0.98)a	0.35 (0.92)a	0.28 (0.88)a	0.20 (0.84)a	0.12 (0.79)a
T_2- Module II (IIHR+AVRDC)	0.92 (1.19)b	0.95 (1.20)b	1.02 (1.23)b	1.08 (1.26)b	1.32 (1.35)c	1.12 (1.27)d	1.06 (1.25)d	0.95 (1.20)d	0.88 (1.17)d
T_3- Module III (Bio-itensive)	0.94 (1.20)b	0.98 (1.22)b	1.06 (1.25)b	1.14 (1.28)b	1.35 (1.36)c	1.17 (1.29)d	1.08 (1.26)d	1.00 (1.22)d	0.94 (1.20)d
T4- Module IV (UAS, Raichur)	0.82 (1.15)b	0.86 (1.17)b	0.93 (1.20)b	0.97 (1.21)b	0.92 (1.19)b	0.60 (1.05)b	0.50 (1.01)b	0.45 (0.97)b	0.34 (0.92)b
T5- Module V (Adoptable)	0.86 (1.17)b	0.91 (1.19)b	0.98 (1.22)b	1.04 (1.24)b	1.05 (1.24)b	0.85 (1.16)c	0.77 (1.13)c	0.67 (1.08)c	0.59 (1.04)c
SEm$\pm$	0.03	0.05	0.04	0.06	0.03	0.03	0.04	0.03	0.04
CD at 5%	0.09	0.15	0.13	0.18	0.09	0.10	0.11	0.09	0.11
CV (%)	9.08	11.36	8.23	10.13	11.17	8.11	12.14	10.68	13.27

*Mean of 40 plants
DAT – Days after transplanting
Means followed by same alphabet do not differ significantly by DMRT at 5%
Figures in the parentheses are $\sqrt{(x + 0.5)}$ values

Table 54: Pooled data of mean population of chrysoperla in different IPM modules for two seasons

Treatments	No of chrysoperla/plant*								
	30 DAT*	40 DAT	50 DAT	60 DAT	70 DAT	80 DAT	90 DAT	100 DAT	110 DAT
T_1- Module I (Farmers practice)	0.55 (1.02)a	0.55 (1.02)a	0.61 (1.05)a	0.54 (1.02)a	0.45 (0.97)a	0.36 (0.92)a	0.29 (0.89)a	0.19 (0.83)a	0.11 (0.78)a
T_2- Module II (IIHR+AVRDC)	0.90 (1.18)b	0.94 (1.20)b	1.00 (1.22)b	1.09 (1.26)b	1.39 (1.37)c	1.21 (1.31)d	1.13 (1.28)d	1.03 (1.23)d	0.93 (1.19)d
T_3- Module III (Bio-itensive)	0.93 (1.20)b	0.97 (1.21)b	1.06 (1.25)b	1.16 (1.29)b	1.42 (1.39)c	1.25 (1.32)d	1.18 (1.29)d	1.08 (1.26)d	0.99 (1.22)d
T4- Module IV (UAS, Raichur)	0.81 (1.14)b	0.86 (1.16)b	0.93 (1.19)b	0.98 (1.21)b	0.99 (1.22)b	0.63 (1.06)b	0.50 (1.00)b	0.45 (0.97)b	0.36 (0.92)b
T5- Module V (Adoptable)	0.86 (1.16)b	0.92 (1.19)b	0.99 (1.22)b	1.05 (1.24)b	1.13 (1.27)b	0.93 (1.19)c	0.80 (1.14)c	0.74 (1.11)c	0.62 (1.06)c
SEm±	0.04	0.05	0.04	0.06	0.03	0.04	0.03	0.04	0.04
CD at 5%	0.11	0.13	0.13	0.17	0.08	0.11	0.10	0.11	0.12
CV (%)	8.12	10.23	11.14	9.12	12.27	10.31	8.61	11.05	9.10

*Mean of 40 plants
DAT – Days after transplanting
Means followed by same alphabet do not differ significantly by DMRT at 5%
Figures in the parentheses are $\sqrt{(x+0.5)}$ values

Table 55: Trap catches of *Leucindoes orbonalis* adults in different modules during 2009 -10, 2010-11 and pooled data for two seasons

Standard Week	Mean no of Moths/Trap/Week								
	2009-10			2010-11			Pooled		
	Module-II	Module-III	Module-V	Module-II	Module-III	Module-V	Module-II	Module-III	Module-V
34	---	5.44	5.33	---	6.10	5.16	---	5.77	5.25
35	---	4. 33	6.00	---	5.67	5.21	---	5.00	5.61
36	4.67	5.18	4.78	5.16	4.83	4.69	4.92	5.01	4.74
37	5.10	6.91	5.44	4.43	7.64	6.98	4.77	7.28	6.21
38	7.34	8.60	9.34	7.67	9.00	8.67	7.51	8.80	9.01
39	11.82	10.49	11.71	12.54	12.33	10.53	12.18	11.41	11.12
40	12.45	11.10	10.33	14.05	13.61	11.05	13.25	12.36	10.69
41	14.30	17.10	13.33	13.23	18.24	12.14	13.77	17.67	12.74
42	18.10	19.37	14.67	17.00	20.4	14.90	17.55	19.89	14.79
43	13.33	16.67	11.53	14.83	14.73	13.10	14.08	15.70	12.32
44	9.31	8.37	7.28	10.00	9.68	8.68	9.66	9.03	7.98
45	8.33	7.15	6.16	7.83	7.44	6.33	8.08	7.30	6.25
46	6.49	5.66	4.13	8.10	6.00	3.98	7.30	5.83	4.06
47	3.10	4.16	2.00	3.63	4.2	2.69	3.37	4.18	2.35
48	3.28	3.63	1.37	4.21	2.23	2.00	3.75	2.93	1.69
49	2.00	1.37	1.00	1.37	2.00	1.16	1.69	1.69	1.08
50	2.33	1.09	0.33	2.00	2.16	1.00	2.17	1.63	0.67
51	1.91	1.00	0.00	1.09	1.09	0.00	1.50	1.05	0.00
Total	123.86	133.29	114.73	127.14	147.35	118.27	125.55	142.53	116.56
Grand Mean	6.88[b]	7.84[a]	6.37[c]	7.06[b]	8.19[a]	6.57[c]	6.98[b]	7.92[a]	6.48[c]
F-Test	Modules	0.48*		0.45*			0.40*		
	Weeks	0.32*		0.27*			0.22*		
	Modules x weeks	0.10*		0.16*			0.14*		

*In a rows means followed by similar alphabet do not differ significantly by DMRT at * Significant at 0.05 level

Table 56. Yield and cost economics of different IPM modules in brinjal during 2009-10 season

Modules	Yield(t/ha) (Mean of 8 pickings)	Inputs & other costs (Rs/ha)	PP cost (Rs/ha)	Total Cost (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	C:B ratio
T_1- Module I (Farmers practice)	49.80b	39000	30120	69120	298800	229680	1:3.32
T_2- Module II (IIHR+AVRDC)	45.81c	37000	27000	64000	268800	204800	1:3.20
T_3- Module III (Bio-itensive)	33.32e	37000	25800	62800	199920	137120	1:2.18
T4- Module IV (UAS, Raichur)	40.18d	37000	28000	65000	241080	176080	1:2.71
T5- Module V (Adoptable)	54.24a	38000	29382	67382	325440	258058	1:3.83
SEm ±	1.26						
CD at 5 %	3.77						
CV (%)	10.41						

*Price of Brinjal- Rs 6/kg, Price – neem cake – Rs. 15/kg, Trichocard – Rs. 6/card
Means followed by same alphabet do not differ significantly by DMRT at 5%

Table 57: Yield and cost economics of different IPM modules in brinjal during 2010-11 season

Modules	Yield(t/ha) (Mean of 8 pickings)	Inputs & other costs (Rs/ha)	PP cost (Rs/ha)	Total Cost (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	C:B ratio
T_1- Module I (Farmers practice)	47.60b	39000	30120	69120	380800	311680	1:4.52
T_2- Module II (IIHR+AVRDC)	43.24c	37000	27000	64000	345920	281920	1:4.41
T_3- Module III (Bio-itensive)	35.80e	37000	25800	62800	286400	223600	1:3.56
T4- Module IV (UAS, Raichur)	39.74d	37000	28000	65000	317920	252920	1:3.89
T5- Module V (Adoptable)	50.17a	38000	29382	67382	401360	333978	1:4.96
SEm ±	1.14						
CD at 5 %	3.41						
CV (%)	11.23						

*Price of Brinjal- Rs 8/kg, Price – neem cake – Rs. 15/kg, Trichocard – Rs. 6/card
Means followed by same alphabet do not differ significantly by DMRT at 5%

DISCUSSION

Brinjal or eggplant (*Solanum melongena* L) is one of the most important vegetable crops in India, and the country is the second largest eggplant producer in the world after China. Though the crop is popular amongst small and marginal farmers, cultivation is often input intensive, especially with respect to insecticides (George *et al.*, 2002). However, its yield and marketable quality are severely affected by brinjal shoot and fruit borer (BSFB), *Leucinodes orbonalis* Guenee (Lepidoptera: Pyralidae). Among the biotic stress factors that hamper the production of brinjal is the shoot and fruit borer, (*Leucinodes orbonalis* Guen.) which is most serious and one of the major constraints in brinjal production. The pest occurs throughout the year at all the stages of crop growth right from seedling to final harvesting stage and causes severe infestation by virtue of its reproductive potential, rapid turnover of generations and continuous perpetuation. Many wild species of Solanum were found resistant to ESFB infestation, but attempts to cross eggplant with its wild relatives to impart resistance had only limited success so far against this monophagous pest (Collonnier *et al.*, 2001). Conventional methods of management of BSFB, including chemical and biocontrol methods, have so far not been encouraging either. Bt transgenic technology has offered promise of sustainable management of BSFB in brinjal. In view of the absence of an effective and rational control programme, farmers are in the habit of applying various insecticides out of their anxiety, often resulting in complicating pest problems.

Hence, it is imperative that an effective management programme should be developed for the brinjal shoot and fruit borer. Keeping this in view, various experiments were conducted at Main Agricultural Research Station, UAS, Raichur during 2009 and 2010. The conclusions drawn based on results obtained during the course of investigation have been discussed here under with relevant literature available on brinjal shoot and fruit borer.

5.1 Studies on insecticide usage pattern in major brinjal growing regions of South India

In the present study, It was evident from the survey of five different states comprising of fourteen different locations that, farmer's sprayed insecticide at an interval of 4-8 days. Farmers from Margoa, Vijaywada, Parbhani and chennai sprayed the insecticides at an interval of 8 days which is highest among all the locations and lowest spray interval of 4 days was recorded from farmers of Bangalore and Raichur locations. The number of application of insecticides in the fourteen locations varied from 18 to 34 in brinjal against shoot and fruit borer. Maximum numbers of 36 sprays were recorded from Raichur followed by 34 sprays from Hyderabad location .Whereas lowest numbers of 18 sprays were recorded from Margoa and Chennai locations.

Highest use of rynaxypyr was observed from Raichur and lowest use was observed from Margoa location. In case of flubendiamide, highest use was observed in Raichur and lowest use of 40 per cent was recorded in Margoa location. Highest and lowest use of emamectin benzoate was recorded in Bangalore and Margoa Locations. In case of spinosad highest use was observed in Raichur, Banagalore and Hyderabad locations and lowest was observed in Margoa and Chennai locations. Highest indoxacarb use was observed in Raichur and lowest use in Margoa locations. In chlorpyriphos, Margoa farmers recorded maximum use of 12 per cent and lowest use of 4 per cent was observed in Coimbatore and Chennai Locations. In case of Thiodicarb, highest per cent use was observed in Hyderabad, whereas lowest use was observed in Vijaywada, West Godavari and Parbhani locations. Maximum Cypermethrin use was recorded in Raichur, Chennai, Coimbatore and Margoa locations. Lowest use rate was observed in Dapoli, Dharwad and West Godavari locations. In case of quinalphos, Margoa recorded 16 per cent and 4 per cent use was recorded in Bijapur, West Godavari and Parbhani. Highest use rate of monocrotophos was recorded in Margoa and lowest use rate was observed in Parbhani, Kolhapur, Vijaywada, West Godavari and Raichur locations. In case of Carbaryl, Margoa recorded maximum use and lowest use was recorded in Dharwad and Raichur Locations. Endosulphan with highest use of 4 per cent was observed in Margoa, Chennai, Coimbatore and Dapoli locations and no usage was observed in remaining all other locations (Fig. 3).

Among the different geographical states of India, Karnataka recorded the highest use of rynaxypyr, flubendiamide, emmamectin benzoate, Indoxacarb and thiodicarb and Goa recorded the lowest use. In case of quinalphos, Goa recorded the highest use and lowest use rate was recorded in Karnataka, Andhra Pradesh and Maharashtra. Whereas, maximum use rate of monocrotophos was observed in Tamilnadu and lowest use rate was noticed in Andhra Pradesh and Maharashtra. No usage was observed in Karnataka growers. Maharashtra farmers observed no usage of carbaryl and.

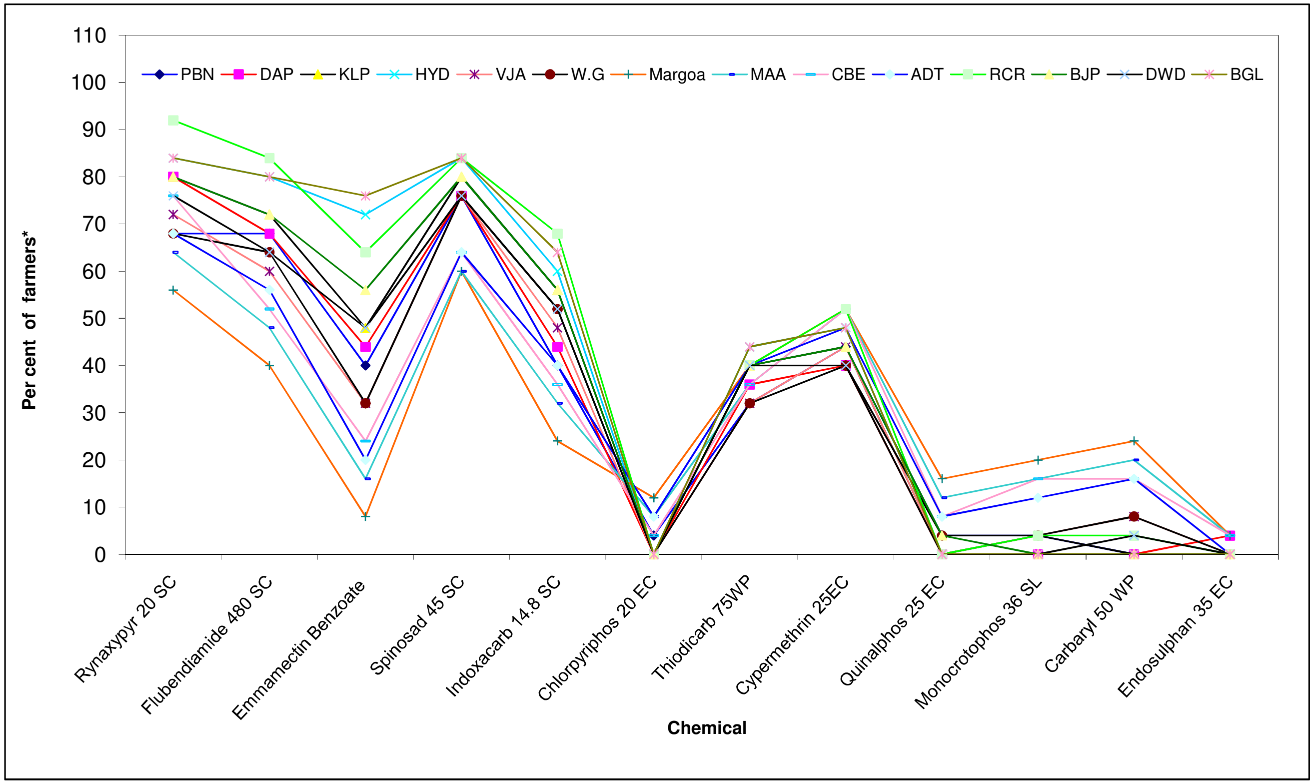

Fig3: Per cent of Insecticides used by brinjal growers against shoot and fruit borer in the surveyed area

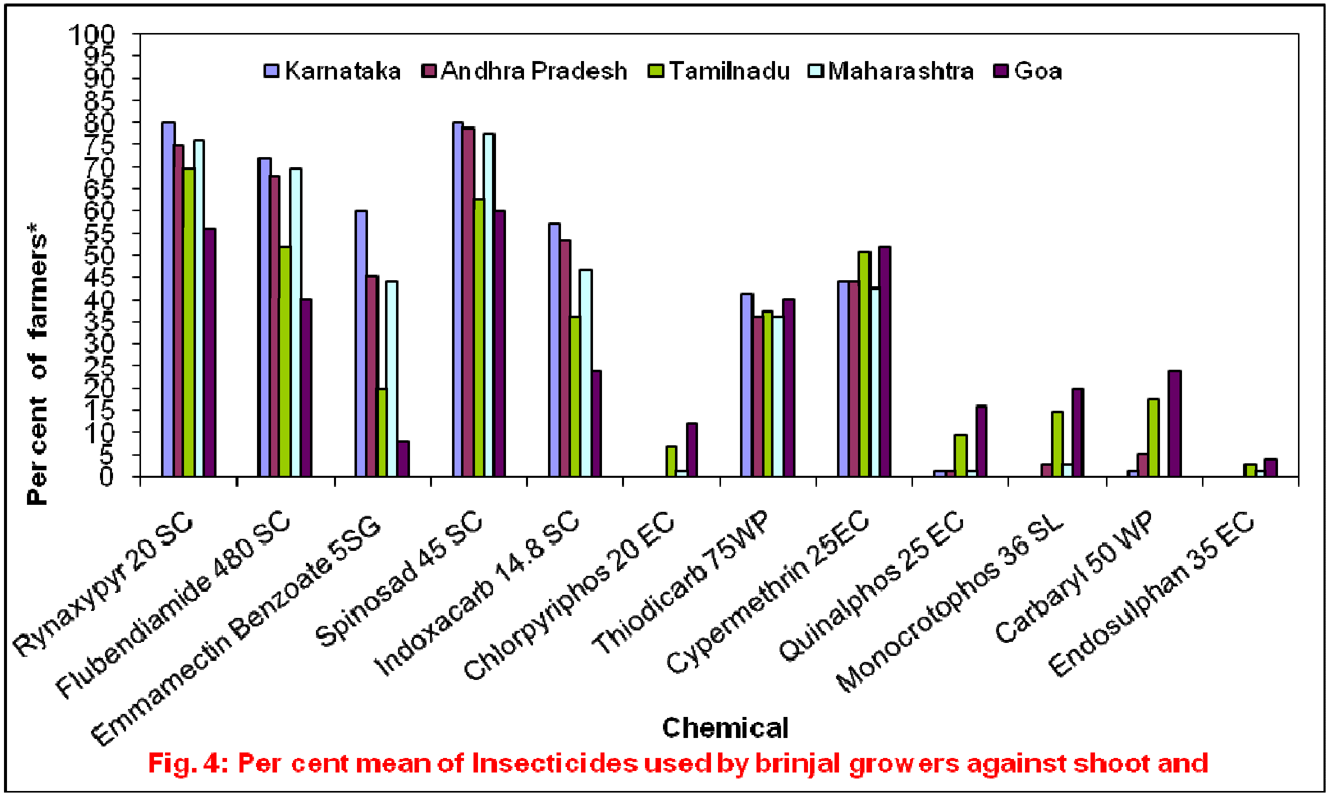

Fig. 4: Per cent mean of Insecticides used by brinjal growers against shoot and fruit borer in the surveyed area

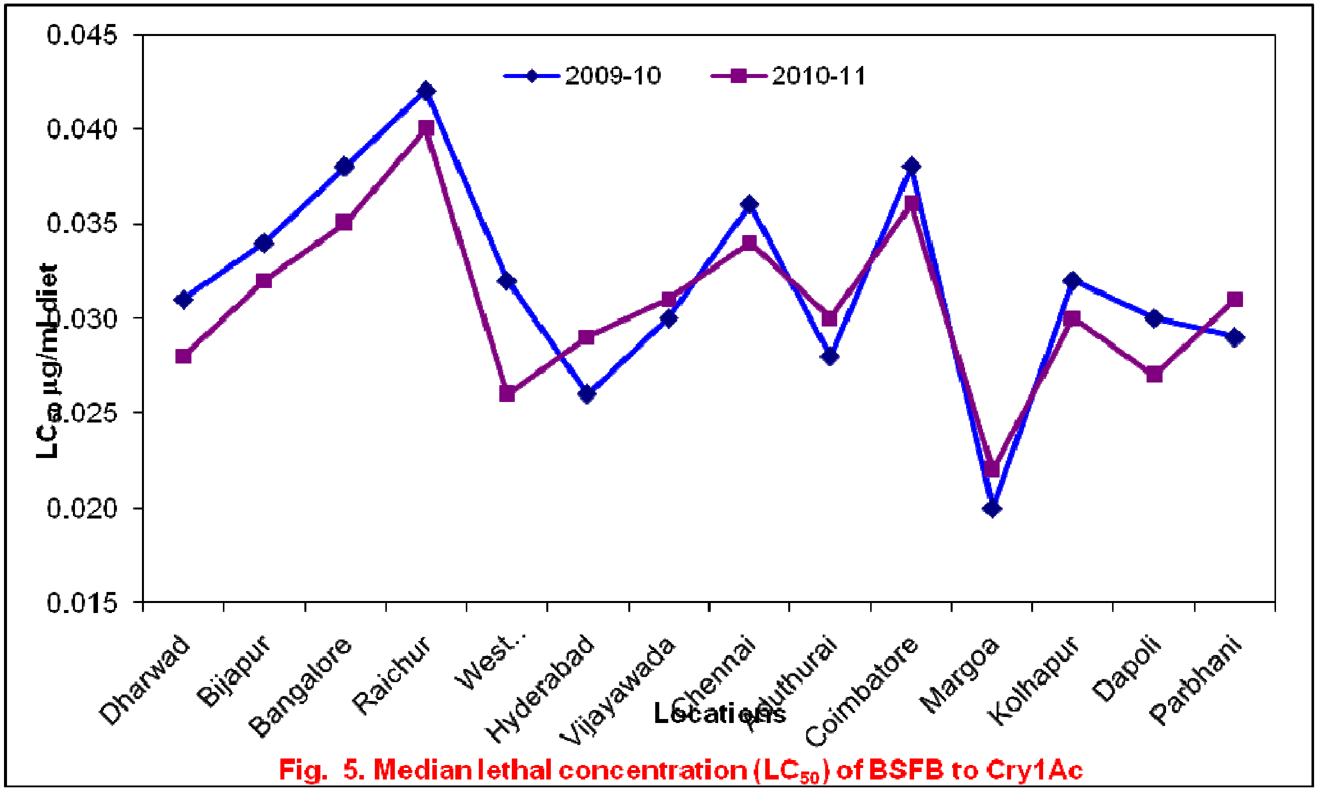

Fig. 5. Median lethal concentration (LC_{50}) of BSFB to Cry1Ac

highest use rate was noticed in Tamilnadu growers with lowest use rate in Karnataka state. Lowest use rate of endosulfan was observed in Maharashtra with highest use rate by Tamilnadu farmers and no usage was observed in Karnataka and Andhra Pradesh states (Fig. 4).

Ali (1994) opined that in summer season for controlling eggplant shoot and fruit borer the farmers of Bangladesh are spraying almost daily, where as in West Bengal, India, frequency of application exceeds three sprays per week. About 47 percent of the total insecticides used in vegetables are used against *L. orbonalis* and the use for growing brinjal is 1.41 kg or L per ha (Anon, 1995). George *et al.* (2002) opined that in orissa, majority of the farmers (41.7%) commonly use carbaryl, endosulfan, carbofuran and cypermethrin in a seven to eight spraying schedule to control shoot and fruit borer and about 56.7 % farmers have found it expensive to control *L. orbonalis* though the use of insecticides. Mohiuddin *et al.* (2009) reported that majority of the farmers of Patiya sprayed insecticides more than 40 times in brinjal cultivation. Especially for Satkania, majority of the farmers sprayed every alternative day while in the winter, the spraying frequency was reduced once a week. Pesticide dealers were the major source of information to farmers on the selection of chemicals and application methods in Satkania, Patiya and Hathazari upazilas districts of Pakistan.

This may be due to the variation in the shoot and fruit borer incidence during different months in different locations and also due to biotic and abiotic factors prevailed during the study period. The reason could also be the varietal differences in fruit infestations and other reason could be the sowing dates of brinjal in the field with variable infestation of the pest. Type of the pesticides recommended by retailers is an important factor for more pesticides use.

5.2 Monitoring of baseline susceptibility in SFB populations of South India to different chemistries and Cry1Ac protein

5.2.1 Baseline susceptibility in SFB populations of South India to Cry1Ac protein

5.2.1.1 Median lethal concentration (LC_{50} and LC_{95}) of Cry1Ac

The present investigations revealed that, in 2009 Kharif season, median lethal concentrations (LC_{50}) for neonates ranged from 0.020 to 0.042 ppm (parts per million) of diet, with the population from Margoa having the lowest LC_{50} value of 0.020 µg/ml diet and that from Raichur having the highest LC_{50} value of 0.042 µg/ml diet (Table). LC_{95} values ranged from 0.529 to 1.829 ppm of diet across the populations of which highest was found in Raichur (1.829 µg/ml diet) and lowest in Margoa (0.529 µg/ml diet) population. LC_{95} values ranged from 0.529 to 1.829 ppm of diet across the populations of which highest was found in Raichur (1.829 µg/ml diet) and lowest in Margoa (0.529 µg/ml diet) population.

In 2010 Kharif season, the Cry 1Ac protein was found to be toxic to all fourteen geographic populations tested. LC_{50} values of neonates among the different populations ranged from 0.022 to 0.040 µg/ml diet and LC_{95} values ranged from 0.610 to 1.742 µg/ml diet across the fourteen populations. The highest LC_{50} value of (0.040 µg/ml diet) was observed in Raichur population and the lowest LC_{50} value of 0.022 µg/ml diet was recorded in Margoa population. Among the populations, Highest LC_{95} value of 1.742 µg/ml diet was recorded in Raichur population and Margoa recorded the lowest LC_{95} value of 0.610 µg/ml diet (Fig. 5).

The present findings are in alignment with the studies of Satpathy *et al.* (2009) who reported that, the laboratory population was more susceptible to Bt protein than the field population. Although variation in susceptibility to Cry1Ac was observed between the two populations of *L.orbonalis*, the magnitude of the difference was small. *Leucinodes orbonalis* (Guenée), in larva collected from Delhi and its suburbs Sonipat, Jhajjar and Sampla. The seven-day median lethal concentration (LC_{50}) of Cry1Ac ranged from 0.002-0.069 µg/g, Cry1Ba from 0.13-0.21 µg/g for three populations and Cry1Ca from 0.12 -0.39 µg/g for four tested populations.

The LC_{50} of Bt strain Aug05 was 0.044 µg/g on the basis of total toxin content, 0.012 µg/g on Cry1Ac and 0.1 µg/g on Cry2Ab content basis for the Delhi population. Cry2Ab was relatively less toxic of all the four Bt toxins and strain tested. These baseline susceptibility studies are useful in developing resistance management tactics in Bt brinjal (Vinay *et al.*, 2013).

The variation in the insect susceptibility to toxins depends upon the tests, the selection regime and the environment with respect to time. Among the factors involved the biotic factors like temperature and biotic factor like host plant seemed to influence susceptibility of insects to cry toxins significantly. As the crop matures and ambient temperature decreases, the susceptibility of the larvae also decreases. The winter months of December seemed to slow larval growth depending upon temperature. The larvae grow healthier as larval period increases with decrease in temperature and hence their progeny seemed to develop a good deal of tolerance to Cry toxins.

5.2.1.2 Moult inhibitory concentration MIC_{50} of *Leucinodes orbonalis* neonates to Cry1 Ac protein.

During the year 2009-10, Moult inhibitory concentration (MIC_{50}) values ranged from 0.003 to 0.014 µg/ml diet and the MIC_{95} values ranged from 0.028 to 0.145 µg/ml diet. Raichur recorded Maximum MIC_{50} value of 0.014 µg/ml diet and Margoa recorded lowest MIC_{50} value of 0.03 µg/ml diet (Fig. 6).

In 2010 Kharif season, the results revealed that Moult inhibitory concentration (MIC_{50}) values ranged from 0.003 to 0.012 µg/ml diet. The MIC_{95} values ranged from 0.055 to 0.130 µg/ml diet. Among the populations collected across the geography, highest MIC_{50} value of 0.012 µg/ml diet was reported in Raichur and the lowest value of 0.003 µg/ml diet was reported in Aduturai. The Highest MIC_{95} value of 0.130 µg/ml diet was observed in Raichur and lowest MIC_{95} value of 0.032 µg/ml diet was noticed in Aduturai.

Baseline susceptibility data revealed 12-fold variability in LC_{50} value of 29 populations tested for *Cry*1Ac susceptibility. The field populations demonstrated 70-fold inter population variation in the insect susceptibility to the *Cry*1Ac protein indicated by MIC_{50}. The variability was 14-fold when MIC_{95} was considered and values ranged from 0.020-0.138 ppm of diet. Average MIC_{95} was found to be 0.059 ppm (Anon, 2006).

The conventional insecticides used routinely by the farmers seem to enhance insect susceptibility to Bt. The resistant/intoxicated insects tend to divert their physiological resources towards meeting fitness costs imposed upon by the selection pressure of conventional neurotoxic insecticides. This makes them more vulnerable to other control agents like Bt acting on site other than those belonging to conventional neurotoxicants.The induction of protease inhibitor gene in crop plants may lead to intake and accumulation of protease inhibitor by target insect, which might in turn have influenced insect susceptibility to Bt. Protease inhibitors may inhibit insect growth and development by inhibiting midgut proteases involved in digestion. Secondary metabolites may also have influence in the variation of the toxicity and its susceptibility in different locations.

5.2.2 Baseline susceptibility in SFB populations of South India to different chemistries

5.2.2.1 Rynaxypyr

In the present study, during 2009-10 and 2010-11, among the populations, Raichur population recorded a maximum LC_{50} values of 2.15 and 2.30 ppm and followed by lowest LC_{50} values was observed in population from Margoa (1.65 and 1.70 ppm). Population from Raichur district developed higher degree of resistance (1.30 and 1.35 folds) followed by least resistance ratio in the population of Chennai (1.02 and 1.04 folds).

Present studies are in agreement with Kodandaram *et al*. (2013) who reported that the LC_{50} values for cynatriniliprole, chlorantraniliprole and flubendamide were 0.62ppm, 1.8 ppm and 11.2 ppm, respectively for *L. orbonalis*. The descending order of toxicity for *L orbonalis* is cynatriniliprole > chlorantraniliprole> flubendamide. The relative toxicity of cynatriniliprole to *L. orbonalis* was evaluated by considering LC_{50} of flubendamide. On the basis of LC_{50} values cyantraniliprole and chlorantranilprole was 18 and 6.2 times more toxic to *L. orbonalis* as compard to flubendamide.

5.2.2.2 Emamectin Benzoate

During 2009-10, Bangalore population recorded a maximum LC_{50} value to emamectin benzoate (4.20 ppm) followed by population from Hyderabad (4.11 ppm) whereas, lowest LC_{50} value was observed in population from Margoa (2.15 ppm). The resistance ratio (RR) at LC_{50} calculated against susceptible field strain to measure the level of resistance development was found to be highest for population of Bangalore (1.95 folds) and Least resistance ratio was observed in the population of Chennai (1.09 folds). The value of LC_{95} ranged from 35.80 to 14.20 ppm. The highest LC_{95} value of 35.80 ppm was recorded in the population of Bangalore and lowest value of 14.20 ppm was recorded from Margoa population.

In 2010-11, it is evident from the study that Bangalore population registered a maximum LC_{50} value to emamectin benzoate (4.41 ppm) and lowest LC_{50} value was observed in population from Margoa (2.24 ppm). The computed resistance ratio at LC_{50} in comparison with susceptible field strain was highest for population of Bangalore (1.97 folds) and the least resistance ratio was observed in the population of Chennai (1.09 folds). Maximum LC_{95} value was recorded from population of Bangalore (39.16 ppm) and lowest LC_{95}value of 13.93 ppm was observed in Margoa Population.

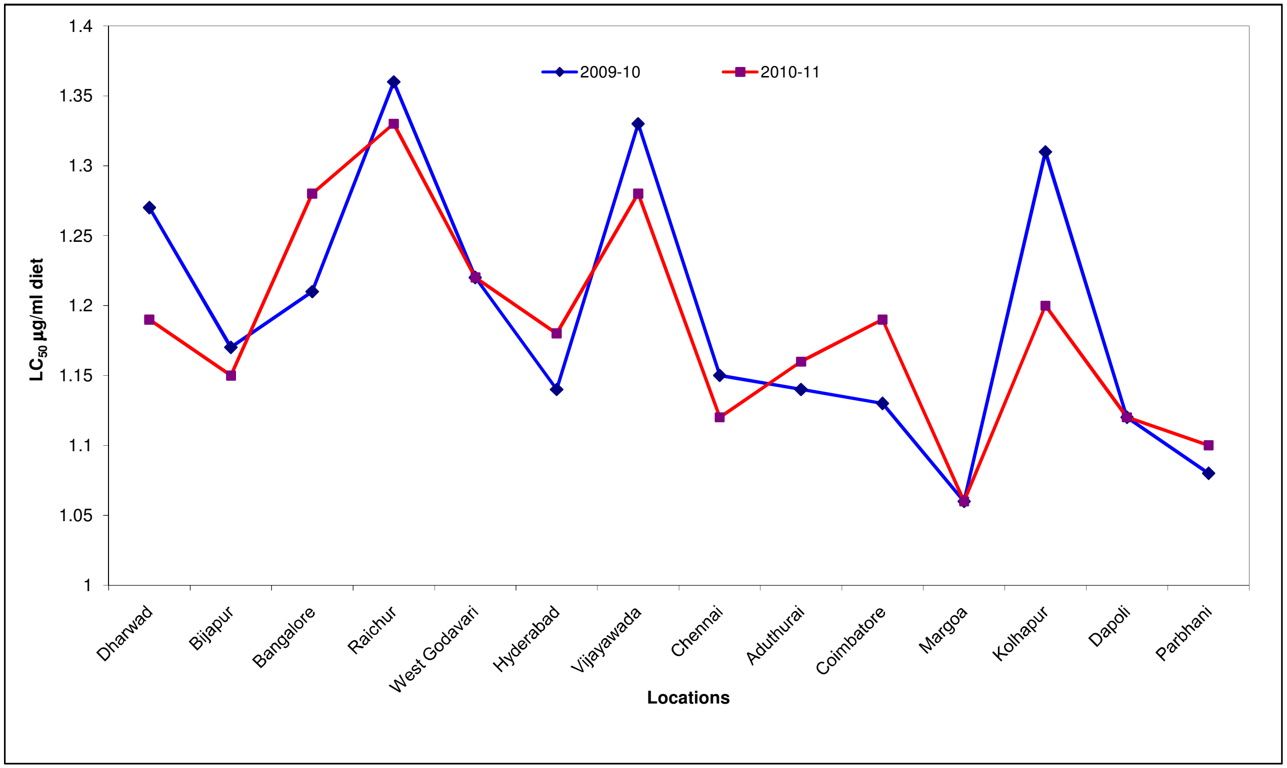

Fig 6: Moult Inhibitory concentration MIC_{50} of BFSB to Cry1Ac

Anon (2013) reported that, four populations of *L. orbonalis* collected from Bangalore, Guntur, Dharmapuri & Coimbatore were subjected to dose mortality bioassays against three insecticides to estimate resistance ratio. The study revealed upto six fold variation in insecticide susceptibility with respect to the insecticides fenvalerate, phosalone and emamectin benzoate in the populations of *L. orbonalis* tested. Quantification of midgut carboxylesterase from these four populations of *L. orbonalis* revealed significantly elevated activity in larvae collected from Guntur region.

5.2.2.3 Flubendiamide

The present investigations during 2009-10 it is clear that, Raichur population required highest quantity of insecticides to induce desired effect (50% kill) (2.80 ppm) followed by lowest LC_{50} value observed in population from Margoa (2.10 ppm). The resistance ratio (RR) against susceptible field strain was found to be highest for population of Raichur (1.33 folds) and the least resistance ratio was observed in the population of Chennai (1.04 folds). Highest LC_{95} was reported in Bijapur (26.14 ppm) and the lowest was recorded in population of Coimbatore (11.02 ppm).

During 2010-11, maximum LC_{50} value of 2.94 ppm to flubendiamide in Raichur population and the lowest LC_{50} value was observed in population from Margoa (2.14 ppm). The resistance ratio (RR) against susceptible field strain at LC_{50} was found to be highest for population of Raichur (1.37 folds) and least resistance ratio was observed in the population of Chennai (1.07 folds) Maximum LC_{95} of 28.20 ppm was recorded from the population of Bijapur and lowest LC_{95} value of 10.19 ppm was reported in Aduthurai population.

Studies are in corrugation with Kodandaram *et al.*(2013) who reported that, the LC_{50} values for cynatriniliprole, chlorantraniliprole and flubendamide were 0.62ppm, 1.8 ppm and 11.2 ppm, respectively for *L. orbonalis*. The descending order of toxicity for *L orbonalis* is cynatriniliprole > chlorantraniliprole> flubendamide. The relative toxicity of cynatriniliprole to *L. orbonalis* was evaluated by considering LC_{50} of flubendamide. On the basis of LC_{50} values cyantraniliprole and chlorantranilprole was 18 and 6.2 times more toxic to *L. orbonalis* as compard to flubendamide.

5.2.2.4 Spinosad

The toxicity of spinosad varied among different strains of fourteen geographical populations, in the year 2009-10, the Raichur population registered highest LC_{50} value (2.77 ppm) and Whereas, Margoa recorded the least LC_{50} value (2.30 ppm). The LC_{95} values across the geographic populations varied from 12.82 to 29.14 ppm. Maximum value of 29.14 ppm was recorded in Kolhapur population and least value of 12.82 ppm was recorded in Coimbatore population. Resistance ratio at LC_{50} value was highest in Raichur population (1.20 folds) and lowest resistance ratio was recorded by Chennai (1.03 folds).

Whereas, during 2010-11, maximum resistance to spinosad was observed in Raichur population (2.93 ppm) .The least LC_{50} value was noticed in Margoa (2.42 ppm). Maximum LC_{95} value of 23.76 was registered in Raichur population and least was recorded in Chennai (12.93 ppm). Resistance ratio at LC_{50} value was highest in Raichur population (1.21 folds) followed by lowest ratio was recorded in Chennai (1.01 folds).

Kavuri Yogi and Ashwani kumar (2010) studied the efficacy of insecticides against *Leucinodes orbonalis* Guenee under laboratory conditions. Larval mortality in 3rd instar larvae ranged between 52.87-81.78 in treatments emamectin benzoate, chlorofenpyar, and novaluron on 3rd day. Observations on 5th and 7th day indicated a greater per cent kill of the larvae and treatments indoxacarb, spinosad and Neem have not given expected kill.

5.2.2.5 Indoxacarb

During the year 2009-10, Maximum LC_{50} value to indoxacarb was recorded in Raichur population (4.80 ppm) whereas, Minimum LC_{50} was observed in Margoa population (3.20 ppm). The LC_{95} values ranged from 20.68 to 40.27 ppm. Highest LC_{95} was recorded in Bangalore (40.27) and the lowest LC_{95} value of 20.68 in Margoa population. The resistance ratio against susceptible strain was found to be highest for population of Raichur (1.50 folds) and Least resistance ratio was recorded in population from Chennai (1.04 folds).

For the year 2010-11 also maximum LC_{50} value to indoxacarb was recorded in Raichur (4.97 ppm) and minimum resistance was observed in Margoa (3.28 ppm). In case of LC_{95}, Bangalore population recorded the highest value of 43.33 ppm and lowest LC_{95} value of 20.05 ppm was recorded in Chennai population. The resistance ratio against susceptible field strain was found to be highest for Raichur (1.52 folds) and lowest ratio was recorded in Chennai (1.04 folds).

Literature on baseline susceptibility of indoxacarb to brinjal SFB is totally lacking.Hence, it could not be compared and discussed with earlier reports and this study is first of its kind in this regard. Hence it is compared with *Helicoverpa* population data .Donald *et al.* (2005) evaluated Dose–mortality studies using diet overlay bioassays using first instar *Helicoverpa zea* and tobacco budworm, to Indoxacarb and pyridalyl. They revealed that The LC_{50} values of indoxacarb and pyridalyl for these insect species ranged from 1.05 to 1.33 ppm and 1.54 to 1.55 ppm, respectively. The indoxacarb LC_{90} for tobacco budworm was 4.54 ppm.

5.2.2.6 Cypermethrin

The data on the LC_{50} values obtained during 2009-10 to cypermethrin revealed that, Raichur population recorded a maximum LC_{50} value to cypermethrin (42.00 ppm) followed by population from Hyderabad (40.30 ppm) and lowest LC_{50} value was observed in population from Margoa (35.00 ppm). The LC_{95} of Hyderabad (141.62 ppm) was found to be highest and lowest LC_{95} value of 122.74 ppm was recorded in Coimbatore population. The least resistance ratio was observed in the population of Chennai (1.00 fold).

During 2010-11, Hyderabad population registered a maximum LC_{50} value to cypermethrin (58.60 ppm) and lowest LC_{50} value was observed in population from Dharwad (44.07 ppm). Highest LC_{95} value was recorded in Raichur population (226.33 ppm) and lowest LC_{95} value of 134.41ppm was recorded from Dharwad population. The resistance ratio (RR) against susceptible strain was again found to be highest for population of Hyderabad (1.33 folds) and least resistance ratio was observed in the population of West Godavari and Dapoli (1.03 folds). The results are in line with Latif *et al.* (2010) who tested nine insecticides such as azadirachtin 0.03EC, abamectin 1.8EC, flubendiamide 24WG, chlorpyriphos 20EC, cartap 50SP, carbosulfan 20EC, thiodicarb 75WP, cypermethrin 10EC, and lambdacyhalothrin 2.5EC belonging to different chemical groups against eggplant shoot and fruit borer under laboratory. Among them, carbosulfan and flubendiamide showed the highest toxicity against fourth instar larvae of *L. orbonalis* after 24 and 48 hours of exposure.

5.2.2.7 Thiodicarb

The data on the LC_{50} values of thiodicarb showed that, during 2009-10, Bangalore population recorded a maximum LC_{50} value of 65.00 ppm and lowest LC_{50} value was observed in population from Chennai (50.00 ppm). Highest LC_{95} value was recorded in population from Raichur (281.30 ppm), whereas lowest value of LC_{95} recorded from West Godavari population (171.93 ppm). The *L. orbonalis* population of Bangalore district developed higher degree of resistance (1.27 folds) at LC_{50} against susceptible field strain and the least resistance ratio was observed in the population of Coimbatore (1.03 folds).

During 2010-11, Bangalore population recorded a maximum LC_{50} value to thiodicarb (74.82 ppm). Lowest LC_{50} value was observed in population from Coimbatore (63.18 ppm). Highest LC_{95} value of 313.53 ppm was recorded in Hyderbad population and lowest LC_{95} value of 224.35 ppm was observed from West Godavari population. Accordingly the highest degree of resistance (1.20 folds) against susceptible strain was recorded in Hyderabad and least resistance ratio was observed in the population of Parbhani (1.01folds).

5.2.2.8 Carbaryl

The LC_{50} values of carbaryl differed strikingly among fourteen geographic populations of *L. orbonalis*. A comparative analysis of LC_{50} during 2009-10 cropping season revealed that, Raichur population recorded a maximum LC_{50} value to carbaryl (150.00 ppm) whereas, lowest LC_{50} value was observed in population from Chennai (120.08 ppm). Raichur population recorded maximum LC_{95} value of 1135.67 ppm and lowest was observed in Chennai (782.60 ppm) population. Resistance ratio (RR) at LC_{50} calculated against susceptible strain to measure the level of resistance development was found to be highest for population of Raichur (1.25 folds) and lowest resistance ratio was observed in Margoa (1.02 folds).

Similarly during 2010-11, Raichur population registered a maximum LC_{50} value to carbaryl (158.23 ppm) and lowest value was observed in population from Chennai (138.16 ppm). Highest LC_{95} value was recorded in Hyderabad (1193.84 ppm) and lowest was observed in Chennai (909.09 ppm) populations. The computed resistance ratio at LC_{50} in comparison with susceptible strain was highest for population of Raichur (1.13 folds) and the least resistance ratio was observed in the population of Chennai (0.99 folds).

Razmi *et al.* (1991) reported persistent toxicity of nine insecticides, viz, fenitrothion, methyl parathion, malathion, endosulfan, monocrotophos, quinalphos, phosphamidon, carbaryl and dimethoate against the neonate larvae of *Leucinodes orbonalis* Guen. Amongst these insecticides, the residues of malathion, quinalphos and dimethoate were found to have the quickest knock-down meet till four days as evidenced by LT_{50} values, being 3.33, 3.35 and 3.97 days, respectively. The persistent toxicity (PT) of phosphamidon was the highest while malathion proved to be the less persistent insecticide.

5.2.2.9 Quinalphos

LC_{50} values obtained to quinalphos for fourteen different geographic populations of *L. orbonalis* showed that, during 2009-10 Hyderabad population registered highest LC_{50} value (190.00 ppm). Whereas, least resistance was recorded by Margoa population (100.00 ppm). Highest LC_{95} was recorded in population of Hyderabad (1294.42 ppm) and lowest LC_{95} value of 532.27 ppm was observed in Margao population. Resistance ratio at LC_{50} value was highest in Hyderabad (1.90 folds) and lowest ratio was recorded by Chennai (1.10 folds).

During 2010-11, maximum resistance to quinalphos was observed in Hyderabad population (197.16 ppm) and least LC_{50} value was noticed in Margoa (121.60 ppm). Whereas, highest LC_{95} value was recorded in Hyderabad (1382.09 ppm) and lowest was recorded in Margoa (629.89 ppm). Highest resistance ratio to quinalphos was recorded by Hyderabad (1.62 folds). Lowest ratio was recorded by Chennai (1.02 folds) followed by Coimbatore (1.07 folds) and Aduthurai (1.12 folds).

Razmi *et al.* (1991) reported persistent toxicity of nine insecticides, viz, fenitrothion, methyl parathion, malathion, endosulfan, monocrotophos, quinalphos, phosphamidon, carbaryl and dimethoate against the neonate larvae of *Leucinodes orbonalis* Guen. Amongst these insecticides, the residues of malathion, quinalphos and dimethoate were found to have the quickest knock-down meet till four days as evidenced by LT_{50} values, being 3.33, 3.35 and 3.97 days, respectively. The persistent toxicity (PT) of phosphamidon was the highest while malathion proved to be the less persistent insecticide.

5.2.2.10 Monocrotophos

During the year 2009-10, Maximum LC_{50} value to monocrotophos was recorded in Bangalore (180.00 ppm) population. Least LC_{50} value of 140.00 ppm was observed in Margoa population. The value of LC_{95} was highest in population of Raichur (1322.45 ppm) and the lowest value of 941.28 ppm was recorded in population of Margoa. The resistance ratio against susceptible strain was found to be highest for population of Bangalore (1.29 folds) and Least ratio was recorded in population from Chennai (1.05 folds).

Similarly during 20010-11, maximum LC_{50} value to monocrotophos was recorded in Bangalore (187.48 ppm) and minimum resistance was observed in Margoa (155.23 ppm) population. The value of LC_{95} was highest in population of Hyderabad (1329.55 ppm) and whereas, lowest was in population of Margoa (828.93 ppm). The resistance ratio was found to be highest for Bangalore (1.21 folds) and Least ratio was recorded in population from Chennai (1.04 folds).

The information on baseline susceptibility to monocrotophos is very much lacking and hence results are compared and discussed with other lepidopteran species. The Mahbubnagar population recorded a maximum LD_{50} value to monocrotophos (80µg/µl) followed by the population from Buldana (36 µg/µl). The lowest LD_{50} value was observed in the population from Jalna (0.37µg/µl) followed by Karimnagar (13µg/µl) and Parbhani (18µg/µl). The Mahbubnagar strain showed the highest resistance to monocrotophos (216 fold) and the least resistance was observed in the population of Karimnagar (35 fold).

5.2.2.11 Chlorpyriphos

The data on LC_{50} values of chlorpyriphos to fourteen different geographic popualations of *L. orbonalis* for the 2009-10 cropping season revealed that, Bangalore population recorded a maximum LC_{50} value of 240.00 ppm followed by population from Raichur (238.04 ppm) and lowest LC_{50} value was observed in population from Margoa (210.12 ppm). The value of LC_{95} was highest in population of Bangalore (1670.25 ppm) and least value was recorded in population of Chennai (1028.37 ppm).

The higher degree of resistance ratio was observed in Bangalore (1.20 folds) population. Least resistance ratio was recorded in population of Coimbatore (91.03 folds).

During 2010-11, Bangalore population recorded a maximum LC_{50} value to chlorpyriphos (249.83 ppm) and lowest LC_{50} value was observed in population from Chennai (212.40 ppm). Highest LC_{95} value was recorded in Kolhapur (1809.67 ppm) and lowest value of 1295.64 ppm was observed in Chennai population. Highest degree of resistance (1.18 folds) against susceptible strain was recorded in Bangalore and least resistance ratio was observed in the population of Coimbatore (1.02 folds).

Studies for baseline susceptibility of chlorpyriphos was lacking and hence results are compared with other lepidopteran species. Dhawan *et al.* (2007) reported that LC50 values of emamectin benzoate, novaluran, pyridalyl, flubendiamide, chlorantraniliprole and thiodicarb were 0.0001, 0.0020, 0.0037, 0.0040, 0.0390 and 0.0410 per cent respectively. On the basis of LC50 value, the order of toxicity of different insecticides was emamectin benzoate > novaluran > pyridalyl > flubendiamide > chlorantraniliprole > chlorpyriphos > thiodicarb with relative toxicity of 390.0, 19.50, 10.54, 9.75, 8.86, 1.00 and 0.95 respectively.

5.2.2.11 Endosulfan

During the year 2009-10, maximum LC_{50} value to endosulfan was recorded in Raichur (240.00 ppm) and minimum LC_{50} was observed in Margoa (180.00 ppm). Maximum value of LC_{95} was observed in Raichur population (1651.00 ppm) and least LC_{95} value was recorded in Margoa (1229.46 ppm). The resistance ratio against susceptible strain was found to be highest in Raichur (1.33 folds) and least ratio was recorded in population from Chennai (1.01 folds).

Similar trend was observed during the year 2010-11, highest value of LC_{50} to endosulfan was recorded in Raichur (247.42 ppm) and minimum resistance was observed in Aduthurai (194.39 ppm). Highest LC_{95} of 1774.00 ppm was recorded in Raichur population and lowest value of LC_{95} was recorded in Aduthurai (1162.45 ppm). The resistance ratio against susceptible strain was found to be highest for Raichur (1.27 folds) and least ratio was recorded in population from Chennai (1.01 folds) followed by Margoa.

As the literature on baseline susceptibility to endosulfan is lacking, so the results were compared and discussed with other lepidopteran species. Chaudhari *et al.* (2008) conducted bioassay of five insecticides viz., fenvalerate, cypermethrin, quinalphos, carbaryl and endosulfan under laboratory against populations of *Helicoverpa armigera* collected from known pesticide usage locations in Maharashtra. The log dose probit assays indicated that *H. armigera* population from Amalner with heavy pesticide usage area recorded higher LD_{50} values compared to Madha population representing low pesticide usage area. Irrespective of locations, fenvalerate was most toxic to *H. armigera* followed by cypermethrin, endosulfan was least toxic to *H. armigera* (Fig. 7 and 8).

The genetic plasticity of *L. orbonalis* is apparent in its ability to detoxify many synthetic insecticides in addition to the secondary plant metabolites present in its narrow array of host plant species. In response to the stresses, the populations of *L. orbonalis* have adapted to the insecticide applications by changing their eco-behavioural pattern, feeding physiology and reproduction. This in turn led to excessive and indiscriminate use of insecticides by desperate farmers across the geographical locations. This is also due to lack of suitable alternatives and the unsynchronized use of insecticide classes that led to continuous population exposure to all the insecticides.

5.3 Genetic diversity assessment of brinjal shoot and fruit borer (*Leucinodes orbonalis* G.*)* populations occurring in south India using mitochondrial DNA markers

On the basis of simple matching coefficients all the selected populations were grouped into 5 clusters. Cluster 5 had maximum of four populations followed by cluster 1, 2 and 3 with three populations each and cluster 4 with a single population.

The minimum genetic relatedness was 18 per cent between Bangalore and Hyderabad populations. The highest genetic similarity of 90 per cent was evident between the populations of Aduthurai and Coimbatore.

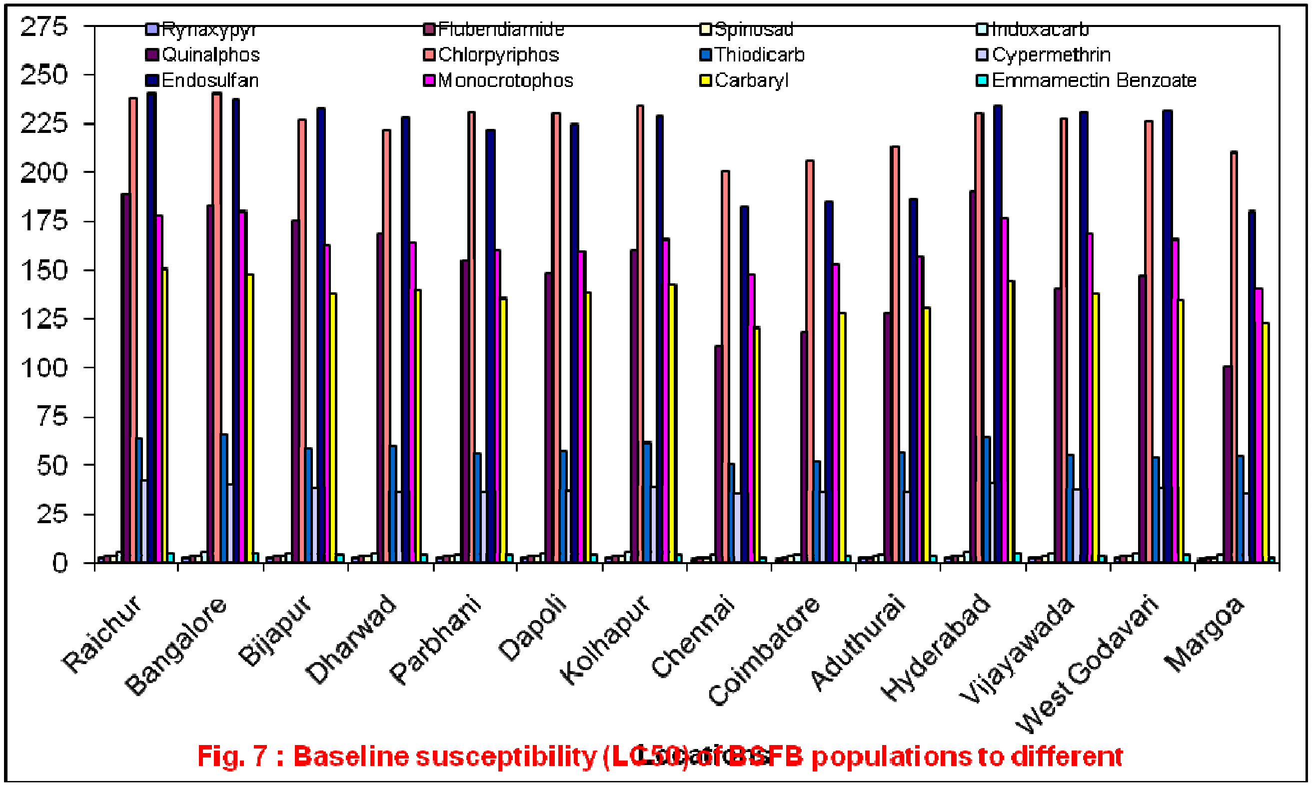

Fig. 7 : Baseline susceptibility (LC50) of BSFB populations to different Insecticides in South India (2009-10)

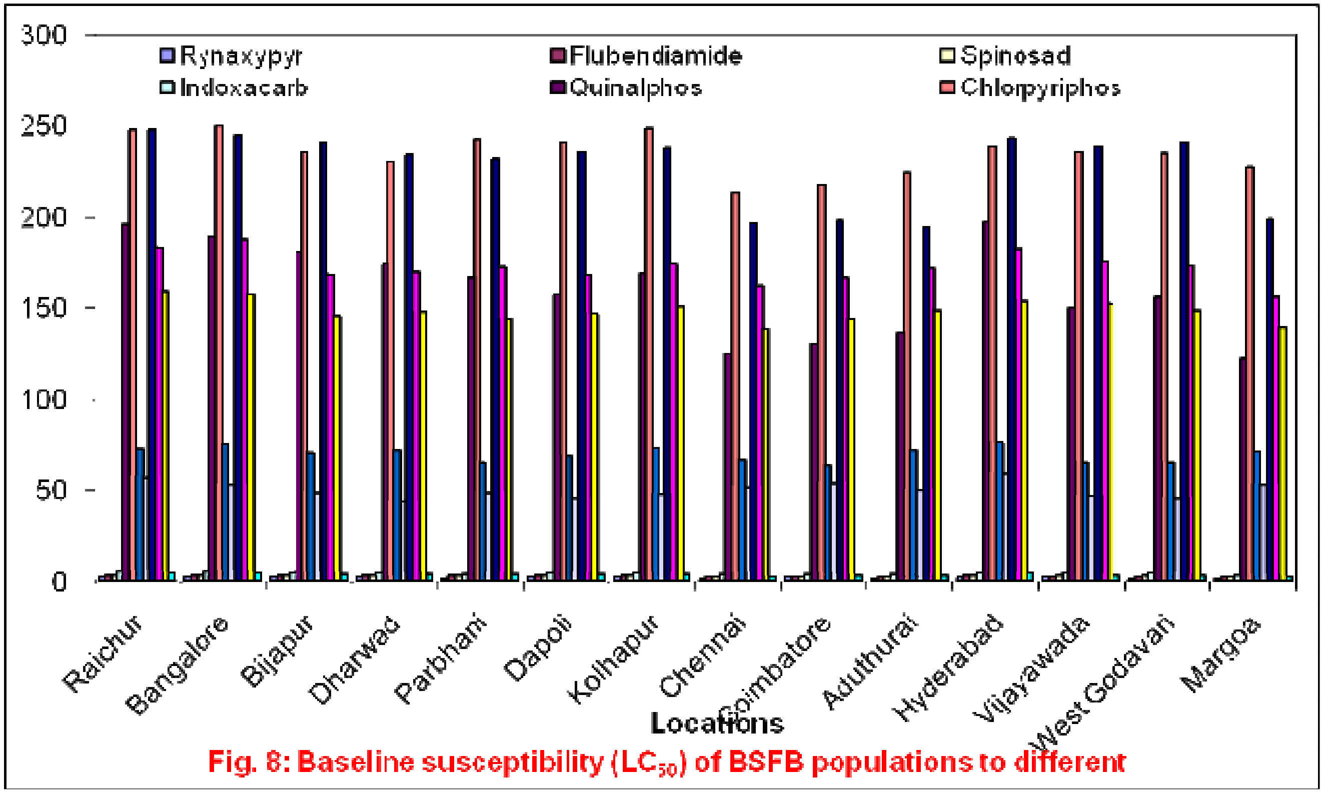

Fig. 8: Baseline susceptibility (LC_{50}) of BSFB populations to different Insecticides in South India (2010-11)

The first group (X) comprised nine populations while the distinct second group (Y) consisted of only five populations (Goa, Bangalore, Raichur, Bijapur and Dharwad). The X group is subdivided into X1 and X2 at a similarity coefficient of 0.52, where the X1 group comprising three geographical populations. X2 comprised six populations included two distinct groups (at a similarity coefficient of 0.72) X2.1 and X2.2; X2.1 group consisting of populations from Hyderabad, Vijaywada, West Godavari, while X2.1 comprised population from Aduthurai, Chennai and Coimbatore. The Y group is subdivided into Y1 and Y2 at a similarity co-efficient of 0.62,where Y1 consisting of single population of Goa and the Y2 group comprising four geographical populations consisting of Bangalore, Raichur, Bijapur and Dharwad .

The present study revealed high level of genetic heterogeneity among *L. orbonalis* populations. The mean similarity coefficient varied from 0.18 to 0.90 across populations. Significant genetic differentiation at 158 loci was found among populations in close proximity, as well as among those from distant parts of the range. On a larger scale, genetic differences among populations appeared to result from low dispersal rates between populations. Substantial heterogeneity (0.10–0.82) occurred throughout the ecosystems. Large genetic differences between X and Y clusters in the dendrogram were likely to be due to gene flow restrictions by physical or temporal means.

Genetic distinctiveness was low in two commonly and equally dispersing populations (Daly and Gregg, 1985). Murugan *et al* (2009) reported low level of genetic distances among twelve *L. orbonalis* populations of Tamilnadu, with high level of gene flow. In six different Tamil Nadu populations of *L. orbonalis,* Karthikeyan *et al.* (2005) found high level of genetic heterogeneity. The mean similarity coefficient varied from 0.25 to 1.00 across populations, while mean similarity coefficient between 0.20 to 1.00 using RAPD markers. Geetharajalakshmi *et al*. (2006) found similarity coefficient of 0.41 to 0.77 using Lepidopteran specific random primers in 10 populations of Tamil Nadu. The results are in aggregation with Jian cheng chang *et al*. (2014) who examined genetic diversity of *L. orbonalis* in eight populations from six countries using mitochondrial cytochrome c oxidase subunit I DNA sequences. No correlation between genetic diversity and geographic distance was detected among populations. No significant gene flow was found among local populations in different countries. India was confirmed to be the source of genetic variation in *L. orbonalis* populations.

The genetic heterozygosity detected in present study, among populations in southern parts of india was on higher side (0.10 to 0.82).This indicates that he selective use of Mtd primers could produce distinct and reproducible patterns, resulting in detection of higher variability and it reflects high genetic variability in sothern parts of india.

5.4 Population dynamics of SFB in selected wild species of brinjal

The present study indicated that, during both the seasons (2009-10 & 2010-11) among the six wild species selected *viz*., *Solanum torvum*,*Solanum indicum*, *Solanum viarum*, *Solanum incanum*, *Solanum virginianum* and *S.macrocarpon*, two species *S. torvum* and *S. viarum* were found to be dominant species at all the surveyed locations. The shoot and fruit damage in *S.torvum* varied from 1.93 to 16.51 and 15.62 to 46.45 per cent and differed significantly during different months in both the seasons of 2009 and 2010 respectively. Over all mean shoot and fruit infestation was to found to be 7.16 and 27.29 per cent (Fig.9 and 10).

Solanum indicum recorded highest shoot and fruit infestation which varied from 2.50 to 29.20 per cent and 10.00 to 44.24 per cent. Similarly maximum shoot and fruit damage was found to be from September to march during both the seasons. The mean shoot and fruit infestation recorded was 15.45 and 26.78 per cent.

Data revealed that, in case of *S.viarum* species no shoot infestation was observed throughout the period. Whereas, fruit damage was very minimum and varied from 2.10 to 7.28 per cent. The mean fruit damage was found to be 1.72 per cent. The level of shoot and fruit infestation in *S.incanum* species varied from 1.10 to 5.58 per cent from both the seasons of 2009 and 2010. Whereas, fruit infestation was found to be varied from 1.00 to 8.30 which differed significantly during the various months. Over all mean shoot and fruit infestation found to be 1.92 and 3.63 per cent.

The data from the table revealed that, no shoot infestation was recorded in *S. virginianum* throughout the seasons of 2009 and 2010. The fruit damage differed significantly during the different months and ranged from 10.30 to 30.24 per cent. The mean fruit infestation of 13.55 per cent was recorded. The species *S. macrocarpon* recorded both the shoot and fruit damage. The shoot infestation varied from 5.00 to 50.00 per cent and the extent of fruit damage ranged from

16.66 to 56.00 per cent. The mean shoot and fruit damage was found to be 5.40 to 21.37 per cent. Among the six wild species surveyed, three species are classified under tolerant category followed by two species under highly resistant category and only one species was found to be fairly resistant to brinjal shoot and fruit borer.

The results are in corrugation with Dhankhar *et al.* (1980) who reported that wild species *Solanum sisymbrifolium*, *S.integrifolium*, *S.xanthocarpum*, *S.nigrum* and *S. khasianum* have earlier been found free from the damage of shoot and fruit borer damage, while *S. incanum* showed infestation of 8.6 per cent. Kale *et al.* (1986) recorded the shoot infestation (both on number and weight basis) on *S.incanum*, *S.xanthocarpum* and *S.sisymbrifolium* and found that these wild species are immune as they showed no infestation.

Sridhar *et al*. (2001) reported that, fifty-four brinjal germplasms, including 5 wild species and some F< sub>1</ sub> crosses were screened for resistance to *L. orbonalis*, during 1999-2000, under field conditions in Bhubaneswar. Three wild species, i.e. *S. khasianum*, *S. viarum* and *S.incanum*, were found to be resistant from fruit infestation (0.5-10.0%). *S.viarum* and *S.macrocarpum* are highly resistant to eggplant fruit and shoot borer. The insect incidence was less than 1% in *S.viarum* and 7–8 per cent in *S. macrocarpum*, compared with 40–45 per cent infection in the cultivated variety Arka Nidhi and the Mahyco hybrid (Anon., 1998).

Many biochemical factors are known to be associated with insect resistance in crop plants. It is obvious in many cases that the biochemical factors are more important than morphological and physiological factors in conferring non-preference and antibiosis. Some biochemical constituents may act as feeding stimuli for insects. Occurrence at lower concentration or total absence of such biochemicals leads to insect resistance. The biochemical constituents like glycoalkaloid (solasodine), phenols, phenolic oxidase enzymes namely polyphenol oxidase and peroxidase are available in brinjal and these biochemical constituents possess insect resistant properties.

5.5 Development and validation of IRM/IPM strategies for SFB management in brinjal ecosystem

For effective management of brinjal shoot and fruit borer five IPM modules were developed and verified over two seasons. These modules were compared for their total effectiveness and economic advantage.

5.5.1 Incidence of Shoot damage

During 2009-10 and 2010-11, the data clearly indicated that, at 30 DAT, Module-II (IIHR+AVRDC) and Module-V (Adoptable module) recorded shoot damage of 23.88 and 23.46 per cent, where both were on par with each other and differed significantly with rest of the treatments. Similar trend was followed at 40 and 50 DAT. At 60 DAT, Module -I (farmers practice) recorded shoot damage of 17.21 per cent and Module -V (Adoptable module) (17.57 %) were on par with each other and differed significantly compared to rest of the treatments. Similar observations were noticed at 70 and 80 DAT. At 90 DAT, where in Module-V (Adoptable) recorded lowest shoot damage of 10.84 per cent followed by Module-I (farmers practice) (12.41 %), which were found to be on par with each other and differed significantly with other treatments. Similar observations were also noticed at 100, 110 and 120 DAT (Fig. 11).

The results are in line with Saifur Rahman *et al*. (2002) who reported that among the IPM package 1, IPM package and IPM package 3. IPM package 3, consisting of grafted plants treated with cymbush resulted significantly lowest shoot and fruit infestation with significantly highest yield. Muralikrishna *et al.* (2002) indicated that less shoot infestation of 9.36 per cent by *L. orbonalis* was observed due to application of phorate at transplanting followed by foliar spray of Bt + carbaryl. Rath and Dash (2005) reported that, IPM module comprising of application of neem cake at 100 kg/acre, installation of about 25-30 pheromones traps per acre from flower bud initiation until the final harvesting and mechanical clipping of infested shoot on weekly basis and spraying of neem oil every 10-12 days interval recorded less shoot damage of 1.83 and 1.79 per cent in IPM plots as compared to 12.67 and 9.52 per cent in Non IPM.

5.5.2 Incidence of fruit damage

Data from 2009-10 and 2010-11 cropping seasons revealed that, in case of first four pickings, lowest fruit damage was recorded in Module-V (Adoptable module) (18.74 to 16.79 %) and Module- I (farmers practice) (19.20 to 16.50 %) which were on par with each other and differed significantly with each other. Whereas, in remaining pickings of fifth, sixth, seventh and eighth pickings, significantly lowest fruit damage was recorded in Module-V (Adoptable module) (13.66 to 7.46 %) followed by Module-I (farmers practice) (14.86 to 8.77 %), Module- II (IIHR+ AVRDC) (16.14 to 10.29 %), Module-IV (UAS Raichur) (17.65 to 11.72 %) and Module- III (Bio-intensive) (19.21 to 13.24 %) which differed significantly with each other (Fig. 12).

Similar results were reported by suradkar *et al*. (2008) who reported that, Spinosad+ *M.Anisopliae*+ chelating agent+ Cartap hydrochloride module was found to be the most effective In reducing shoot and infestation (7.47%), fruit damage (25.59%) giving maximum yield (81.82q/ha). Bhavani *et al*. (2009) concluded that among the treatments combinations tested for the management of brinjal shoot and fruit borer. T_8 comprosing of shoot clipping at weekly interval + application of carbofuran 3G @ 5gm/plant at 30 DAT + spraying of profenofos 50 EC@ 0.1 % from flower initiation for 3 times at 15 days for three times recorded significantly less intensity of shoot (13.24%) and fruit (20.65 %) with fruit yield (260.15 q/ha) by recording 63.46 % increase over control.

5.5.3 Natural Enemies Population

5.5.3.1 Coccinellids

Data for two years (2009-10 and 2010-11) revealed that, Module-I (Farmers practice) recorded lowest population and differed significantly with rest of the modules at all days of observations. Whereas, Module II, III, IV and V were on par with each other at 30, 40, 50 and 60 DAT. Highest population was recorded in Module II and Module III which were on par with each other and differed significantly over rest of the modules. Modules IV and module V differed significantly with each other at 80, 90, 100 and 110 DAT.

Present investigations are in conformity with Sandeep Kaur and Subash Singh (2013) who reported that the population of spiders was highest in module M2 (1.27). Significantly highest lady beetle population (0.44) was recorded in module M2. The population of natural enemies was observed to be higher in IPM module M2 after the control module M4.

5.5.3.2 Chrysoperla

During the cropping season of 2009-10 and 2010-11 the data revealed that, significantly lowest population was recorded in module-I (Farmers practice) at all observations. At 30 DAT, module-I (Farmer practice) recorded lowest population followed by module-V, module-IV, module-II and module –III (0.93/plant) which were on par with each other. Similar trend was noticed at 40, 50 and 60 DAT. Module-III was on par with module-II and differed significantly with module-IV and module-V and both modules differed significantly at 80, 90, and 110 days after transplanting (DAT).

Present investigations are in aggrement with Sandeep Kaur and Subash Singh (2013) who reported that, significantly higher population of green lace wings (4.60) were recorded in control M4 followed by M2 (4.42).

It was evident that use of botanicals and safer chemicals enhances the natural enemies in crop, therefore, must be encouraged to maintain the biodiversity in cropping systems.

5.5.4 Trap catches

Trap catches of *Leucinodes orbonalis*was recorded at weekly interval from 34^{th} standard week to 51^{st} standard week in all the three modules in both the years (2009-10 & 2010-11). During the period of 2009-10 cropping season, Overall mean adult moths per trap over 18 weeks recorded was higher in Module-III (133.29 adults/trap) followed by module-II and module-IV which recorded 123.86 and 114.73 mean adults moths per trap over the same period and differed significantly from each other. Similarly during the second year of study (2010-2011) moths trapped were less compared to previous year. Data indicates that, mean number of adult moth trap catches was highest in the Module-III (142.53 adults/trap) followed by other two modules with 125.55 and 116.56 adults per trap in Module-II and Module-V. In all the modules the peak trap catches of moths was noticed in the 42^{nd} standard week (Fig.13).

Cork *et al*. (2003) reported that Pheromone trap catches in jessore, Bangladesh were reduced significantly from 2.0 to 0.4 and 1.1 to 0.3 moths per trap per night both in young and mature crop of check and IPM plots. The fruit infestation was significantly reduced from an average of 41.8% and 51.2% in check plots of young and mature crops to 22% and 26.4% in the associated IPM plots.

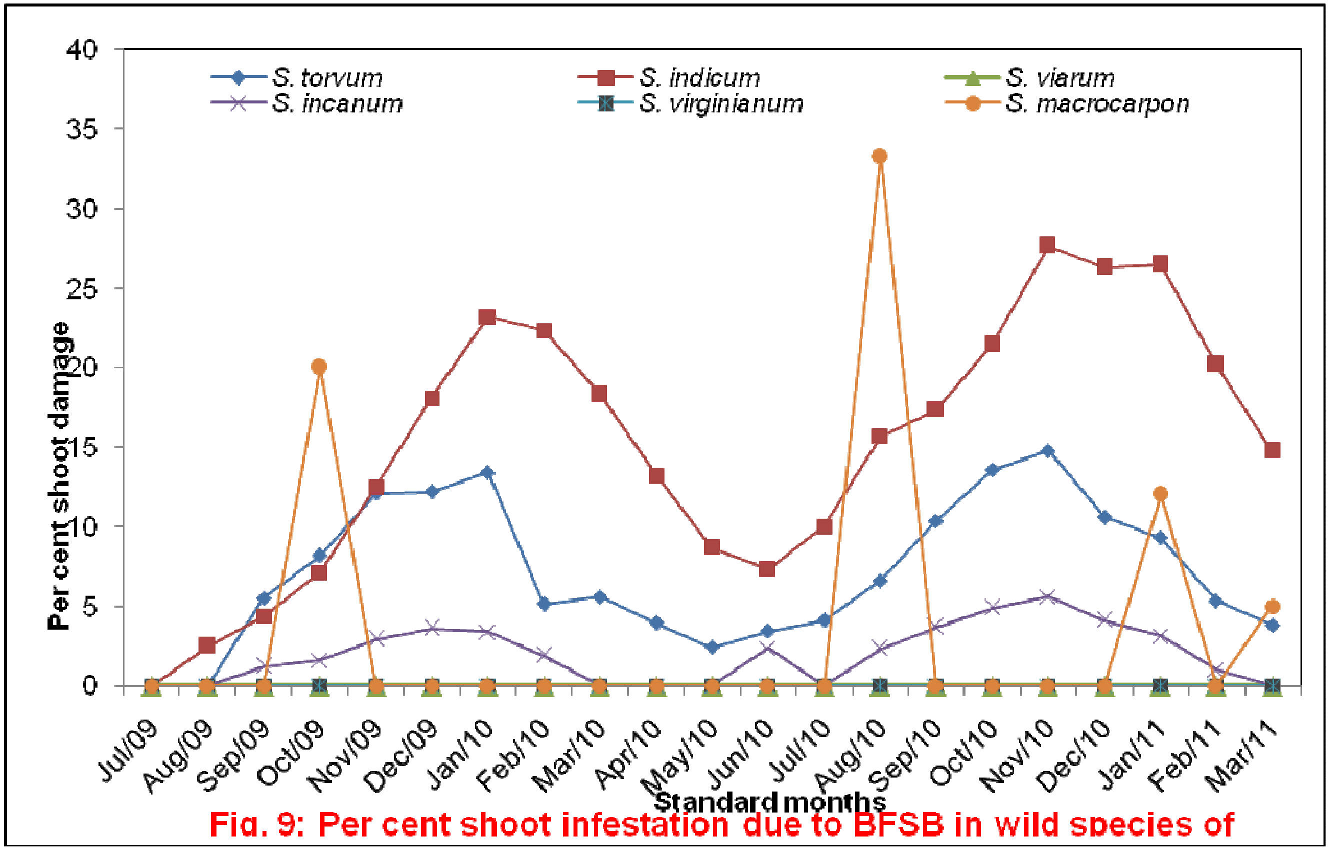

Fig. 9: Per cent shoot infestation due to BFSB in wild species of Brinjal

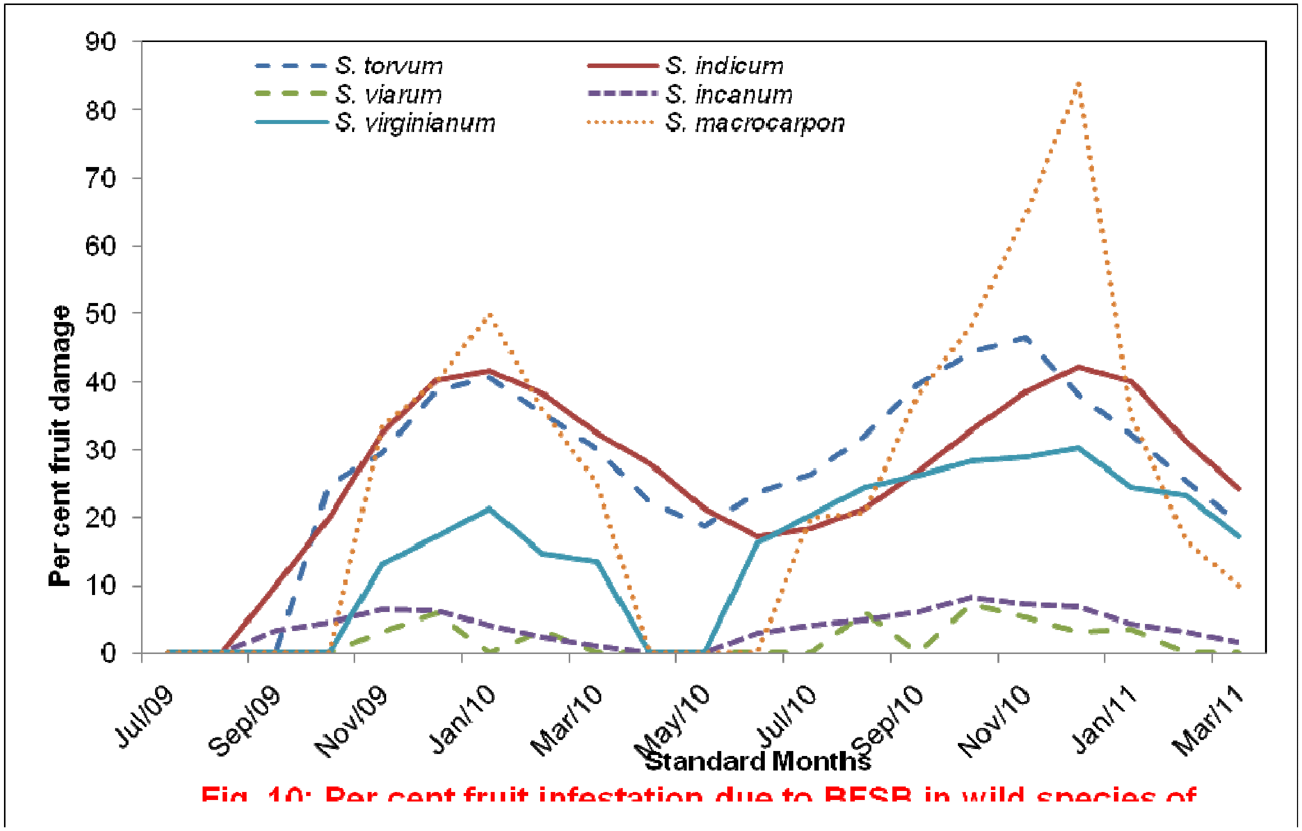

Fig. 10: Per cent fruit infestation due to BFSB in wild species of Brinjal

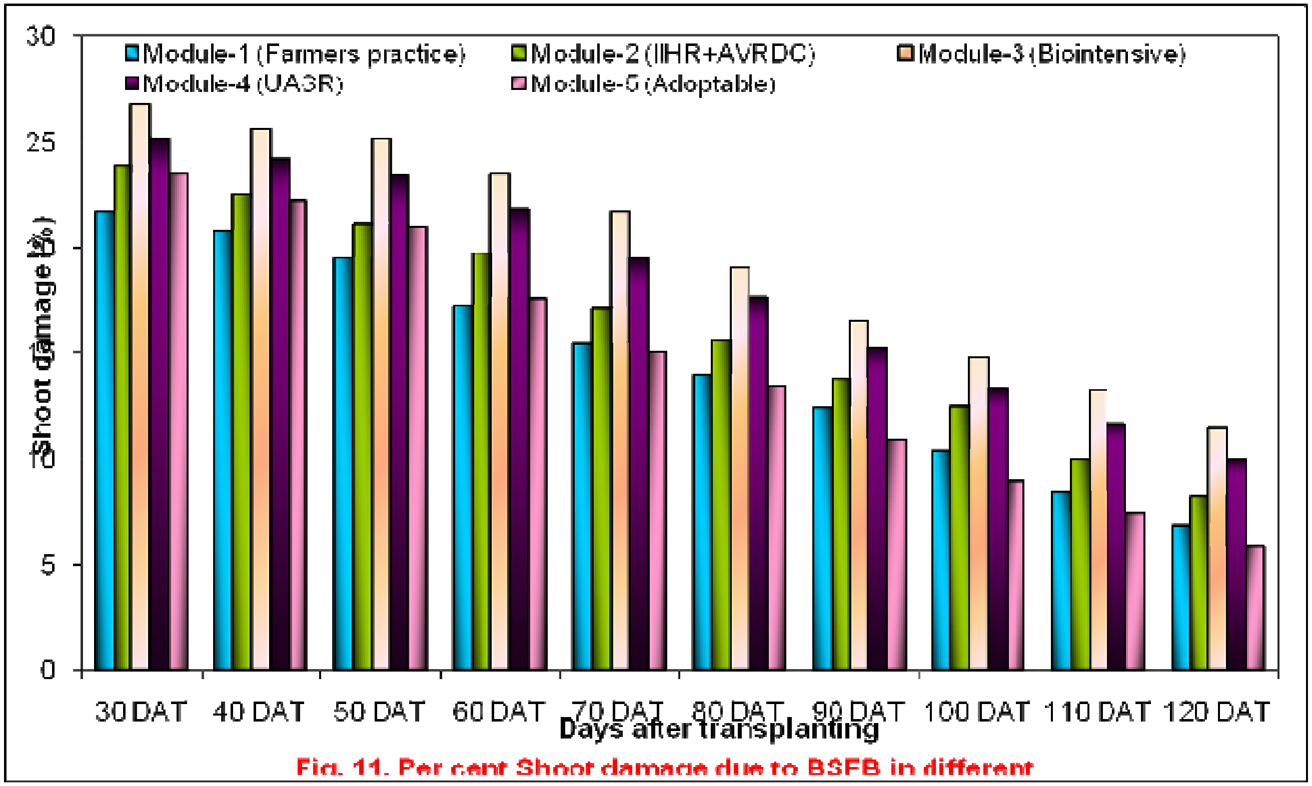

Fig 11: Per cent Shoot damage due to BSFB in different modules

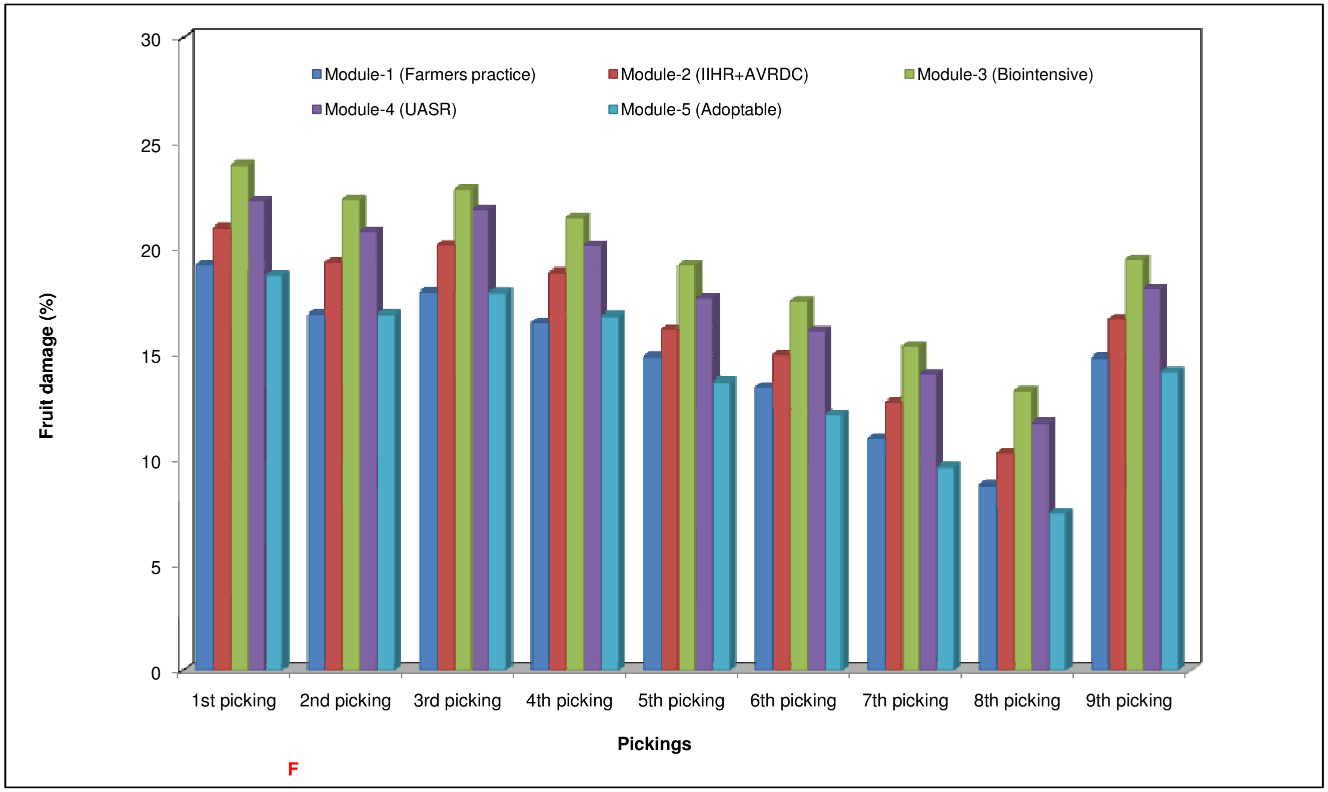

Fig 12: Per cent fruit damage due to BSFB in different modules

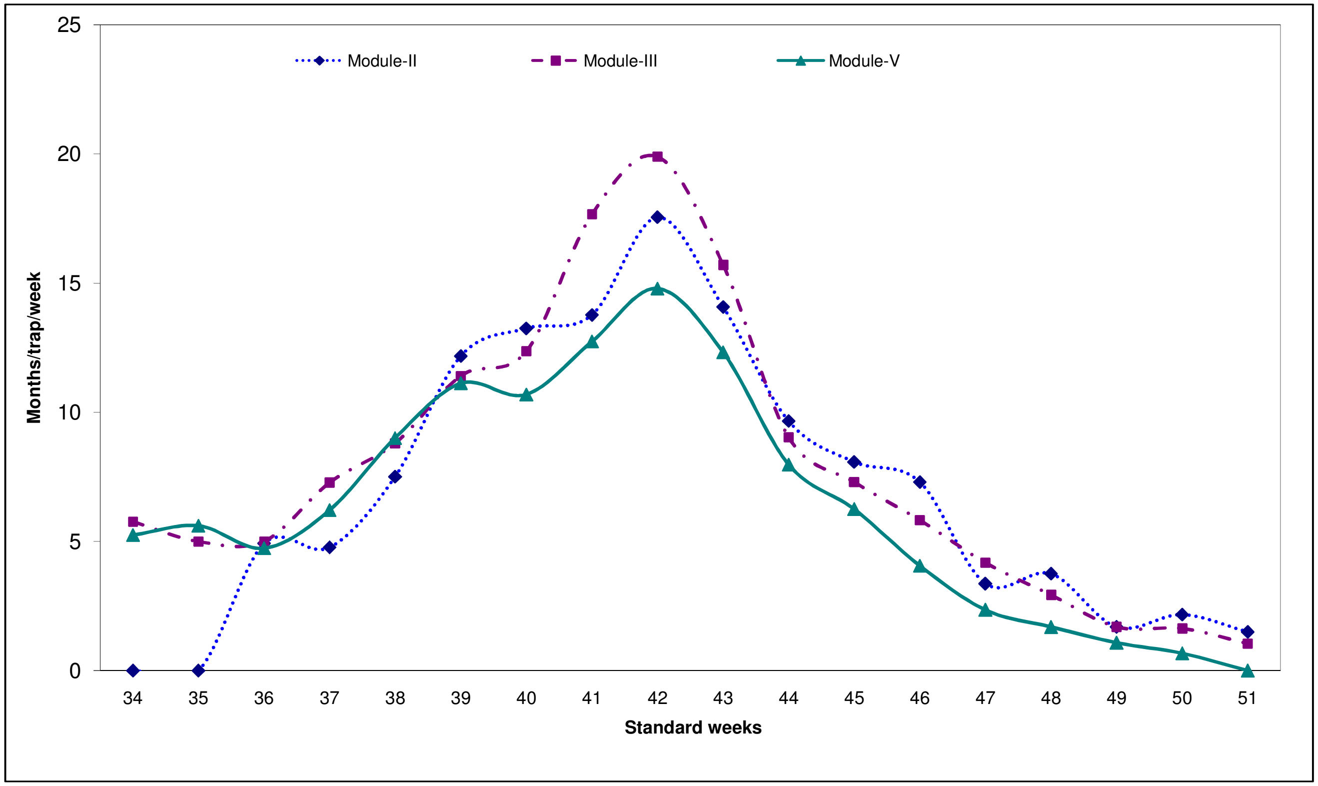

Fig 13: Trap catches of adult moths of BSFB in different modules

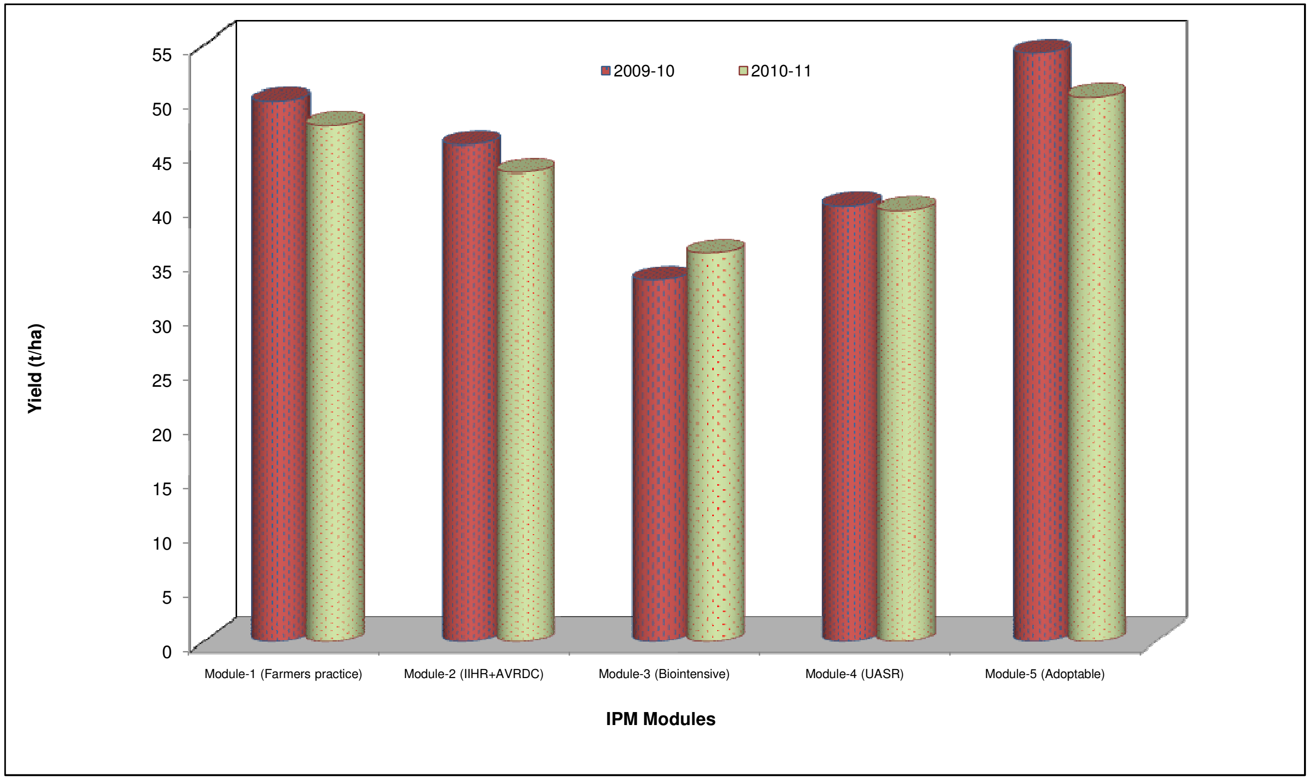

Fig 14: Impact of different IPM modules on yield of brinjal

Geetha lakshmi *et al*. (2009) reported that, spraying of Insecticides cypermethrin 25 EC (1.5 ml/l) and chloropyriphos 20 EC (2.5 ml/l) at 10 days interval beginning from 15 days after planting (DAP) and until 80 DAP, application of neem cake @ 35 kg at 30 DAP at the time of top dressing and at 45 DAP commensurate with flowering, setting up of pheromone impregnated lures on water trap recorded the mean number of moths trapped per day was less than 1.There was no significant difference in the number of moths trapped during different weeks of crop growth.

5.5.5 Yield and cost economics

All the modules differed significantly in terms of yield during 2009-10 cropping season. Among the modules significantly highest yield of 54.24 q/ha was recorded in Module- V (Adoptable) with highest net returns (Rs.258058/ha) and C: B ratio of 1:3.83 followed by Module -I (farmers practice) with yield of 49.80 q/ha with net returns of (Rs.229680) and C: B ratio of 1:3.32 and lowest yield of 33.32 q/ha was recorded in Module-III (Bio-intensive) with net returns of Rs.137120/ha and C:B ratio of 1:2.18 respectively (Fig.14).

During 2010-11 season, maximum yield of 50.17q/ha was recorded in Module-V (Adoptable) with net profit of Rs.333978/ha with C:B ratio of 1:4.96 followed by Module-I (farmers practice) which recorded yield of 47.60 q/ha with net returns of Rs.311680/ha and C:B ratio of 1:4.52.Whereas, significantly lowest yield of 35.80 q/ha was recorded in Module-III (Bio-intensive) with C:B ratio of 1:3.56

The results are in agreement with Abdul Latif *et al*. (2009). They concluded that among the 8 different IPM packages evaluated for management of brinjal shoot and fruit borer, package 6 (mechanical control + potash @100 kg/ha + field sanitation in combination with flubendiamide 24WG applied at 5% level of shoot and fruit infestation showed the better performance by reducing 80.63% fruit infestation with 108.83% healthy fruit yield and decreased 74.13% infested fruit yield over control. The BCR of 4.12 and 4.00 was obtained in IPM package 6 with 8 and 5 sprays, respectively.

Sardana *et al*. (2008) reported that, adoption of IPM technology resulted in reducing the number of sprays to 1-2 from 4-6 in non-IPM fields and with fruit yields of 450.1, 454.1, 484.0 q/ha and 274.1, 354.6 and 405 q/ha in non-IPM fields with higher CBR of 2.27-2.89 in IPM compared to 1.04-2.12 in non –IPM fields.

Future line of work

1. Estimation for level of MFO's and other enzyme systems conferring resistance in different geographic populations of brinjal shoot and fruit borer
2. Diversity analysis using other molecular markers such as SSR, ISSR, AFLP etc.
3. Cross mating experiments between the geographical populations to evaluate crossing compatibility.
4. F_2 screening of geographic populations for the detection and quantification of rare resistant alleles.
5. To study the Biochemical factors responsible in wild brinjal for resistance against shoot and fruit borer.
6. Monitoring of temporal and spatial baseline susceptibility changes and resistance after commercialization of Bt Brinjal.
7. Development of IPM module for Bt Brinjal after commercial approval.

SUMMARY AND CONCLUSIONS

During the present investigation, survey was conducted to study the insecticide usage pattern in major brinjal growing regions of South India. Efforts were made to monitor the baseline susceptibility in SFB populations of South India to different chemistries and Cry1Ac protein, assessment of genetic diversity of brinjal shoot and fruit borer (*Leucinodes orbonalis* G) using mitochondrial DNA markers, to study the population dynamics of SFB in selected wild species of brinjal and development of IRM/IPM strategies for SFB management in brinjal. The field and laboratory experiments were carried at Department of Agricultural Entomology and Main Agricultural Research Station during 2009-10 and 2010-11 at University of Agricultural Sciences, Raichur, Karnataka.

Survey made in different major brinjal growing regions across the south india revealed that farmers sprayed insecticide at an interval of 4-8 days. Farmers from Margoa, Vijaywada, Parbhani and chennai sprayed the insecticides at an interval of 8 days, which is highest among all the locations and lowest spray interval of 4 days was recorded from farmers of Bangalore and Raichur locations. The number of application of insecticides varied from 18 to 34 in brinjal against shoot and fruit borer. Maximum number of 36 sprays were given at Raichur followed by 34 sprays in Hyderabad. Whereas, the lowest number of 18 sprays were given at Margoa and Chennai.

Among the insecticides highest usage of rynaxypyr was and lowest use of endosulfan was observed. Among the different geographical states Karnataka and Tamilnadu recorded highest use rate of rynaxypyr and whereas in Andhra Pradesh, majority of the farmers used spinosad (78.67%). Farmers in Maharashtra state use the highest per cent of spinosad (77.33 %). Whereas, Goa farmers used highest rate of spinosad (60 %).

Median lethal concentrations (LC_{50}) for cry1Ac during 2009-10 for neonates of *L. orbonalis* ranged from 0.020 to 0.042 ppm of diet. Population from Margoa recorded the lowest LC_{50} and the highest LC_{50} value was observed in Raichur population. During 2010-11, LC_{50} values of neonates among the different populations ranged from 0.022 to 0.040 µg/ml diet. Highest LC_{50} value of (0.040 µg/ml diet) was observed in Raichur population and Lowest LC_{50} value of 0.022 µg/ml diet was recorded in population of Margoa. Moult inhibitory concentration (MIC_{50}) values ranged from 0.003 to 0.014 µg/ml diet and the MIC_{95} values ranged from 0.028 to 0.145 µg/ml diet. Raichur recorded Maximum MIC_{50} and Margoa recorded lowest $MIC_{50.}$

Insecticide bioassay in F1 generations for most widely used insecticides clearly indicated that resistance to conventional insecticides is prevalent in all most all the study locations, highest being in Raichur of Northern karnataka which recorded higher RF values compared to southern part. Very conspicuously, for all insecticides, populations from Goa i.e., Margoa recorded low levels of resistance. It is clear from the bioassay data that the *L. orbonalis* population acquired resistance, which is variable to the insecticide and also to the geographical area. Distinctive differences in LC_{50} values to different populations suggest differential rate of development of resistance in *L. orbonalis*.

Irrespective of the locations, highest development of resistance was noticed in 2010-11 compared to 2009-10, which may be attributed to mild level of shoot and borer infestation in south Indian brinjal ecosystem and in turn low level of insecticide selection pressure. Among twelve insecticides, highest level of resistance development was noticed against chlorpyriphos and endosulfan.

On the basis of simple matching coefficients all the selected populations were grouped into 5 clusters. Cluster 5 had maximum of four populations followed by cluster 1, 2 and 3 with three populations each and cluster 4 with a single population.

The first group (X) comprised nine populations while the distinct second group (Y) consisted of only five populations (Goa, Bangalore, Raichur, Bijapur and Dharwad). The X group is subdivided into X1 and X2 at a similarity coefficient of 0.52, where the X1 group comprising three geographical populations. X2 comprised six populations included two distinct groups (at a similarity coefficient of 0.72). The Y group is subdivided into Y1 and Y2 at a similarity co-efficient of 0.62,where Y1 consisting of single population of Goa and the Y2 group comprising four geographical populations consisting of Bangalore,Raichur,Bijapur and Dharwad

Among the six wild species *viz.*, *Solanum torvum*, *Solanum indicum*, *Solanum viarum*, *Solanum incanum*, *Solanum virginianum* and *S.macrocarpon*, two species *S. torvum* and *S.viarum* were found to be dominant species at all the surveyed locations. Among six wild species, three species are classified under tolerant category followed by two species under highly resistant category and only one species was found to be fairly resistant to brinjal shoot and fruit borer.

Among the different IPM modules, all the modules differed significantly with respect to shoot damage. Least shoot damage of 14.23 per cent was noticed in case of Module-V (Adoptable module) followed by Module- I (farmers practice) (14.61%), Module- II (IIHR+AVRDC) (16.42 %), Module- IV (UAS Raichur) (18.16 %) and Module -III (Bio-intensive) (19.74 %) which differed significantly from each other.

All the modules differed significantly with respect to fruit damage. The lowest fruit damage of 14.14 per cent was recorded in Module-V (Adoptable) (14.14%) followed by Module- I (farmers practice) (14.81%), Module-II (IIHR+AVRDC) (16.67%), Module-IV (UAS Raichur) (18.06 %) and Module- III (Bio-itensive) (19.48%).

Module-I (Farmers practice) recorded lowest population of coccinellids and *chrysoperla* which differed significantly with rest of the modules at all days. Whereas, Module II, III, IV and V were on par with each other at 30, 40, 50 and 60 DAT. Highest populations was recorded in Module II and Module III which were on par with each other and differed significantly over rest of the modules at 80, 90, 100 and 110 DAT.

Mean adult moths of *L. orbonalis* per trap over 18 weeks recorded higher in Module-III (133.29 adults/trap) followed by module-II and module-IV which recorded 123.86 and 114.73 mean adults moths per trap over the same period and differed significantly from each other.

All the modules differed significantly in terms of yield during both the years of cropping seasons. Maximum yield of 50.17q/ha was recorded in Module-V (Adoptable) with C: B ratio of 1:4.96 followed by Module-I (farmers practice) which recorded yield of 47.60 q/ha and C:B ratio of 1:4.52. Significantly lowest yield of 35.80 q/ha was recorded in Module-III (Bio-intensive) with C: B ratio of 1:3.56.

Conclusions

- The present study clearly indicated that across the major brinjal growing regions of south India, farmers sprayed insecticides at an interval of 4-8 days. The number of applications of insecticides varied from 18 to 34 in brinjal against shoot and fruit borer per season.
- Majority of the brinjal famers across the south India used rynaxypyr followed by spinosad against shoot and fruit borer, *Leucinodes orbonalis*.
- Farmers in Tamilnadu and Goa states still use old chemicals for the control of brinjal shoot and fruit borer.
- LC_{50} values of Cry1Ac indicated that populations of *L.orbonalis* across the geographic locations were extremely sensitive to Bt proteins.
- Among twelve insecticides, highest level of resistance development was noticed against chlorpyriphos and endosulfan across the populations of fourteen geographic locations.
- Genetic diversity across the fourteen populations revealed that, similarity co-efficients ranged from 0.38 to 0.90 among populations. Genetic similarity of 90 per cent was evident between the populations of Aduthurai and Coimbatore.
- Two species *S. torvum* and *S.viarum* were found to be dominant at all the surveyed locations. Three species are classified under tolerant category and two species under highly resistant category with only one species was found to be fairly resistant to brinjal shoot and fruit borer.
- Adoptable module significantly reduced shoot and fruit damage recording highest fruit yield with maximum C:B ratio.

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* Original not seen

Appendix – I: Questionnaire for survey of insecticide usage pattern against shoot and fruit borer (SFB)

1 .Personal data

a. Name of village (Tq & District) **b**. Farmers name

c. Date of data collection **d**. Size of the farm

2. Details of brinjal growing

i) Area under eggplant 2–3 years before: __ ha, At present: __ ha, At present under IPM: __ ha

ii) Variety/hybrid iii) No of crops iv) Since when

3. Agronomic details

i) Spacing ii) Fertilizer iii) Irrigation facility iv) Yield (t/ha)

4. Plant protection measures

a) List the number of times you applied pesticides at particular stage(s) of the Crop.

What chemicals did you apply during those stages?

1. Crop stage
2. Number of applications
3. Pesticide name
4. No of sprays
5. Sole or mixture
6. Interval
7. Spray volume
8. Dosage
9. Type of sprayer
10. Qty. of pesticide application

b) What percentage of your total eggplant production will be damaged by ESFB during:

2009: _______ %, 2010: _______ %

c) How did you control this pest? (✓)

1. _______ Apply pesticide
2. _______ Hand picking/shoot clipping
3. _______ Other method(s), please specify: _________

d) When did you take action to apply pesticides? (✓)

1. _______ After severe attack
2. _______ After initial attack

3. _______ Without observing any insect
4. _______ As per government recommendations
5. _______ Schedule-based sprays

e). In general, estimate the percentage of damage reduced by the insecticides that you used (✓)

_______ Less than 25% _______ 50–75% _______ 25–50% _______ more than 75%

f) Was there any pesticide(s) which will be not effective at all after spraying? Yes / No

If yes, name the pesticide(s): ___________________________

g) How do you spray pesticide(s)?

1. _______ With sprayer machine. 2._______ other means (please specify): _______________

9. Cost economics

Item	2–3 years before	A t present
a. Yield of brinjal (Q/ha)		
b. Price received (Rs./kg)		
c. Input cost (Rs./ha)		
- Hired labour		
- Animal labour		
- Machine power		
- Sprayer machine		
- Seed cost		
- Pesticide cost		
d. Cost of IPM (Rs./ha)		
e. Net return (Rs/acre)		

Appendix – II: Composition of larval diet for Leucinodes orbonalis

	Ingredients	Quantity per litre of diet (g)
a)	Soaked Black gram flour	140.00 g
b)	Brinjal fruit powder	100.00 g
c)	Yeast	13.00g
d)	Sucrose	20.00g
e)	DL-α-tocopheral acetate	0.35 g
f)	Agar –Agar (powder)	20.00g
g)	Methyl para hydroxy benzoate	2.50g
h)	Sorbic acid	1.00g
i)	Ascorbic acid	4.30 g
j)	Formaldehyde 10%	2.00ml
k)	Ethanol	3.0 ml
l)	Wesson's salt mixture	5.00g
m)	Multi Vitamin mix solution	10.00ml
n)	Distilled water	1000 ml

Appendix III: Stock dilution preparation for dose –response bioassays (Diet incorporation)

<table>
<tr><th>Test material</th><th colspan="3">Specifications</th><th colspan="4">Primary dilution</th></tr>
<tr><td rowspan="2">1. Cry1Ac

2. MVP-II (19.7 %)</td><td rowspan="2" colspan="2">Primary stock (µg/ml)
Final 1st dilution (µg/ml)
Total no of dilutions
Serial dilution ratio :
Sample dilution in diet :
Diet /well (µl)
No of wells/dilution:</td><td rowspan="2">200
1.00
7
1/3
1/5
800
32</td><td colspan="3">Primary stock solution (µl)
Water volume (µl)
Total volume (µl)</td><td>207
8,073
8,280</td></tr>
<tr><td colspan="3">Diet incorporation
Sample/dilution (ml)
Diet/dilution (ml)
Total Volume/dilution (ml)
Diet/test material (ml)
Diet/test-Inclusive UTC (ml)</td><td>
5.52
22.08
27.6
154.56
353.28</td></tr>
<tr><td>Dilution</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Initial Volume (µl)</td><td>8,280</td><td>8,280</td><td>8,280</td><td>8,280</td><td>8,280</td><td>8,280</td><td>8,280</td></tr>
<tr><td>Volume removed for next dilution (µl)</td><td>2,760</td><td>2,760</td><td>2,760</td><td>2,760</td><td>2,760</td><td>2,760</td><td>0.00</td></tr>
<tr><td>Volume remaining for this dilution (µl)</td><td>5,520</td><td>5,520</td><td>5,520</td><td>5,520</td><td>5,520</td><td>5,520</td><td>5,520</td></tr>
<tr><td>Volume to discard (µl)</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>2,760</td></tr>
<tr><td>Stock sample conc. (µg/ml)</td><td>5.00</td><td>1.667</td><td>0.556</td><td>0.185</td><td>0.062</td><td>0.021</td><td>0.007</td></tr>
<tr><td>Diet sample conc.(µg/ml)</td><td>1.00</td><td>0.333</td><td>0.111</td><td>0.037</td><td>0.012</td><td>0.004</td><td>0.001</td></tr>
</table>

Dilution procedure

1. 207 µl primary stock + 8.073 ml water

↓

1.0 ppm in diet

↓

2. 2.76 ml (No.1) + 5.52 ml water

↓

0.333ppm in diet

↓

3. 2.76 ml (No.2) + 5.52 ml water

↓

0.111ppm in diet

↓

4. 2.76 ml (No.3) + 5.52 ml water

↓

0.037ppm in diet

↓

5. 2.76 ml (No.4) + 5.52 ml water

↓

0.012ppm in diet

↓

6. 2.76 ml (No.5) + 5.52 ml water

↓

0.004 ppm in diet

↓

7. 2.76 ml (No.6) + 5.52 ml water

↓

0.001 ppm in diet Discard 2.76 ml →

Appendix IV: Monthly Meteorological data for the year 2009-10 to 2010-11 at Main Agricultural Research Station, Raichur, 584 102

Months	Rainfall (mm)	Temp. (^0C)		Relative humidity (%)	
		Maximum	Minimum	Maximum	Minimum
July 09	1.80	33.86	22.32	79.60	48.00
August 09	42.28	33.30	21.95	83.50	57.25
September 09	41.10	32.13	21.63	88	62.50
October 09	72.52	31.80	19.32	82.80	51.60
November 09	20.53	31.28	18.68	90.50	71.25
December 09	0.00	30.15	15.83	89.00	54.25
January 10	0.00	31.64	15.76	88.00	42.00
February 10	0.00	34.30	17.73	84.75	38.25
March 10	0.00	38.73	21.18	74.50	32.25
April 10	0.48	40.96	24.02	59.00	22.40
May 10	10.50	40.08	21.63	68.50	31.00
June 10	21.00	35.48	21.83	80.50	47.25
July 10	53.00	32.48	19.86	88.60	64.20
August 10	33.53	31.60	16.90	91.50	64.00
September 10	40.25	31.00	16.98	89.75	67.25
October 10	10.08	31.62	19.32	90.20	62.00
November 10	1.80	31.48	18.30	92.50	53.50
December 10	0.95	29.83	13.10	87.75	39.50
January 11	0.00	31.86	12.20	91.40	41.60
February 11	0.00	32.13	15.38	77.00	24.50
March 11	0.00	37.98	18.88	77.00	25.50

POPULATION DYNAMICS, BASELINE SUSCEPTIBILITY, GENETIC DIVERGENCE AND MANAGEMENT OF BRINJAL SHOOT AND FRUIT BORER (*Leucinodes orbonalis* G.) IN SOUTH INDIA

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ABSTRACT

Investigations were carried out on insecticide usage pattern, baseline susceptibility to different group of insecticides and Cry1Ac protein, genetic diversity, population dynamics and validation of IPM strategies against *L.orbonalis*in brinjal were undertaken during 2009-10 and 2010-11 at MARS and Department of Entomology, College of Agriculture, Dharwad, Karnataka, India.

Across the major brinjal growing regions of south India, farmers applied insecticides from 18-34 sprays at an interval of 4-8 days against *L.orbonalis* per season. Maximum usage of 36 sprays were noticed in Raichur farmers and lowest number of 18 sprays was observed from Margoa and Chennai farmers. Majority of the brinjal famers across the south India used rynaxypyr followed by spinosad against *L.orbonalis*. LC_{50} values of Cry1Ac indicated that populations of *L.orbonalis* across the geographic locations were extremely sensitive to Bt proteins. Lowest and highest LC_{50} and MIC_{50} was noticed in Margoa and Raichur population across the south india. Among insecticides, highest level of resistance development was observed against chlorpyriphos and endosulfan in fourteen geographic populations. Among the insecticides the highest resistance ratio was observed in Raichur and lowest was observed in Margoa populations. Genetic diversity across the fourteen populations revealed that, similarity co-efficients ranged from 0.38 to 0.90 among populations. Genetic similarity of 90 per cent was evident between the populations of Aduthurai and Coimbatore. Among six species of wild brinjal, two species *S. torvum* and *S.viarum* were found to be dominant at all the surveyed locations three species (*S.torvum*, *S.indicum* and *S .macrocarpon*) are classified under tolerant category and two under highly resistant (*S.viarum* and *S. incanum*) category and with only one species found to be fairly resistant (*S. virginianum*) to *L.orbonalis*. Among the different IPM modules, adoptable module significantly reduced shoot and fruit damage recording highest fruit yield with maximum C: B ratio.