Chapter I – INTRODUCTION

Introduction

"If there is a large gathering of spiders...... Everything will be satisfactory.
- 2000 years old Chinese writing"

With the dawn of agriculture came the modifications of vast fertile land to cultivate crop that provide stable grains and cereals to the mankind. This practice of monoculture in due course of time resulted in emergence of phytophagous insects. These insects, ever since, have been competing with humans for the same resources and were categorised as pests by humans. As the insects became more and more adept in partitioning the resources, human beings were forced to use various measures to control the population of insects. Use of agrochemicals has been the most prevalent practices of man in his efforts to minimize loss and maximize production of his crop.

In 1962, Rachel Carson published the book "Silent Spring" which showed the serious consequences of indiscriminate use of chemical pesticides. This book presented evidences of accumulation of toxins in fat bodies of organisms like birds, fishes etc. Besides the impact of insecticides on wildlife and waterways, they also poisoned the beneficial organisms like Ladybird beetles, Mantids and Hymenopteran parasitioids (*Trichogramma* species) that parasitized or preyed upon the target pests (aphids, insect eggs, moths).

Another impact of pesticide usage which also became evident was the development of resistance in insect populations to chemicals resulting in failure of the technique of chemical control (Perry *et al.,* 1998). For example, Lepidopteran pest *Helicoverpa armigera* developed resistance to DDT, Malathion (organophospate group of chemicals). Despite resistance being recognized as a problem, the need for alternative non-chemical control methods was apprehended. Research on alternatives was considered low priority, except by some individuals. For example, DeBach (1951) saw very early that only ecological understanding could protect the farmer from problems inherent in use of chemicals. Thus the concept of Integrated Pest Management (IPM) came into being. IPM was developed by federal IPM trust USA as an applied science since its inception in 1972, as a part of Huffaker Project by EPA (Environmental Protection Agency), NSF (National Science Foundation) and USDA (United States Department of Agriculture). IPM incorporates Chemical, Cultural, Mechanical and Biological control. Maximum emphasis is on Biological control which is of two types; Classical and Conservation.

Classical biological control emphasizes on collection, mass rearing and release of living organisms into agroecosystems. Examples include the mass rearing of *Chrysoperla carnea* (Green lace wing), *Bacillus thuringiensis* (BT), *Trichoderma* sp. (Fungus), *Trichogramma* sp. (Microhymenopterans) etc. The demerit of the use of classical biological control was a periodic inundation of biocontrol agents in the field. As these agents fail to sustain themselves in the field, hence they are effective only for a short duration of time within the fields. Conservation Biological Control incorporates

(i) habitat management for promoting natural enemy assemblages in the field and

(ii) diversification and conservation of the native population of predatory and parasitic arthropods already present in the agroecosystem by providing over-wintering sites to them during adverse environmental conditions. The commonly found natural enemies in the fields include carabid beetles, reduviid bugs, spiders, ladybird beetles, praying mantis etc.

Among all the natural enemies of insect pests, spiders occupy a variety of niches in agroecosystems. Like insect pests they also secondarily adapted to the man made agroecosystem because there were more aggregation of pests in the crop field. There they were doing a yeoman service to the farmer as a biological control agent. Several studies by researchers from our own laboratories indicated that there are large numbers of spider species that are specialized to capture insect pests in the agroecosystems (Dolly Kumar and Shivakumar, 2005; Siliwal and Dolly Kumar, 2002).

Studies have been conducted in the surrounding areas of Vadodara namely; Savli, Padra, Dabhoi, Timbi, Chhani and Waghodia. These studies have been conducted in several pulses and cereal crops like paddy, pigeon pea, wheat and jowar; cash crops like castor, tobacco, sugarcane and cotton; vegetable crops like cabbage, cauliflower, radish, chilli, spinach and potato; orchard trees like mango, moringa, and plantations of banana (Shivakumar, 2006 and Siliwal, 2000). Shivakumar (2006) found that the spiders are numerically more abundant than any other natural enemy found in the agroecosystem. One of the common spiders of agroecosystem in this part of Gujarat was found to be the social spider *Stegodyphus sarasinorum* Karsch (1891). But the use of pesticides was also affecting these beneficial and non target organisms. Thus the present study was conducted to evaluate the effect of selected agrochemicals on the social spiders getting exposed to spray drift in an agroecosystem. The advantage of such a study would be the better incorporation of entomophagous arthropods in IPM Program.

Department of Agriculture And Cooperation (DAC) in the Union Ministry of Agriculture has been promoting the Integrated Pest Management (IPM) approach under the scheme "Strengthening & Modernization of Pest Management". But the consumption of pesticides has remained static at nearly 40,000 Metric Tonnes (MT) in Technical grade since 2003 to 2006. (Information from website of Directorate of Plant protection, Quarantine and Storage accessed on 28th Aug'09). A report by DAC, Government of Gujarat mentions that 2,650 MT of Pesticides have been consumed in Kharif 2008 and Rabi 2008-09; which is likely to rise to 2,850 MT in 2009-10. Hence, it is the need of the hour to conserve and enhance the natural enemy population in agroecosystems by judicious use of pesticides having low toxicity to non-target organisms.

A review of manipulative field studies showed that in 75% of cases the generalist predators like spiders, reduced pest numbers significantly (Naranjo, 2001). Spiders are the dominant macro-invertebrate predators found in terrestrial ecosystems (Turnbull, 1973; Wise, 1993; Samu, 2003). Field experiments done in paddy agroecosystem in China have established the status of spiders (*Pirata subpiraticus, Lycosidae sp.* etc.) as generalist predators (Heong *et al.*, 1991). Long life cycle and difficult laboratory rearing of spiders, reduces the possibility of inundative release. Scientists now are exploring the possibilities of sustaining the population of generalist predators along non- crop habitats like field margins which can serve as refuge in adverse conditions, enhance beneficial insect populations, biodiversity and environmental protection, besides being a practical option for farmers (Marshall, 2002, Shivakumar 2006).

Studies done on the biodiversity of field margins have revealed that, they provide over-wintering sites, retreat sites, refuge areas and web attachment sites which can help in encouraging colonization and maintenance of spider population in the ecosystem (Maloney *et al.,* 2003; Kamplicher *et al.,* 2000; Rypstra *et al.*, 1999). Field experiments suggest that diversification of plants along the edges of the field margins provides a refuge to natural enemies during pre and post harvest season (Thomas *et al.*, 1991; 1992; Corbett and Rosenheim, 1996; Denys and Tscharntke, 2001).

In an agroecosystem, spiders occupy a variety of niches and are found among flowers (Crab Spiders of Family Thomisidae), among leaves (Sac web spiders of Family Clubionidae and Lynx spiders of Family Oxyopidae), among the barks or stem of the plant (Jumping spiders of Family Salticidae and Ground spiders of Family Lycosidae) and in between two plants (Orb web spiders of Family Araneidae). These spiders are also found along the field margins along with few species of social spiders like *Anelosimus eximius, Stegodyphus sarasinorum* and *S. dumicola, Agelena consociata* etc (Young and Edwards, 1990).

The social spiders live in colonies or groups. These groups may be made up of as many as 1000 adults. The colony members cooperate to build and maintain web or nest, capture the prey cooperatively and share brood care (Buskirk, 1981; Aviles, 1997). All the colony members mature and breed within the natal nest generation after generation (Bilde *et al.,* 2005; Aviles and Bukowski, 2006). There are over 23 species of social spiders scattered in 11 genera and 8 widely separated families (Agnarsson *et al.,* 2006).

The level of sociality varies among individual species. In few species of the family Araneidae namely, *Metabus gravidus* and *Nephila clavipes* (Buskirk, 1986) each colony member in these aggregations spins its own web and behaves as individual spider. More complex interactions are seen only in four spider species and one such species is *Stegodyphus sarasinorum* Karsch. The other widely studied social spiders are *Anelosimus eximius* and *A.studiosus* in South America, *Agelena consociata* in Africa and *Mallos gregalis* from Mexico. All these species construct a large central web that is occupied by all the members of colony. The members combine their labours to construct a web that is much larger and far more elaborate in architecture than the web of any single spider. They save on the cost of silk (for building individual webs) and by working together, social spiders can capture prey as large as 10 times their size, which is also advantageous from biological control point of view, whereas a solitary spider can only occasionally prey on an insect of its own body size (Helmuth, 1999). This pattern of behaviour is nonetheless an example of sociality that is not easily equated with any pattern of sociality among insects.

In India, studies on spiders of agroecosystems have started only recently (Rajashekhar and Raghvendran, 2001; Siliwal *et al.,* 2005; Dolly Kumar and Shivakumar, 2005). In Vadodara (Western India), social spider *Stegodyphus sarasinorum* is found commonly along field margins; their webs cover branches of shrubs like *Prosopis, Calotropis and Acacia* etc. Sometimes their webs are also found extending onto wired fences along the field margins. These spider species have been previously reported from other parts of India (Jackson and Joseph, 1973; Tikader 1987, 1986). Jackson and Joseph (1973) gave a detailed description of the life cycle of the social spider *Stegodyphus sarasinorum;* however subsequent studies on social spiders have been few. There are unconfirmed reports that in South Indian villages the webs of social spider *S. sarasinorum* are used as an effective pest control device against stem borers in paddy fields and in houses to control houseflies (Shankar, 2002; CIKS, 2007). There is little evidence of these spiders being explored as bio-control agents or as a part of Integrated Pest Management (IPM) strategies in India. An International NGO (non-government organization) named IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development) active in India has shown interest in role of social spider *S. sarasinorum* as biological control agent (Shankar, 2002). Hence an effort has been made in the present study to explore the same by regular observations and by recording the pests trapped in the webs of these spiders.

In the International scenario, studies on social spiders focus on the intriguing behaviour of these spiders. Smith and Engel studied the population structure and cooperative prey capture in *Stegodyphus sarasinorum* Karsch in 1994. Salomon *et al.* (2008) studied the effect of nutrition on the reproduction in *Stegodyphus dumicola.* The benefits of cooperative prey capture in newly hatched spiderlings of *Anelosimus studiosus* were studied by Jones and Parker (2000). Aviles and Tufino (1998) studied fitness of spider in relation to colony size in *Anelosimus eximus*. Lubin *et al.* (2009) studied the dispersal of male spiders in social spiders in relation to inbreeding. Similarly, Aviles and Bukowski (2006) studied inbreeding depression in sub-social spider *Anelosimus jucundus.* Social spiders have the advantage of trapping prey several times larger than its own body size (Yip *et al.,* 2008, Pasquet and Krafft, 1992; Nentwig, 1985). They can be effective in controlling the population of insect pests like Orthopterans, Dipterans and Coleopterans unlike most of the invertebrate predators.

Field margins receive pesticide spray drift due to wind at the time of pesticide application on cultivated crops. As a result of the spray these agrochemicals form a thin film/ layer on the web of *S.sarasinorum* and the spiders come in contact with the pesticides while moving on the web. These spiders maybe directly exposed to spray if they happen to be on the surface at the time of application. The classes of agrochemicals commonly used in Central Gujarat are organophosphates, carbamates, synthetic pyrethroids, botanicals like Neem based formulations and herbicides like Glyphosate.

Insect pests and their predators are affected by varying degrees as a result of direct exposure to pesticides and to pesticidal residues present on the crop. The degree of impact ranges from mortality to varying degrees of sublethal effects which lead to alteration in reproductive behaviour (Tietjen, 2006), foraging efficiency (Pekar, 1999) and web building behaviour (Haughton et al., 1999; Samu and Vollrath, 1992). Studies have shown that as compared to insect pests, natural enemies are highly susceptible to insecticides. Moreover nowadays the safety of pesticides to non-target organisms like spiders have become desirable for the pesticides companies to register their products (Hassan, 1992).

Pekar (1999) compared the susceptibility of spiders to different classes of pesticides. Results showed that hunting spiders (for example *Pardosa pseudoannulata*) are more susceptible to pesticides. Amongst web building spiders, irregular and sheet web builders (for example *Cyrtophora cicatrosa*) are more resistant than orb web builders (for example *Argiope aemula*). Maloney *et al.* (2003) found that *Pardosa pseudoannulata* is highly tolerant to botanical insecticides such as neem based chemicals, but it was found to be severely affected by organophosphate and pyrethroid insecticides. Pekar and Charles (2005) studied the residual toxicity of commonly used pesticides in Apple orchards on the susceptibility of 6 species of spiders. It was found that permethrin was toxic to all the spiders while BT sprays were non-toxic. Pekar and Benes (2008) showed that herbicide (clomazone) was non toxic to *Pardosa* sp, *Philodromus* sp *and Theridion* sp *and Dictyna* sp. Deltamethrin treatments were highly toxic to all the above mentioned spiders. Effects of two pesticides Lambda Cyhalothrin and Fenvelarate were studied on two Ergionid spider species *Ergione atra* and *Oedothorax apicatus* by Dinter and Poehling (1995); and the pesticides were found to be more toxic to males than females. Field studies undertaken by Van Den Berg *et al.* (1990) in cotton agroecosystem, revealed that spiders of families Lycosidae, Clubionidae, Linyphiidae were severely affected by pesticidal spray while Therridids were least affected as their webs were located in a manner in which they escaped direct spray of insecticides. *Pardosa crassipalpis* of Lycosidae family was the most dominant spider collected from the fields. It is a ground hunter and does not build a web for trapping its prey. Spiders of family Clubionidae are also hunters; they hide inside their web during the day and hunt at night. Linyphiids build sheet webs, which are usually horizontal and thus these spiders get exposed to pesticidal spray either through the webs or through contact with foliage. While the webs of Therridids are usually close to the ground and thus may escape the spray of pesticides.

The sublethal effects of pesticides usually go unnoticed, if toxic responses of pesticides on population can be detected at sub-lethal levels, they can be sensitive indicators of the negative impact of the pesticides (Desneux *et al.,* 2007). Biomarker responses to pollutants have been successfully measured in a wide range of species including birds, mammals, aquatic vertebrates as well as invertebrates and soil-dwelling invertebrates like earthworms (Booth *et al.,* 1998; Van erp et al., 2002). There have been several studies on Acetylcholine Esterase (AChE) and Glutathione complex as important biomarkers in natural enemies for exposure to several pesticides (Rumpf *et al.,* 1997; Kreissl and Bicker, 1989; Van Erp *et al.*, 2002).

Cholinesterase (ChE) activity is a very significant biomarker as pesticides belonging to carbamates, organophosphates, pyrethroids and neonicotinoids are neurotoxic and target the cholinesterase enzyme. One of the commonly studied ChE is Acetylcholine esterase (AChE) because it is a major component in all synaptic transmissions. Glutathione is an enzyme complex which functions as an antioxidant, mitigates the effects of reactive oxygen species, and detoxifies reactive xenobiotic metabolites through conjugation reactions (Wilczek *et al.,* 2004). Two enzymes

Glutathione S Transferase (GST) and Reduced Glutathione (GSH) are important markers for understanding the pesticide toxicity in arthropods. Damage to the cell membranes in an organism can be detected by the presence of Lipid Peroxidase enzymes. Thus Lipid peroxidation (LPO) was measured to assess the level of cellular damage as a result of application of various classes of pesticide.

It is now widely acknowledged that field margins and landscape management has a positive impact on conservation of natural enemies and increase in predator population, leading to decrease in yield losses (Ostman, 2002; Clough *et al.*, 2005). Such studies can be particularly vital from Indian perspective wherein the farmers find it difficult to afford the growing prices of insecticides and might find it easier to manipulate the landscape of their small land holdings.

Research Aims

In view of the above, this study was aimed at analyzing the Compatibility of Social spiders to various Agrochemicals for incorporation in IPM programs of crops.

- Analyse the Prey Composition of *Stegodyphus sarasinorum* Karsch present along the Field Margins in different cropping seasons to understand the potential of this spider species as biocontrol agents in an agroecosystem.
- Identify the Lethal (LD_{50} and LC_{50}) and Sub-Lethal Doses\ Concentration of various classes of commonly used Agrochemicals on *S. sarasinorum*.
- Study the toxic influence of selected pesticides on web-building behaviour of *S.sarasinorum*.
- Enzyme biomarkers were used to understand the differential tolerance to selected pesticides and the detoxification mechanism in *S.sarasinorum*. The enzyme biomarkers studied were Reduced Glutathione (GSH), Glutathione S Transferase (GST), Lipid Peroxidase (LPO) and Acetylcholinestrase (AChE).

The present study shall give a better understanding of spiders as beneficial arthropods of agroecosystems and the effect of pesticides on them; and the results obtained from this study would be advantageous for incorporation of entomophagous arthropods in IPM Program.

TYPES OF SPIDER WEBS FOUND IN AGROECOSYSTEM

Sheet web of a ground spider *Hippasa sp.*

Orb web of *Argiope aemula*

Irregular web of *Cyrtophora cicatrosa*

Irregular web of *Stegodyphus sarasinorum*

WEB ARCHITECTURE OF SOCIAL SPIDER *Stegodyphus sarasinorum*

Web of *S. sarasinorum* on a barbed wire fence

Labyrinths in the web of *S. sarasinorum* with egg masses

STAGES OF SOCIAL SPIDER *Stegodyphus sarasinorum*

Sub-adult of *S. sarasinorum* in field condition

Mature females of *S.sarasinorum* in laboratory