CHAPTER I

INTRODUCTION

In recent years, the increasing awareness of the deleterious effects of indiscriminate use of artificial inputs in agriculture, such as chemical fertilizers and pesticides, has led to adoption of biorational alternatives in conventional farming. Although Stern et al., (1959) introduced the concept of integrated control of pest during the time when broad-spectrum insecticides such as organochlorine, organophosphates, carbamates were most popular among the farmers. Today,after 50 years, today pest control practices are evolving rapidly to provide instant pest control, resulting in yield enhancement. The deficiencies or lugholes in development and application of biorational alternatives have been identified over the last few decades. So, the products under biorational alternatives, which are developed in recent decades, are currently in use or in early stage of development, while the others are yet to appear. Therefore today, the emphasis has been shifted from mere pest control to sustainable crop protections. These crop protections are based on holistically harmonizing all biorational alternatives including chemical controls.

Biorational pest control measure

The "biorational" measures are environmentally conservative methods that protect the desired plants from pests while safe-guarding other useful organisms from harmful side effects present in the surrounding environment. Since, these measures are least-toxic pest control strategies; they are preferred in bio-intensive integrated pest management. While the biorational measures are being implemented within ecological framework, it also takes into consideration the economic thresholds and injury levels.

The biorational method means- both chemical and biological controls can thrive together in eco-friendly manner. The holistic methods thus form the basis of the modern day Integrated Pest Management concept (Horowitz et al., 2009).

The biorational tactics begin with application of "old, tried and trusted" cultural and mechanical practices such as diverse cropping, crop rotation, intercropping, cover crops, altered planting, rouging of sick plants, traps using food baits, light and color as attractants. Today, some of these old practices are as good as when they were been first introduced (Diver & Hinman, 2008). Apart from these tactics, it also consists of biological, botanical and biochemical control methods to eradicate completely or at least reduce pest problems.

Biological control

Generally, when people think of insects, they think of pests. But, a lot of people do not know that not all insects are pests. In fact, many of them are beneficial. Many beneficial insects play an important role in reducing and controlling populations of both plant and insect pests. These are termed as biocontrol agents. These natural enemies of the pests or bioagents can be broadly divided into predators, parasitoids and pathogens. Predators are free living organisms and require many hosts to feed upon to complete its life cycle. The predatory insect members belong to many orders like: Odonata, Phasmida, Neuroptera, Coleoptera, Diptera and Hymenoptera. Parasitoids are those insects which parasitize other insects.

Pathogen or microbial pesticides consist of microorganism such as viruses, bacteria, fungi or protozoa. More broadly, microbial pesticides are generally considered a form of biological control, as they entail the usage of living organisms to induce mortality of target pests. Whereas, pathogens are promotion of bioagents holds promise for reduction in the use of chemical pesticides in future scenario. This is an ecologically sound approach to introduce parasitoids for the pest suppression because once established, it is relatively permanent, non-disruptive and often self- perpetuating.

The value of biological control is now well recognized particularly in the context of environmental protection as well as stable pest management strategy. Until late fifties, India did not have any organization for carrying biocontrol research. The systematic biocontrol research in India started with the establishment of commonwealth institute of biological control in 1957.

Later on, India coordinated research project on biological control of crop pests and weeds which was started in 1977 under ICAR. Further, it was elevated to project directorate of biological control with its head quarter in Bangalore. It has various centres, spread across the country for carrying out field studies of bio suppression of major crop pests and weeds. Along with this, other ICAR institutes and agricultural universities are carrying out biocontrol research. Under certain situations, 40-50% population of the pests are reduced by biocontrol agents including predators-coccinellid beetles, lace wings, bugs, spiders; parasitoids-trichogrammatids etc. More than 26 biological agents from India have been successfully established in other countries (Virk et al., 2011).

The most common parasitoid used all over India is *Trichogramma chilonis* for management of many lepidopteran pests. In Tamilnadu, mass rearing of *Trichogramma chilonis* is carried out on a large scale for controlling *Chilo sacchariphagus* in the field of sugarcane breeding institute, Coimbatore (Geetha & Balakrishnan, 2011). However, it was probably the impact of the Indian agricultural crisis of the late 1980s, i.e. failure of chemical insecticides to control *Helicoverpa armigera*, *Spodoptera litura* and other pests in cotton (Kranthi, 2002), that prompted to develop systematic Integrated Pest Management (IPM) and insecticide resistance management programmes in India. Additional drivers for microbial production research include increasing reports of high levels of chemical pesticide residues in fruits, vegetables, mother's milk and groundwater.

Subsequently, in India, research in the field of microbial pesticide development has been substantial. The microbial pesticides used in India are listed in Table 1. In this, microbial bacteria *Bacillus thuringiensis* (Bt) ranks first in terms of consumption in India. *Bacillus thuringiensis* is a gram positive spore forming bacterium that produces crystalline proteins called delta endotoxin which kill the target insects (Schnepf et al., 1998). Bt toxins has pesticidal properties against whiteflies, aphids, leafhoopers and other sucking pest (Rosas-Garcia, 2009).

Following *Bacillus thuringinesis*, antagonistic fungi such as *Trichoderma* sp. and other bacteria like *Pseudomonas fluorescens* are dominating the Indian markets. But, the production of nuclearpolyhedrosis viruses (NPV), granuloviruses (GV), and entomopathogenic fungi are also established and still expanding.

Nuclearpolyhedrosis viruses (NPVs) have numerous viral particles "packaged" together in a crystalline envelope within insect cell nuclei. Granulosis viruses (GVs) have one or two viral particles that are surrounded by a granular or capsule like protein crystal, found in the host cell nucleus. Gowda & Naik, (2008) reported that biopesticide *Hyblea puera* (NPV) is currently under development for controlling teak defoliator.

Like viruses, the entomopathogenic fungi often act as important natural control agents that limit insect pest population. Conidia asexual spores cause insect diseases. However, conidia of different fungi vary greatly in ability to survive adverse environmental conditions. Unlike bacterial spores or viral particles, fungal conidia can germinate on the insect cuticle and produce specialized structures that allow the fungus to penetrate the cuticle and enter the insect's body. The entomophagus fungi *Verticillium lecanii* have been used successfully against western flower thrips *Frankliniella occidentalis* and onion thrips *Thrips tabaci* (Ahmadi et al., 2004).

Protozoan pathogens naturally infect a wide range of insect hosts. Although these pathogens can kill their insect hosts, many are more important for their chronic and debilitating effects. The important and common consequence of protozoan infection is reduction in the number of offspring produced by infected insects. Although protozoan pathogens play a significant role in the natural limitation of insect populations, few appear to be suited for development as insecticides. For example protozoa *Nosema pyrausta* used for controlling *Ostrinia nubilalis* (Lewis et al., 2009).

Insect Parasitic Nematodes (IPN) have been known since the 17^{th} century. During the last one decade, remarkable progress has been made in the taxonomy of IPN. Nematodes used in insecticidal products are, however, nearly microscopic in size and they are used much like the truly microbial products. Nematodes used for insect control, infect only insects or related arthropods are called entomogenous nematodes. Entomopathogenic nematodes are lethal &

obligatory parasites of insects. After extensive research, including many successful field trials, interests have been grown in the use of IPNs as biological control agents. They are potential and most promising bio-agents for control of different insect pests of different crops. These entomophagus nematodes are eco-friendly and cost effective (Ali et al., 2005).

The entomogenous nematodes *Steinernema carpocapsae* and *Heterorhabditis heliothidis* are most commonly used in insecticidal preparations which control insect pest members belonging to order Homoptera, Coleoptera, Diptera and Lepidoptera. Hence, exceptional successes along with other biological control agents, India is poised for developing innovative ideas to implement the use of entomophagus nematodes (Divya & Sankar, 2009).

The major goal is to develop local sourcing of bio-pesticides as a means of ensuring availability at a low cost so as to benefit poor farmers and also as a base for expanding an Indian agro-biotechnology industry. The commercial production of bio-pesticides began in the 1980s, but expansion became rapid in the late 1990s stimulated by national and state programmes for IPM promotion (Wahab, 2004).

The state departments of agriculture and horticulture in Tamil Nadu, Kerala, Karnataka, Andhra Pradesh and Gujarat have established biocontrol laboratories for producing selected microbial agents. A few state agricultural universities and Indian Council of Agricultural Research (ICAR) institution also produce small quantities of microbial pesticides (Rabindra, 2005). It has been estimated that there are at least 32 commercial companies that are active in bio-pesticide production, with an additional 32 IPM centres under the Ministry of Agriculture, producing selected biocontrol agents. In total, at least 410 bio-pesticide production units have been established in India, 130 as the private sector (Singhal, 2004).

With the foundation of experience and depth of knowledge, there is lot of scope for commercial low cost production and usage of bio-control agents in future India. There is a strong need to develop pesticide resistant and environment extreme-tolerant strains of parasites and predators. There is immense opportunity for the use of biocontrol agents that have little attentive areas. For example- pests of urban environment, ornamentals and indoor plants.

Botanical control

Insect pests can be controlled by other means than those that cause their rapid death. The plant products which possess an array of good properties including anti-feedant effect, repellency (Koul et al., 2008), pest toxicity, oviposition deterrent, ovicidal activity (Singh, 2011) and insect growth regulatory activity could be used effectively against pests of agriculture importance (Prakash et al., 2008).

The most promising botanicals for present and future use belong to families such as meliaceae, rutaceae, asteraceae, malvaceae, labiatae and cancellaceae (Jacobsan, 1989). As India has rich source of plants that could be harnessed as botanical pesticides, accentuated research on the preparation of bio pesticides has gained ground (Ignacimuthur, 2004).

The most commonly used plants as insecticides are pyrethrum from *Chrysanthemum cinerariifolium* (Trevir.) (Compositae); rotenoids from genera *Derris*, *Lonchocarpus*, *Tepjrosia* and *Mundulea* (Leguminosa); nicotinoids from *Nicotiana* species (Solanacae), Triterpenoids from *Azadirachta indica* (Meliaceae) and alkaloids from *Sabadilla* sp. (Liliaceae). All of them, particularly neem, have been effective against several insect pests including rice cutworm, diamond-back moth, rice brown plant hopper, rice green leafhopper and tobacco caterpillar.

Many Asian countries such as India and Bangladesh (Roy et al., 2005) have used botanical products like tobacco extract and neem oil extract which can be easily and economically collected. These have been found promising and useful for pest control.

Botanical pesticides are good alternative to chemical pesticides. Botanical insecticides have been proved most beneficial in two contrasting applications, one for affluent consumers and the other for farmers in developing countries. Apart from economic considerations and potential health benefits, another important force driving botanicals into these differnet markets is the regulatory environment protection efforts.

Biochemical control

Even after 30 years of introduction, pheromone technology in Indian agriculture is still in its infancy. Worldwide rapid progress has been made in field of research on insect pheromones and other semiochemicals in last two decades. Out of the 24 pheromone source suppliers, 15 are from India. The biological process of synthesis and release of isomers of these complex chemicals has been marvelously researched during last century. The chemistry of pheromones is in its developing stage in India because sophisticated instruments are required for taking up of isolation, identification and synthesis of pheromones. Very few laboratories such as Pheromone groups of IICT, Hyderabad; Organic chemistry group of SPIC, Chennai and Organic chemistry group of BARC, Mumbai have such facilities in India. Some research work on the sex pheromones of the crop pests in India has been taken up in collaboration with foreign scientific organizations such as NRI, London; TNO, Delft, Netherlands and CID, CSIC, Barcelona, Spain etc. (Nandagopal, 2006).

The term pheromone comes from the Greek word- pherein which means "to carry" and hormon means "to excite or stimulate". Most insects appear to communicate by releasing molecular quantities of highly specific compounds that vaporize readily and are detected by insects of the same species. These molecules are known as pheromones. These are of different types depending upon its functions such as sex pheromones, aggregation, alarm, dispersal, social and trail pheromones. All of these pheromones have good potential for use in pest management programs. These are used in the field for monitoring and survey, mating disruption, mass trapping or lure and kill techniques for controlling the insect pests (Cork et al., 2003).

The present scenario of pheromones in India shows that despite of so many insect pests only few are controlled by using pheromone lure which is one of the effective and eco-friendly biorational alternatives. Only few are popular among farmers of Vadodara agricultural fields (Table 2). At least 14 different pheromone lures are currently available in South Asia, of which the most popular are for *Helicoverpa armigera, Spodoptera litura* and *Earias vittella*

(Warburton, 2004). Sales of pheromones only represent around 1% of the world market for insecticides (Hall, 2004).

In India, monitoring of the key insect-pests such as *H. armigera, S. litura, P. gossypiella*, were undertaken in the year 1980. Intensive work has been carried on these insect pests spreading over Karnataka, Haryana, Madhya Pradesh, Tamil Nadu, Andhra Pradesh, Maharashtra, Himachal Pradesh, Punjab and Gujarat. Reena et al., (2009) used the pheromone trap for monitoring the population of *Helicoverpa armiger* in chickpea fields. This information provides the proper control of insect in the fields. Therefore, pheromone traps for monitoring, have a potential for making decisions on the need of remedia measures to control key insect pests. In the 1970s, with the commercial availability of insect sex pheromones for several agricultural pests scientists and entrepreneurs turned their attention to mating disruption as a "biorational" approach for insect control. The use of pheromone traps for mass trapping is an insect control method that has been sufficiently researched (El-Sayed et al., 2006).

In few cases, mating disruption technique was successful in India. In Pakistan, control of *Pectinophora gossypiella, Earias insulana* and *E. vittella* were achieved by mating disruption that saved up to five applications of insecticides per season. While in India, pheromone traps of yellow stem borer, *Scripophaga incertular* on rice was found effective (Cork & Hall, 1998). In Chili, Larrain et al., (2009) found that pheromone was used as a mass trapping technique to decrease the population by trapping males or by disrupting the mating of the pest *Phthorimaea operculella*. Kabre & Dharne, (2009) could minimize *Earias vittella* and *Pectinophora gossypiella* through interrupting the mating behaviour by using sex pheromone. Through literature survey, it is also found that some of the parasitoids and predators intercept the pheromone cues and utilize them for locating their host insects. Like for example, presence of aphid sex pheromone nepetalactone increase parasitisation by *Podisus volucre* on aphids (Lilley et al., 1994). Boo & Yang, (2000) also reported similar type of result wherein sex pheromone of *Helicoverpa assulta* also attracted the *Trichogramma chilonis*. Thus, it also shows that in many cases, pheromone technique is compatible with other control methods. But its small market volume and its high expenditure makes it an uneconomic proposition in

Indian scenario. Thus, it is a potential technology that could help Indian agriculture. Hence, it should be given special consideration for development and dissemination.

Pesticide usage in selected agricultural crops

The present research/study has been carried out in Vadodara, situated in the central part of West Gujarat, having a number of agricultural fields surrounding it. Hence frequently visiting the selected agricultural field-sites and agricultural universities as a part of my research work was convenient. The major crops of these fields are Cotton, Castor, Sugar cane, Pigeon pea, Ladies finger, Brinjal, Radish, Cauliflower, Wheat, Maize, etc. Previous study conducted by Naidu, (2008) in Vadodara recorded 300 species of insects within the agricultural fields of Vadodara. Out of these insects, the study revealed that 49 species are pests. This number was reported from the collection and identification of insects of the severely damaged crops.

The maximum number of insect pests identified is from the orders Hemiptera and Lepidoptera, having 16 and 13 species respectively. Coleoptera is having 9 insect pest species. Minimum insect pests are from the Orders Orthoptera and Thysanoptera having 2 species each whereas from the order Diptera only 1 insect species has been found damaging the crops. The survey also pointed out the status of mealybugs as a major pest of Vadodara fields that prompted the initiation of research on these pests.

As a first step, information regarding diversity and biology of all insects which are infesting agricultural field crops of Vadodara were collected. Personal interviews with farmers and local residents about various pest control measures employed in the fields exposed the fact that the local farmers were mainly depended on chemical pesticides, in spite of having considerable knowledge regarding availability and usage of these biocontrol methods.

In interviews with farmer, it came to be known that they only adopt those components of pest control that show immediate effect and which are easily available. According to them the application of these biorational alternatives are labour intensive compared to chemical control measure. Brithal et al., (2000) mentioned that the control measure, apart from chemical control, are not easily acceptable among farmers because these are host specific, slow in action and have short shelf life. Even the lack of literacy among many farmers of Vadodara is also considered as one of the factors that leads them towards both improper use of pesticides and general apathy towards the use of biocontrol measures. Some of them are unaware to the selection of right pesticide and its application at recommended dosage and time.

The cheaper insecticides like Fenvalerate and Cypermethrin were used at higher than recommended dosages while expensive insecticides like chlorpyriphos, carbaryl and deltamethrin were used at sub-optimum dosage (Mangat et al., 1998). The security instructions and safety measures were not strictly followed. I found that many farmers of Vadodara have not even heard of biorational alternatives. Few trail carried out in fields have not found the encouraging results. This is mainly due to lack of understanding of the characteristics of the biorational products. The success of any biorational method depends on proper training for implementation as well as the understanding of the basic principles underlying the active process by the farmers.

The other reasons why biorational alternations are not popular among farmers are connected to the economy of production of biorational products and lack of appropriate infrastructure for transportation, storage and marketing. Production of these alternatives is spread sparsely. Even no subsidy for use of biorational alternative products is given by Central and State Governments to the farmers of India. The process of registration is burdensome, strict and costly, which discourages potential industrialists. Therefore, lack of encouragement from Government of India is behind the apathy of farmers from going for biorational methods. Similarly Chandurkar, (2004) also reported same reasons for not getting popularization of pheromone techniques in India.

Both literature survey and firsthand knowledge gathered from field visits revealed that in spite of the effective technological development in insecticide synthesis and application for pest management, farmers are facing huge crop loss. Sometimes the yield loss was as high as 60-70%. Dhaliwal et al., (2010) reported that the Indian agriculture is currently suffering an annual loss of about Rs. 8, 63, 884 million due to insect pests. Therefore, toward heavy crop loss, farmers resort to use the pesticides in large quantity, under the adage "if little is good, a lot more will be better" (Aktar et al., 2009).

Habits die hard; the synthetic chemical insecticides have been playing important role in the control of agricultural pests for nearly 50 years and will remain essential in coming years too because of familiarity with the methods of implementation and least labour oriented reasons. In present scenario, India is the fourth largest pesticide producer in the world after US, Japan and China. Domestic consumption of these pesticides is around 39 thousand metric tonnes (TMT). In India 765 of pesticides were used in the form of insecticides against 44% global consumption. The main use of pesticides in India is for cotton crops (45%) followed by paddy and wheat (Subramanian et al., 2007).

With 85,000 MT of production, Indian pesticide industry ranked second in Asia, behind China and 12th globally. In terms of values, the size of the Indian pesticide industry was estimated to be of Rs 7,400-crore in 2007, including exports of Rs 2,900-crore. The level of pesticide usage in India was 480 gm per hectare, while it was 17,000 gm in Taiwan, 17,000 gm in Japan, and 4,500 gm in the US. In Europe, it was close to 3,000 gm per hectare. Correspondingly, crop yields in India were the lowest (Shanker, 2008). Directorate of Plant Protection Quarantine and Storage in 2001 reported that Gujarat is at 5th place in India consuming around 3649 tons of pesticide per annum.

Effect of pesticides

These pesticides also owe many drawbacks. Many species of insect pests have shown resistance to insecticides belonging to different groups (Table 3). The maximum number of resistance development was reported for organophosphate (250) followed by synthetic pyrethroids (156), carbamates (154) and others (85) (Kaushik & Sharma, 2009). In India, Nimbalkar et al., (2009) found the resistance to endosulphan and cypermethrin by *Helicoverpa armigera* collected from Jalana and Aurangabad district of Maharastra. The secondary pest outbreak was also seen during study period. The overall increase in jassid population in North India is due to the extensive use of both of these insecticides for management of the *Helicoverpa armigera*. In previous studies by Kumar & Naidu, (2010) it was observed that an increase in population of pests occurred due to uncontrolled use of dimethoate and carbofuran for aphids and jassids; fenvelarate and deltamethrin for serious pests like *Helicoverpa armigera* and *Spodoptera litura* in the agricultural fields of Vadodara; mainly because the pests developing resistance to pesticides. The farmers ignore their side-effects.

Excessive and indiscriminate use of the toxicants has unlimited hazards for human beings and environment. The vegetable crops and other edible parts of plants are directly exposed to the applied pesticides and are usually consumed before the plant system is able to get rid of pesticide residues or the latter is diluted to the non-toxic level (Iqbal et al., 2009). Fumigation, spraying and dusting of pesticides liberate a fair volume of harmful vapors in the atmosphere and consequently create a certain degree of atmospheric pollution (Mishra et al., 2006). Use of pesticides is harmful to human beings and livestock as toxic residues in food and forage crops enter the physiological system.

In India, various reports are show how insecticides contaminate our river which are used for irrigation purposes and directly enters in our food chain. For example, Begum et al., (2009) found the maximum concentration of HCH pesticide residue in shrimps, fish *Etroplus suratensis* in Cauvery River, Karnataka, India. So, optimum care should be taken for treatment of the river water before supplying to human population. The use of insecticides such as monocrotophos caused eco-toxicological effects in aquatic environment close to agricultural fields and possible effects on fish populations (Maniyar et al., 2011). Humans, live stalk, fish and even wild animals are thus exposed to pesticides through water and food chain.

These pesticides are found even in breast milk. Devanathan et al., (2009) studied the contamination status of organochlorine compound in human breast milk of three metropolitan cities in India (New Delhi, Mumbai and Kolkata). Of the organochlorines analyzed, DDTs was predominant followed by HCHs and PCBs. Such adverse effects of insecticides were also reported from different countries. In Egypt, use of endosulfan in soybean fields has resulted in a decline in population of soil cyanobacteria found in the rhizosphere (Abdel-Raouf & El-Shafey, 2009). Similar observations were reported in Pakistan, where over and misuse of pesticides has resulted in the contamination of food stuffs of the human beings (Khan et al., 2009). There are no pesticides that can be used safely through judicious management.

The massive use of pesticides also leads to the environmental pollution in different forms inflicting global warming and depletion of ozone layer; pest migration and expansion that affect productivity, profitability and safety of food product (Ghimire, 2007). These pesticides cause adverse effect on health of farmers. Mancini et al., (2005) observed acute poisoning effect of pesticides among the male and female cotton grower of Andhra Pradesh, India.

The previous biodiversity studies noted that the use of pesticides affect the insect population. Majority of pesticides destroy beneficial insects such as honeybees which play an important role in pollination (Chiras, 2010). For example, *Trichogramma chilonis* which is a good parasitoid that show toxicity to insecticides such as thiamethoxam, imidacloprid, Virtako, ethofenprox and BPM Cimidacloprid, thiamethoxam, chlorantraniliprole, clothianidin, pymetrozine and ethofenprox (Preetha et al., 2009).

Pesticides are included in a broad range of organic micro pollutants that have following ecological impacts: cancers, tumors and lesions in fish and animals; reproductive inhibition or failure; suppression of immune system; disruption of endocrine (hormonal) system; cellular and DNA damage; teratogenic effects (physical deformities such as hooked beaks in birds) and poor fish health (Dobhal & Uniyal, 2011).

In recent years, the central government has banned a number of pesticides from being utilized in agricultural fields taking into consideration its adverse effects on environment and human. For example, recently endosulphan, caused about 500 deaths in 11 villages of Kasargode district that was officially acknowledged due to the use of endosulfan on the estates of PCK in Kerala since 1995. But, since the late 1970s unofficial deaths were around 4,000. The economic times newspaper reported that Kerala has been strongly demanding a nation-wide ban on endosulfan as it has been claimed that over 500 people have died and the health of thousands of people was adversely affected due to the harmful effects of the pesticides.

From these accounts, it is clear that, in spite of the remarkable advances in pest management strategies over the last half-century, the pest management systems are not able to keep pace with the capacity of pests to adapt to the new environment. The alternatives such as bio-pesticides, though available, are not in much favour.

Currently, bio-pesticides represent only a small fraction (1.3%) of the world pesticide market. The failure of chemical pesticides to give required protection and sustainable yield has claimed for a serious thinking for development of non-chemical pest management strategies. This was the main motive to undertake a study of biorational alternatives to fill the void and also the desire to find solutions for many problems that are faced by farmers during the implementation.

Objectives

The fundamental objective is to minimize the load of pesticides from agricultural fields of Vadodara by developing biorational alternatives which are ecofriendly and cost effective in nature.

Field work:

A. Identification and assessment of damage and extent of insect pests to economically important crops of urban community garden and agricultural fields.

B. Analyze the population dynamics of insect pests and its correlation with the various environmental parameters and natural enemy population.

C. Study different biorational alternatives implemented by farmers against these insect pests for controlling their crops.

These field works give the information which will further support the laboratory research. Following are the laboratory researches undertaken:

Laboratory work:

A. Rearing and breeding of the selected insect pests in the laboratory collected from the agricultural fields in and around Vadodara.
B. Study the biology of one of the major insect pest severely damaging the crops (polyphagous in nature) under laboratory condition- Mealybugs.
C. Isolation and identification of a pheromone lure from mealybug, *Phenacoccus solenopsis* as an alternative to insecticide.
D. Experiments with insecticides on *Scymnobius sordidus* (predators) and *Aenasius bambawalei* (parasitoid) that are bio-control agents of *Phenacoccus solenopsis.*
E. To study the bio efficacy of botanicals against *Phenacoccus solenopsis.*
F. Bio semiotic studies- To observe the effect of volatile extracts from *Phenacoccus solenopsis* on its own species.

By fulfilling above objectives, anticipated outcome of the research work will help the farmers as well as our environment. This work is one of the unique research studies. Alternatives in fields as well as in laboratory trails have been made and these have come out with one biolure which if synthesized, can definitely contribute in adopting alternatives to pesticides. Therefore, this research will maximize the returns by increasing the crop yields. It will motivate upcoming researchers for similar future research.

Summary of the chapter

The effective control of pests is critical for assuring healthy crops and enhancing agricultural productivity. It is essential to increase agricultural production to meet the demands of the growing population. Reduction in crop loss due to pests is an important factor to achieve the demand. Various pest control methods have been adopted by the farmers, of which, one is the use of chemical pesticides, which is still the most common method in many countries due to its economic rates and efficacy. The effectiveness of chemical pesticides in protecting crops, however, has masked the negative impacts associated with their use. For farmers, the most serious issues are the acquisition of resistance to the chemicals by the pests, with frequent pest outbreaks, and health hazards associated with the application of chemicals. For consumers, the main complications are pesticide residues in food and environment. Because of such concerns, there is a great deal of interest in applying non-pesticide control methods. Therefore, concrete steps have to be taken to promote the judicious and ecofriendly crop pest management like use of biorational alternatives to minimize crop loss, in harmony with environment.

……… *"Biologicals and biorationals are an emerging method of control; find out more about them and how to use them"- By Christine Casey*

Table 1: Commercialized biorational alternatives in India*

Sr. No.	Species/ Strain	Type	Target insect pests
MICROBIAL AGENTS			
1	*Bacillus thuringiensis* var. *israelensis*	Bacteria	Dipteran larva
2	*Bacillus thuringiensis* var. *kurstaki*		*Helicoverpa agmigera*, *Pectinophera species* , *Erias insulana* , *Plutela xylostella* and *Leptinotarsa decemlineota*
3	*Bacillus thuringiensis* var. *galleria*		*Helicoverpa agmigera*, *Pectinophera species* , *Erias insulana* , *Plutela xylostella* and *Leptinotarsa decemlineota*
4	*Bacillus sphaericus*		Mosquito larvae/ *Culex spp*
5	*Bacillus subtilis*		Soil-borne diseases
6	*Pseudomonas fluorescens*		Soil-borne diseases
7	*Beauveria bassiana*	Fungus	*Ostrinlo nubilalis*, *furnacalis Guenee*, whitefly, thrips, aphids and mealybugs
8	*Trichoderma viride*		Soil-borne diseases
9	*Trichoderma harzianum*		Soil-borne diseases
10	*Verticillium chlamydosporium*		*Meloidogyne javanica*
11	*Verticillium lecanii*		Aphids and whitefly
12	*Metarhizium anisopliae*		*Dysdurcus cingulatus*, *oxycarenus hyalinipennies*, *Aphis craccivora*, *Mylabris pustulata*, *pericallia ricini*, *Spodoptera litura*, *Helicoverpa armegera*
13	*Paecilomyces lilacinus*		Whitefly and scale insect
14	*Ampelomyces quisqualis*		Whitefly and scale insect
15	NPV of *Helicoverpa armigera*	Virus	*Helicoverpa armigera*
16	NPV of *Spodoptera litura*		*Spodoptera litura*
BIOLOGICAL CONTROL AGENTS			
1	*Trichogramma chilonis*	Parasitoid	*Helicoverpa armigera*, *Spodoptera litura*
2	*Chrysoperla carnea*	Predator	*Bemisia tabaci*, *Aphis spp.*, Scale insect
BOTANICAL PESTICIDES			
1	*Azadirachta indica* (Azadirachtin)	Botanical	Lepidopteran caterpillar , dipteran larvae
2	*Chrysanthemum cinerariifolium* (Pyrethrum)	Botanical	Lepidopteran caterpillar, dipteran larvae

*All are registered under section 9 of Insecticides Act, 1968 for use in India.

Table 2: Pheromone lures present in Indian market (One of the biorational methods of insect pest control)

ORDER	FAMILY	PEST NAME	BIOLURE	TYPE OF PHEROMONE	PURPOSE
Diptera	Tephritidae	*Bactrocera cucurbitae* (Melon Fruit Fly)*	Bacu Lure/ Bador Lure	Sex pheromone	Mass trapping
Lepidoptera	Crambidae	*Leucinodes orbonalis* (Brinjal Fruit & Shoot Borer)	Lucin Lure		Monitoring & Mass trapping
	Yponomeutidae	*Plutella xylostella* (Diamond Back Moth)	Lure		Monitoring & Mass trapping
	Gelechiidae	*Pectinophora gossypiella* (Pink Bollworm)*	Pectino Lure		Monitoring, Mass trapping & Mating disruption
	Pyralidae	*Scirpophaga incertulas* (Rice Yellow Stem Borer)	STB Lure		Monitoring, Mass trapping & Mating disruption
	Crambidae	*Chilo infuscatellus* (Sugarcane Early Shoot Borer)	ESB Lure		Monitoring & Mass trapping
	Crambidae	*Chilo sacchariphagus indicus* (Sugarcane Internode Borer)	INB Lure		Monitoring & Mass trapping
	Noctuidae	*Helicoverpa armigera* (American Bollworm)*	Heli Lure		Monitoring & Mass trapping
	Noctuidae	*Earias insulana* (Spiny Bollworm)*	Earis Lure		Monitoring, Mass trapping & Mating disruption
	Noctuidae	*Earias vittella* (Spotted Bollworm)	Earis Lure		Monitoring, Mass trapping & Mating disruption
	Pyralidae	*Scirpophaga excerptalis* (Sugarcane White Top Borer)*	Scripo Lure		Monitoring
	Noctuidae	*Spodoptera litura* (Tobacco Caterpiller)*	Spodo Lure		Monitoring & Mass trapping

Coleoptera	Anobiidae	*Lasioderma serricorne* (Cigarette Beetle)	Lure	Sex pheromone	Monitoring & Mass trapping
	Dynastidae	*Oryctes rhinoceros* (Rhinoceros Beetle)	RB Lure	Aggregation pheromone	Mass trapping
	Curculionidae	*Rhynchophorus ferrugineus* (Red Palm Weevil)	RPW Lure	Aggregation pheromone	Mass trapping
	Cerambicidae	*Xylotrechus quadripes* (Coffee White Stem Borer)	Lure	Sex pheromone	Monitoring & Mass trapping

*Following pheromone lures are present in Vadodara market

Table 3: Insects showing insecticide resistance in major agricultural crop of India

Crop	Insect pest		Exhibiting resistance to			
	Common name	Scientific name	Op	Carb	Pyr	Ch
Cotton	Cotton jassid	*Amrasca biguttula*	*	…	…	…
	Cotton aphid	*Aphis gossypii*	*	…	…	…
	Cotton white fly	*Bemisia tabaci*	*	…	*	…
	Cotton bollworm	*Helicoverpa armigera*	*	*	…	*
	Potato aphid	*Myzus persicae*	*	…	…	…
	Tobacco leaf caterpillar	*Spodoptera litura*	*	*	…	…
Rice	Rice leaf folder	*Cnaphalocrocis medinalis*	*	…	*	…
	Leaf folder	*Marasmua patnalis*	*	…	*	…
Brinjal	Cotton jassid	*Amrasca biguttula*	*	…	…	…
	Cotton white fly	*Bemisia tabaci*	*	…	*	
	Potato aphid	*Myzus persicae*	*	*	…	…
	Brinjal fruit borer	*Leucinodes orbonalis*	*	…	…	…
Tomato	Cotton bollworm/ tomato fruit borer	*Helicoverpa armigera*	*	…		
Chilies	Cotton aphid	*Aphis gossypii*	*	*	*	
	Potato aphid	*Myzus persicae*	*	…	…	
	Cotton bollworm	*Helicoverpa armigera*	*	*	…	…
Cabbage	Potato aphid	*Myzus persicae*	*	*	*	…
	Diamond back moth	*Plutella xylostella*	*	…	*	*
Cauliflower	Tobacco leaf caterpillar	*Spodoptera litura*	*	…	*	
	Diamond back moth	*Plutella xylostella*	*	*	…	*
Okra	Cotton white fly	*Bemisia tabaci*	*	…	*	*
Mustard	Mustard aphid	*Lipaphis erysimi*	*	…	*	…
Groundnut	Cotton bollworm	*Helicoverpa armigera*	*	*	…	*
	Tobacco leaf caterpillar	*Spodoptera litura*	*	…	…	…
Tobacco	Tobacco aphid	*Myzus nicotianae*	*	*	*	…
	Potato aphid	*Myzus persicae*	*	*	*	*
	Tobacco leaf caterpillar	*Spodoptera litura*	*	*	*	*
Chickpea and pigeonpea	Cotton bollworm	*Helicoverpa armigera*	*	*	*	*

Op – Organophospahate; Carb- carbamate; Pyr-Pyrethroids; Ch- Chlorinated hydrocarbon;

*- resistance developed; … information not available