

CHAPTER -I

1.0 INTRODUCTION

1.1 History of Agriculture in India

“When God created the Garden of Eden, she didn't use synthetic fertilizers, pesticides, herbicides, and GMO apples.” **Khang Kijarro Nguyen.**

The history of agriculture in India dates to millions of years when there was an era of Indus Valley civilization. The Rigveda hymns indicate ploughing, fallowing, irrigation, fruit, and vegetable cultivation. Agriculture is the lynchpin of the Indian economy and contributes 18% to the GDP (Bhardwaj & Sharma, 2013). Agriculture is one of the strongest sectors of the Indian economy. The major agricultural produce includes rice, wheat, cotton, jute, tea, and many others. The reasons for good agricultural practices in India are suitable and favourable climate, strong and well extensive research. Some of the milestones in agriculture include the Green revolution (1968), White (Milk) revolution (1970), Ever-green revolution (1996). The green revolution leads to excess use of synthetic fertilizers, insecticides, and withdrawal of water (Figure 1). There was a gradual development of resistance developing to these insecticides. Resistance to pyrethroids and DDT was first reported in houseflies, *Musa domestica* which was termed as knockdown resistance (Harrison, 1951). Later on, mosquito *Aedes aegyptii* demonstrated the ability to develop resistance to a wide variety of organophosphates, carbamates, and pyrethroids (Mazzarri & Georghiou, 1995). In 1967, the resistance populations were distributed among 14 orders of Arthropoda, with 91% of all of these appearing in 6 of the 14 (i.e., Diptera, Lepidoptera, Coleoptera, Acarina, Hemiptera/ Homoptera, and Hemiptera/Heteroptera); this has remained fairly constant through 1980 (Forgash, 1984). After this, neonicotinoid resistance was observed in pests like aphids, whiteflies, beetles, planthoppers, bugs, thrips and lepidopteran pests like tobacco budworm (*Heliothis virescens*) (Nauen & Denholm, 2005).

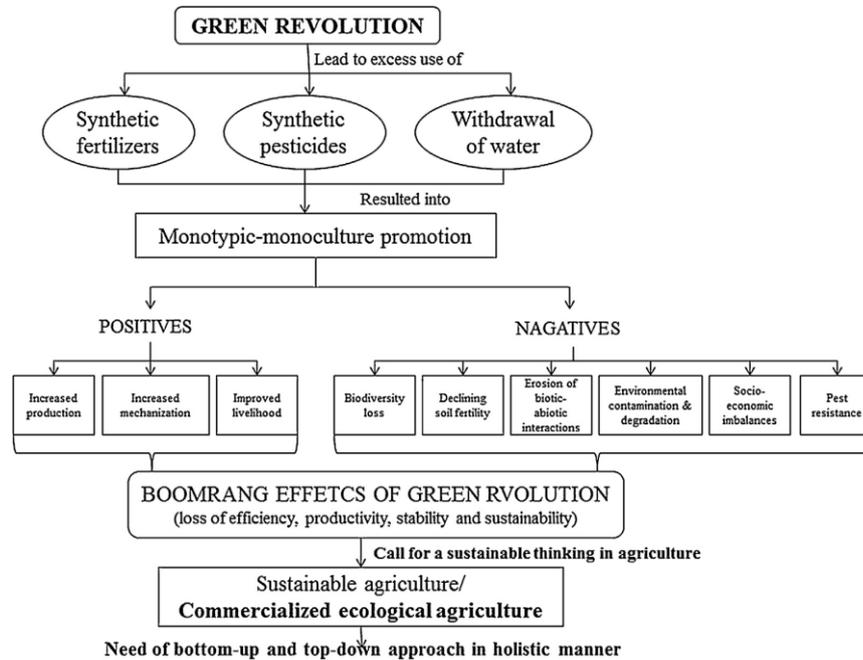


Figure 1 Environmental impacts of the Green Revolution and need for sustainable agriculture. Source: (Srivastava, Singh, Tripathi, & Raghubanshi Singh, 2016)

1.2 The use of pesticides in agriculture

The Indian pesticide production industry started with the setting up of a BHC technical plant at Rishra near Kolkata in 1952. Shortly after, Hindustan Insecticides Ltd. set up two units to manufacture DDT. In 1969, Union Carbide set up a small plant (Union Carbide India Ltd (UCIL)) in Bhopal, the capital city of Madhya Pradesh, to formulate pesticides. The Bhopal facility was part of India's green revolution aimed to increase the productivity of crops. The industry produced various pesticides, mainly seven brand carbaryl insecticide and temikcbrand aldicarb pesticide. All the pesticides produced at UCIL were sold in the Indian market. The Union Carbide continued pesticide production until the 1984 Bhopal disaster (Abhilash & Singh, 2009). The word pesticide refers to a wide range of chemicals used to control pests, including insecticides, fungicides, herbicides, nematicides, plant growth regulators and many others. By the 15th century, toxic chemicals such as arsenic, mercury and lead were being applied to crops to kill pests. In the 17th century, nicotine sulphate was extracted from tobacco leaves for use as an insecticide. 19th century saw the introduction of two more natural insecticides, Pyrethrum and Rotenone.

During 1950s, arsenic-based insecticides were dominant. The book “Silent Spring” by Rachel Carson was published soon after the glory days of chemical pesticides in 1960’s

The introduction of other synthetic insecticides – organophosphate (OP) insecticides in the 1960s, carbamates in the 1970s and pyrethroids in the 1980s and the introduction of herbicides and fungicides in the 1970s–1980s contributed greatly to pest control and agricultural output (Aktar, 2009). The pesticide usage is very high in states like Maharashtra, Punjab, Uttar Pradesh, and less consumption in West Bengal, Gujarat, and Karnataka (Abhilash & Singh, 2009). The main use of pesticides is for economically important crops like cotton, paddy, wheat, castor, etc. The use of pesticides is preferred by most farmers because of the myth of providing a quick solution to the detrimental problem of pests. When there is heavy pest pressure, the pesticides are applied for getting a quick control. In this whole process, it is forgotten that the effects of pesticides are much more as compared to the quick solution provided. Resistance development, toxic effects on plants, long term effects on farmer's health, contamination of the environment. Even the non-target animals ranging from micro-organisms to different kinds of birds, animals, plants, and weeds are affected due to the indiscriminate use of pesticides (Cedergreen & Streibig, 2005) The high-value crops are always subjected to some or the other insecticides to get a fast control. Insecticide mixtures are usually applied in the field to enhance the spectrum of the control when multiple pests are attacking simultaneously (Attique, Khaliq, & Sayyed, 2006). They are also recommended to increase the efficacy of the control of a single pest to delay the development of insecticide resistance or to combat current resistance in a pest species (El-Mageed, 2011). Thus, it has been observed that the usage of pesticides is uncontrolled, as the farmer needs a quick solution to the attack of pests. Particularly in India, the rampant use of pesticides has been the main contributor to pollution as well as toxic effects (Figure 2). According to a technical report by ICAR (Indian Council of Agricultural Research), it is very crucial to regulate and boost the use of cost-effective and environmentally safe pesticides. Along with this, it is also very important with delineating the outdated pesticides which can harm human health as well as the environment. Hence there is a need to reorganize the data related to the production of pesticides and its consumption

and ultimately its trade data. As an alternative to harmful pesticides, bio-pesticides have played an important role in reducing environmental hazards. The Consumption of biopesticides has increased from 219 tonnes in 1996-97 to 683 tonnes in 2000-01, and further to around 3000 tonnes in 2015-16. (Sinha, 2008)

Indiscriminate pesticide use is detrimental to the environment and human health and increases insects' resistance to pesticides (Srinivasan Ramasamy, 2012). With the positive impacts of all types of agriculture revolution, there were negative impacts too. They included the slow build-up of pest pressure, control of crops by all types of insect pests, the greed of farming leading to the introduction of pesticides. The usage of pesticides started way back in 1948-49 with introducing BHC and DDT. Hence there was an introduction of various pesticides for controlling a wide range of insect pests. As the farmers think "if little is good, a lot more would be better". The rampant use of pesticides caused tremendous loss to the environment and health of human beings. The pest controlling chemicals caused a subsequent imbalance in natural resources, as pesticides persisted and soaked in the environment for a longer time. The below figure indicates the consumption of pesticides in India versus the world.

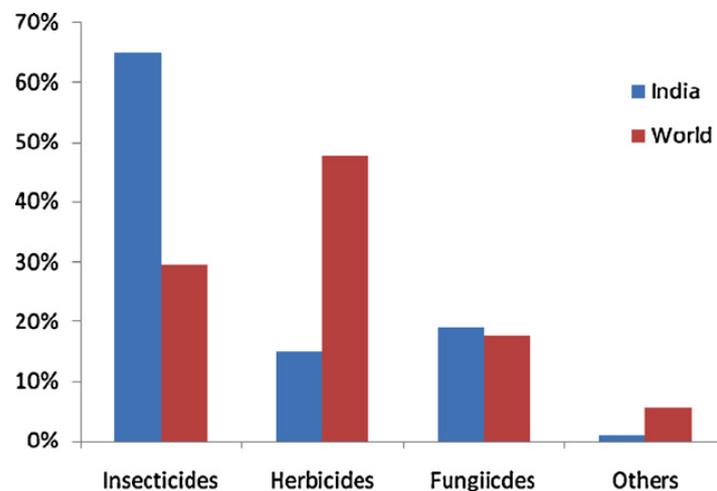


Figure 2 Pesticide consumption in India versus the world

Source: (Abhilash & Singh, 2009)

1.3 The problem of resistance development

According to the famous Darwin's theory, the survival of the fittest is inevitable. This applies to all the elements of nature: Plants, animals, insects, micro-organisms and ultimately human beings. When we talk about insecticide resistance, plants and pests are involved. It is a result of the accelerated microevolution, that the insecticide resistance gains impetus. Thus, the insecticide resistance must be continuously monitored and must form an integral part of chemical control to enable the detection of resistance as early as possible and to take necessary measures (Prabhjot Kaur, 2015). The pressure of selection wielded by insecticides leads to an increase in the frequency of the genetic condition, which is expressed as "Resistance" within the exposed population (Hong Tong, 2013).

Previous exposure with insecticides can confer resistance to newly introduced insecticides through cross-resistance reducing the effectiveness of new insecticides (Rehan, Saleem, & Freed, 2011). The problem of the development of resistance to insecticides is more acute in *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) because of its polyphagous nature and rapid multiplication (Ramakrishnan, Saxena, & Dhingra, 1984). The current study is carried out on laboratory culture of *Spodoptera litura*. This pest was brought from the nearby fields of Vadodara, Gujarat. *S. litura* is resistant to a wide range of insecticides, which has led to sporadic outbreaks of the pest and failure of crops (Mushtaq Ahmad, Iqbal Arif, & Ahmad, 2007). It is recognized as a serious cosmopolitan pest with a considerable host range of economically important crops such as cotton, groundnut, soybean, tomato and many other crops (Uematsu, 1992). The tobacco caterpillar, *Spodoptera litura* is an agriculturally important pest species. The management of the pest has, therefore, become increasingly difficult all over the world and the most commonly used insecticides are ineffective in controlling it (Tong, Su, Zhou, & Bai, 2013). The insecticide resistance is a serious problem that has gained impetus because of the extensive use of insecticides. Baseline data on the susceptibility of the target pest to the toxicant is the most important factor for insecticide use especially for monitoring the development of resistance (Kaur, P and Kang, 2015).

Resistance to insecticides is a major problem associated with the chemical control of insect pests (Munir Ahmad, Sayyed, Saleem, & Ahmad, 2008). Previous exposure and selection with insecticides can confer cross-resistance to newly introduced insecticides. The presence of pests on different crops throughout the year has widely exposed it to insecticides and resulted in the rapid development of resistance to a range of these insecticides (Bisset, Rodriguez, Soca, Pasteur, & Raymond, 1997).

The insecticides are classified into various groups according to the toxicity levels i.e extremely toxic, highly toxic, moderately toxic and slightly toxic. Hence keeping in mind, the indiscriminate use of various types of insecticides and toxicity levels conferred by insecticides, this study has been planned to observe the effect of various insecticides. Commercial formulations of insecticides used in this experiment were: Auzar® (Cypermethrin 25% EC, Biostadt) and Dursban® (Chlorpyrifos 20%EC, Dow Agrochemicals). Both these insecticides have greater effectiveness against all lepidopteran pests like *Spodoptera litura*, *Helicoverpa armigera*, *Plutella xylostella*, *Scirpophaga incertulas*, *Earias vittella*, *Scirpophaga auriflua*. Out of these, *Spodoptera litura* is an indigenous pest of a variety of crops in South Asia and was found to cause 26–100% yield loss in groundnut (Dhir, B. C., Mohapatra, H. K., & Senapati, 1992). Following the reports of various insecticides which are sprayed by farmers in fields, this work was planned as a laboratory study in controlled environment. This study is expected to be fruitful in implementing integrated pest management strategies. It will prove to be a helpful data for the agriculture professionals as well as scientists working towards a common cause of resistance development in pests like *Spodoptera litura*, *Helicoverpa armigera*, *Plutella xylostella*, *Scirpophaga incertulas*, *Platydera gossypiella*, *Earias insulana*, *Percallia ricini*, etc. The purpose of this study is to take into account the development of resistance of *Spodoptera litura* a major pest of crops. Other pests such as those belonging to family Hemiptera, *Aphis gossypii*, *Aphis craccivora* and *Myzus persicae* (Family: Aphididae); Bemisia tabaci (Family: Aleyrodidae); *Phenacoccus solenopsis* (Family: Pseudococcidae) is considered as a serious threat to crops which was causing the major infestation to cotton, brinjal, cauliflower, cabbage, chickpea in Vadodara fields (Kataria & Kumar, 2012). According to Wang, Lou, & Su (2019), armyworm *Spodoptera*

litura when exposed to 21 insecticides (traditional and modern) showed resistance in most of the insecticides. High resistance was found in Metaflumizone and Emamectin benzoate, moderate resistance in Chlorantraniliprole and low resistance in Spinosad. Another study shows the mechanism of underlying resistance in *S. litura*, through RNA-Seq approach. It concludes the involvement of TOM, a tetrasaccharide along with other upregulated genes responsible for resistance (Li et al., 2019). The pest selected for this study causes much damage to crops like cotton, groundnut, soybean, tomato, etc. at their vegetative stages along with the stages of blossoming. Thus, it becomes important to continuously monitor the level of resistance developed.

1.4 Agricultural fields of Vadodara

Vadodara, formerly known as Baroda, is the third-largest city of Gujarat. It is located on the banks of the Vishwamitri river. Vadodara is located at 22.30°N 73.19°E in western India at an elevation of 39 meters (128 ft). It has a semi-arid climate. The agricultural fields are mainly located around the city in the localities namely, Chhani (15kms, North of Vadodara), Dabhoi (30 km southeast of Vadodara, Savli (26 km from Vadodara), Waghodiya (25 km from Vadodara). The main crops of Vadodara include Castor (Figure 4) , Cabbage (Figure 5), Cotton (Figure 6)Pigeon Pea, Sorghum, Spinach, Cauliflowers, Brinjal, Chickpea, Maize, Wheat. A survey was carried out in different areas to get information about the main crops and pests attacking these crops. Field visits were carried out mostly in the mornings between 6:00 am and 8:00 am in 2017 and 2018. These visits were very helpful for getting the information on chemical sprays applied to different fields by farmers. The un-realistic and injudicious use of synthetic pesticides for the past several years led to outbreaks of many insects and non-insect pests (Kataria & Kumar, 2012) (

Figure 3) Castor and cotton are economically important crops. The farmers of Vadodara do tireless efforts for getting a proper yield of these crops. In the process, they have also started the use of pesticides. During the whole survey of all the fields, some farmers were interviewed for noting down the condition of crops, the overall health of crops, pest pressure, the amount of pesticide usage, irrigation program, and history of sprays done, if any. The pest percentage found was also recorded

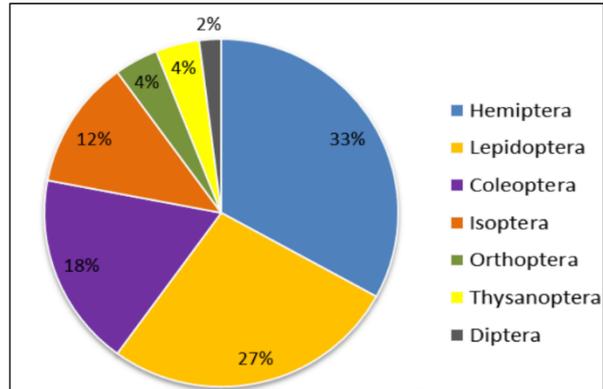


Figure 3 Pest Percentage in agricultural fields of Vadodara

Source: (Kataria & Kumar, 2012)



Figure 4 Agricultural fields of Castor in Savli, Vadodara, Gujarat



Figure 5 Agricultural fields of Cabbage in Chhani, Vadodara, Gujarat



Figure 6 Damage assessed in Cotton fields, Savli, Vadodara, Gujarat



Figure 7 Damage of *Spodoptera litura* in Castor leaf



Figure 8 Tomato leaf infested by *Spodoptera litura*



Figure 9 The leaf of cabbage showing feeding of *Spodoptera litura*

The destruction caused by this pest was evident in some patches of the field. Leaves were heavily damaged due to this pest (Figure 7, Figure 8) They indicate the level of impairment caused by *Spodoptera litura* in natural conditions. In the fields of castor and cabbage, there were some plants completely infested by this pest, and there were some partially infested (Figure 9). There was heavy pest pressure found in the fields of castor. As the farmers shared the incidence, I realized the concern and seriousness of it through their worried faces. During all these interviews, the farmers also shared the efforts made by them to overcome this situation, but unfortunately, the rampant use of insecticides had made the situation even worse, worse than before.



Figure 10 Egg mass of *Spodoptera litura* underside of Castor leaf



Figure 11 Castor leaf completely damaged by *Spodoptera litura*

During the survey, there were egg masses and completely eaten leaves of castor observed (Figure 10 and Figure 11). This massive amount of damage ignited a spark in me to perform studies on resistance developed due to this pest. The farmers who were interviewed shared a few instances when they had to suffer from huge losses due to the high pest attack.

1.5 Insecticide: Resistance and Modes of action

The word Resistance is deep. Deep in two ways as it not only stops the insects from responding to insecticides but also shows the ignorant and negligent attitude of mankind. Insecticide resistance can be defined as the decreased susceptibility of a pest population to an insecticide that was previously effective in controlling the pest. Insecticide resistance is a genetically based phenomenon.

Pest species evolve insecticide resistance via natural selection. Most resistance organisms are the one to survive and pass on their genetic traits to their offspring (Figure 12).

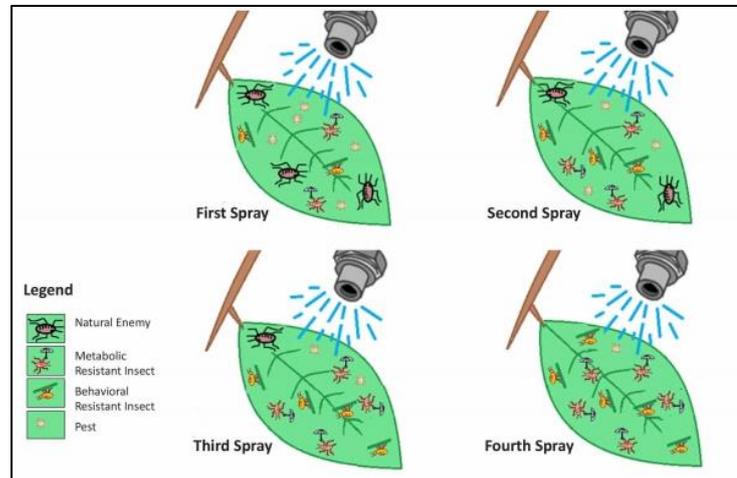


Figure 12 The conceptual diagram of resistance development in insect pests

(Source: <https://www.greenhousecanada.com/inputs/crop-protection>)

By the 15th century, toxic chemicals such as arsenic, mercury, and lead were being applied to crops to kill pests. In the 17th century, nicotine sulfate was extracted from tobacco leaves for use as an insecticide. 19th century saw the introduction of two more natural insecticides, Pyrethrum and Rotenone. During 1950s, arsenic-based insecticides were dominant. DDT discovered by Paul muller was dominant during and after 1950. In the 1975 DDT was replaced by Organophosphate and Carbamates in the USA. Later, Pyrethrin compounds have become the dominant insecticide. The first legislation providing federal authority for regulating pesticides was enacted in 1910. During the 1940s, production and utilization of chemical pesticides were at its peak. The 1940s and 1950s thus considered as the start of the pesticide era. Rachel Carson in her book “Silent Spring” published in 1962 documented the detrimental effects of the indiscriminate use of pesticides on the environment. Resistance likely to begin with the first application of insecticide, but the rate of resistance development may be so slow that it goes unnoticed for several years. The rate of development depends on several factors including increased detoxification facilitated by enzymes. They are classified based on their structure and mode of action.

Many insecticides act upon the nervous system of the insect (e.g., Cholinesterase (ChE) inhibition) while others act as growth regulators or endotoxins. Three enzymes are involved in detoxification: Cytochrome P450 monooxygenases, Glutathione S- Transferases (GSTs) and Hydrolases. IRAC (Insecticide Resistance Action Committee) has classified the insecticides into various groups according to their modes of action.

1.6 The pest that caused havoc: *Spodoptera litura*

During the survey of the agricultural fields of Vadodara, the pest *Spodoptera litura* created a great curiosity in my mind. I was particularly interested in this pest, as it was common to almost all different crop fields like Castor, Cotton, Cabbage, Maize. The tobacco caterpillar, *Spodoptera litura* F. (Lepidoptera, Noctuidae) is recognized as a serious cosmopolitan pest with a considerable host range of economically important crops such as cotton, groundnut, soybean, tomato and many other crops (Uematsu, 1992). It has caused higher economic losses to crops at their blossoming and vegetative stages with 70 to 100% yield loss (Mushtaq Ahmad et al., 2007). Insecticide resistance must be continuously monitored and must form an integral part of chemical control to enable the detection of resistance as early as possible and to take necessary measures (Kaur, P and Kang, 2015). The development of resistance is more severe in *Spodoptera litura*, as it has a very wide host range and rapid multiplication ability (Ramakrishnan et al., 1984). The presence of pests on different crops throughout the year has widely exposed it to insecticides and resulted in the rapid development of resistance to a range of these insecticides (Munir Ahmad et al., 2008). Hence considering all the facts and figures, I decided to take up the work of insecticide resistance developed in *Spodoptera litura* from generation to generation. The agricultural fields surveyed were very helpful for creating an insight into the true scenario of the damage caused by this pest. With all this

background in my mind, a thought process slowly built up to perform a deep study in this area, which was less explored.

“Somewhere, something incredible is waiting to be known” Sharon Begley

1.7 Aim of the study

Investigate generation turnover and time taken to develop insecticide resistance in Oriental leaf-worm the *Spodoptera litura* subjected to repeated application of various classes of insecticides.

To fulfill the above aim, the following objectives were undertaken:

1. To study percentage hatchability and mortality rate of *Spodoptera litura* exposed to commonly used insecticides namely Cypermethrin, Chlorpyrifos, Spinosad and Coragen
2. Repeat the study over generation to find the development of insecticide resistance in terms of increase in survival and percentage hatchability to the doses of insecticides which were found effective in eliminating the *Spodoptera litura* population in the previous generation
3. To ascertain the relationship, if any, between generation turnover and the onset of insecticide resistance through a carefully controlled laboratory study

“Repeated use of the same class of pesticides to control a pest can cause undesirable changes in the gene pool of a pest leading to a form of artificial selection named as pesticide resistance”

“The more we pour the big machines, the fuel, the pesticides, the herbicides, the fertilizer, and chemicals into farming, the more we knock out the mechanism that made it all work in the first place” **David Brower**