CHAPTER 1

1. INTRODUCTION

The Earth is a place with myriads of organisms living in it. The climate is changing, and food availability is limited for various reasons like overpopulation, urbanization, pest infestations, etc. Industrialization, urbanization, and modernization have impacted food security **(Jie & Hui, 2014)**. In countries like India, overpopulation is connected with malnutrition due to food competition **(Upadhyay & Palanivel, 2011)**. Urbanization threatens food security in emerging economies like ours **(Kookana et al., 2020)**. Such a trend also results in hiked food prices **(Bandara & Cai, 2014)**. More than 60% Indian population is dependent on agriculture, and also for their living. There has been an observed decline in Agri-production. Such trends lead to severe problems relating to food security and the country's nutritional status **(Mathur et al., 2007)**.

There is a dependence on agriculture and its products for human existence. Agriculture gives a wide assortment of natural amenities and disamenities. On the good side, farms give open space and landscape. On the wrong side, it significantly supports various environmental issues **(Lichtenberg, 2002)**.

In India, meeting up with the growing demands of the country in terms of food production has been a challenge for a long time. India is also the highest consumer of pulses in the world, so food production as per demand is still less in the country **(Ali & Gupta, 2012)**.

The concept of "food security" refers to a nation's ability to meet its citizens' dietary energy needs by having adequate access to food. Self-sufficiency, or the state of a nation producing enough food to feed its whole people, is referred to as national food security. When combined with other estimates, a household food security estimate can be a useful tool for creating and implementing nutrition-improving policies and programmes **(Pinstrup-Andersen, 2009)**.

Even though economic growth has shown an increase in India, actual growth in all sections of the population has not occurred. There are problems of inequalities in access to credit, health care and education, poverty, and unemployment. Above all, poor performance of the agriculture sector is a significant concern **(Dev, 2009)**.

There has been an issue with the agricultural practices which have been running for a long time. Today, an Indian farmer needs to look back at the unwise pattern, use, or misuse of the resource by the predecessor. He needs to find what to and what not to do for himself. The farmers also have to deal with numerous technological and marketing challenges **(Chadha, 2003)**.

1.1. AGRICULTURE FIELDS AND PESTS

"Agriculture was the first occupation of man, and as it embraces the whole earth, it is the foundation of all other industries."

Edward W. Stewart

There are many crop fields in and around Vadodara. This includes castor, maize, cotton, cauliflower, and banana **(Figures 1.1-1.6)**. However, farmers cannot make the expected profits due to the invasion and infestation by various pests of the agricultural fields.

Since humans started cultivating wild plants for their own needs, insects, birds, rodents, and other animals, plant pathogens, and weeds have all become competitors for crop yield. Mankind has always believed in rotation of crop by adopting various methods. For e.g., mechanical control to conservative insecticides. This includes to sometimes allowed a crop portion for the pests. There are newer insect control techniques **(Walker, 1983)**. The agriculture fields of Vadodara have flourished with several crops of importance. The farmers of Gujarat are educated and aware of the current scenario of agriculture and have been implementing various innovative techniques to improve production. Climate and pest infestation are the biggest challenges, and amongst these, whenever a new challenge comes, like, in the form of an invasive pest, it adds to the problem.

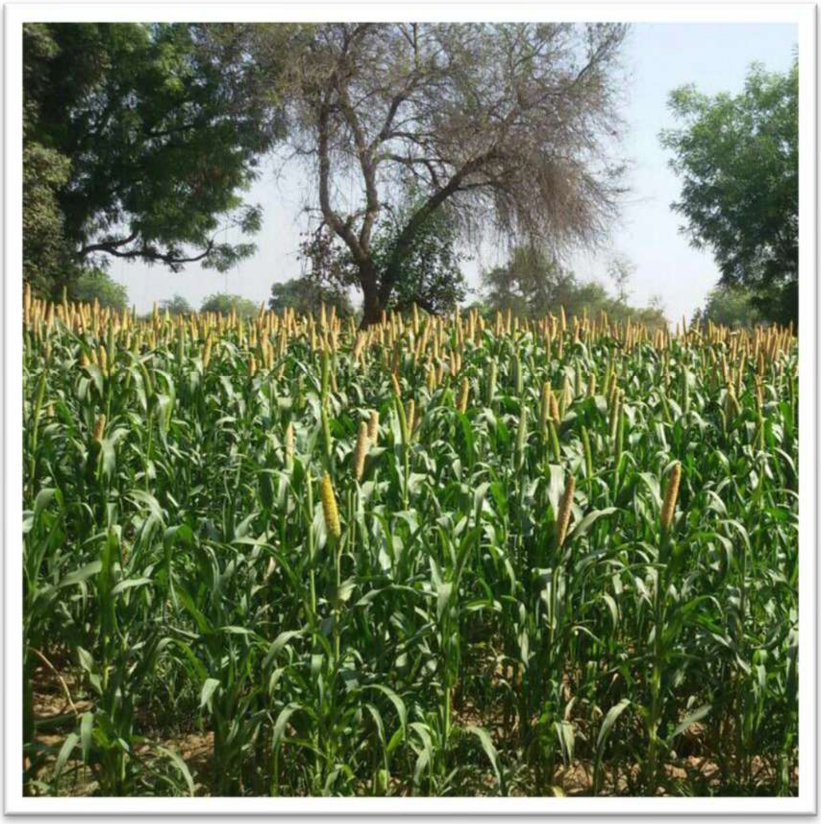


Figure 1.1: Maize field in the region of Chhani (North of Vadodara). The most preferred crop of *Spodoptera frugiperda*

Figure 1.2: Maize field in the region of Savli (North of Vadodara)

Figure 1.3: Castor field in the region of Padra (Southwest of Vadodara)

Figure 1.4: Cotton field in the region of Dabhoi (South east of Vadodara)

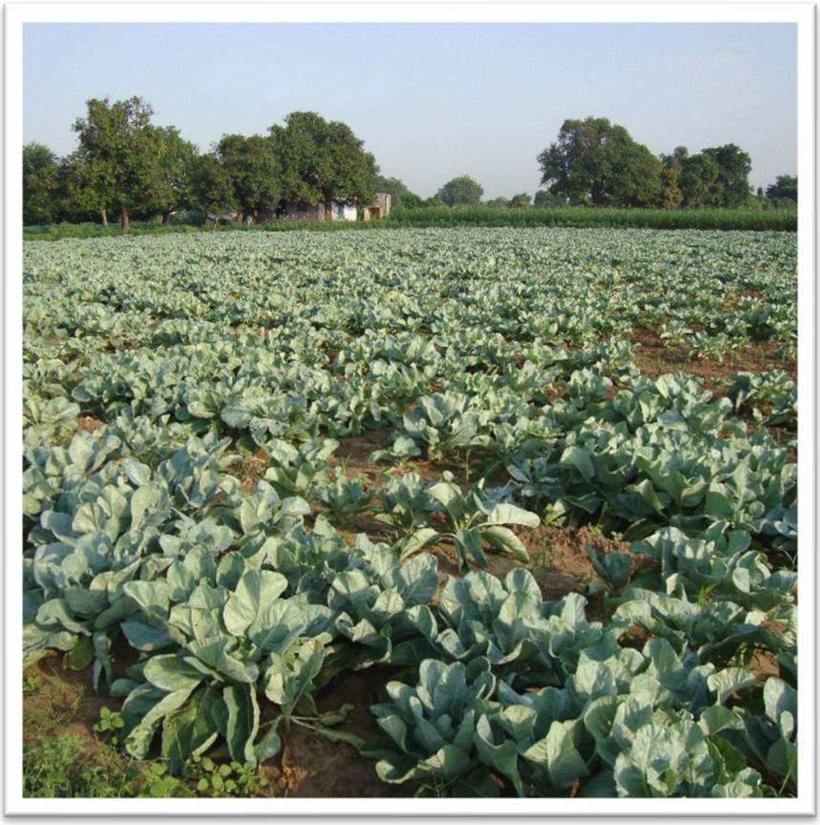


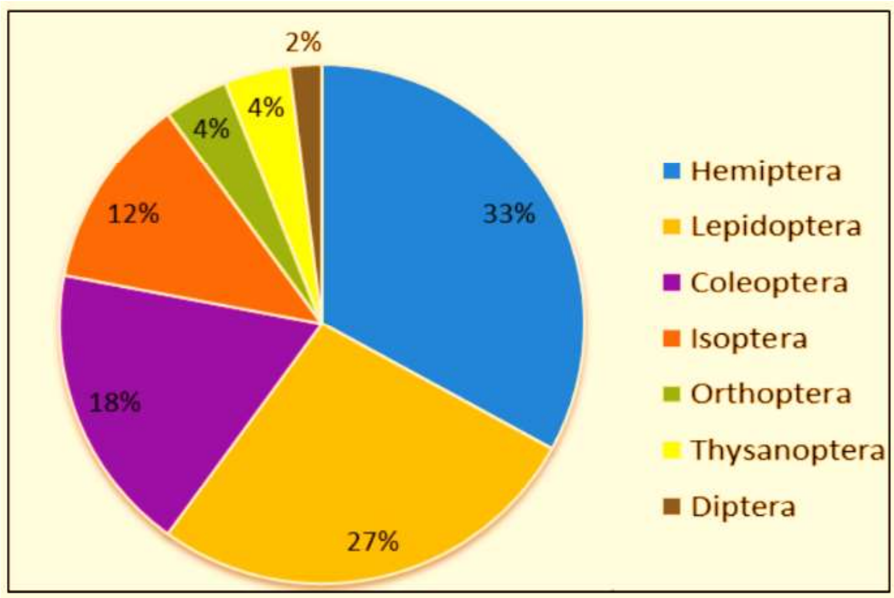
Figure 1.5: Cauliflower field in the region of Sherkhi (West of Vadodara)

Figure 1.6: Banana field in the region of Waghodia (East of Vadodara)

1.2. VARIOUS INSECT ORDERS CREATE THE PROBLEM

"The first day, one is a guest, the second a burden, and the third a pest."

~ Jean de la Bruyere



Graph 1.1: Percentage of pests in Vadodara agricultural fields **(Kataria & Kumar, 2012)**

The most devastating effects and destruction of already produced crops in agricultural fields with much investment in money and labour are caused by pests in the form of weeds, fungi, nematodes, insects, etc. A constant threat to crops remains due to pests **(Bruce, 2010)**. Amongst all the major pests of the agriculture fields, insects are said to be the ones causing high levels of damage. Global warming will further result in huge crop losses and food security problems due to low pest control efficacy **(Sharma, 2014)**. Insects, in general, are very dominant as they occupy the largest population amongst all living organisms known on the Earth. Insect pests can be in the form of mainly household and agricultural pests. Even though they are just a Class of the Phylum Arthropod, their population exceeds many Phyla of the animal kingdom combined.

For this reason, they can cause severe destruction in the fields, owing to the large-scale food requirement for survival. The agricultural insect pests mainly belong to Order Orthoptera (eg. *Gryllotalpa fossor*, *Schistocerca gregaria*), Hemiptera (e.g. *Aphis gossypii*, *Bemisia tabaci*), Coleoptera (e.g. *Holotrichia insularis*, *Oryctes rhinoceros*) and Lepidoptera (e.g. *Spodoptera litura, Plutella xylostella*). Coleoptera, followed by Lepidoptera, are the most significant insect order, therefore, high diversity of these species is also observed **(Stork, 2018)**.

In Vadodara, the maximum pest percentage has been occupied by orders Hemiptera and Lepidoptera **(Graph 1.1) (Kataria & Kumar, 2012)**.

The damage caused by pests, primarily insects, is one of the major concerns facing the agriculture industry, despite the fact that there are many other issues as well. With new techniques and cutting-edge technology, countries all over the world, whether developed or developing, have increased agricultural production; insect issues have always been a serious challenge in anticipated production. Insect issues have grown and gotten progressively worse. Given that they have existed for more than 250 million years while humans have only existed for one million, insects are the most challenging nuisance to control. So, despite the fact that agriculture, which evolved as man changed over time, has always been threatened by insect pests **(Banwo & Adamu, 2003)**.

Cereal rice, wheat, and maize are the staple source of food in India as well as the world. The crop losses in cereals like rice is a significant concern as it limits the production for the vast population dependent on it. Insects cause 27.9% of damage in rice **(Mondal et al., 2017)**.

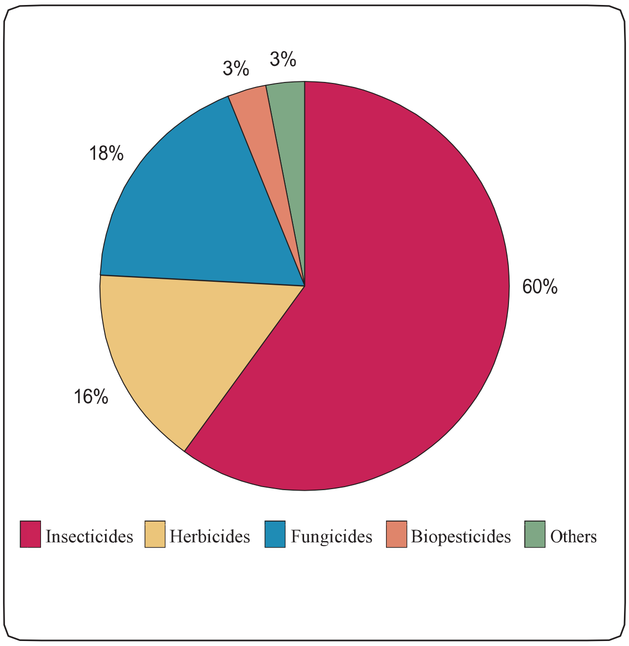
Of the enormous number of insect species on Earth, the troublemakers are not even one per cent, amounting to around 3,000 species. These can be either agricultural pests or vectors of human-animal disease **(William, 1967)**.

Recently in the year 2020, around April and May, India saw a sudden and severe outbreak of locusts in various places like Rajasthan, Delhi, and Gujarat. The Ministry of Agriculture has said it is the most significant locust attack in Gujarat and Rajasthan since 1993-94 and has caused estimated losses of 5-6 Crore rupees so far **(Joshi et al., 2020)**.

1.3. MENACE OF INSECTICIDES

"To make agriculture sustainable, the grower has got to be able to make a profit."

Sam Farr



Graph 1.2: The consumption pattern of pesticides in India **(Agarwal & Garg, 2015)**

There is a large market for pesticides in the world. These work against a different group of troublemakers. Therefore, the consumption pattern varies in India and the world as per the group's dominance **(Graph 1.2)**. If little is good, more is better. This has been the behaviour of farmers towards pest control by using pesticides. However, it has serious repercussions later on. Organisms on the planet have always competed with other species for food. Humans' biggest rivals are the most diverse group of all animals, i.e. the insects. The most popular pesticide of all time was DDT, a breakthrough discovery. However, the search for alternative pesticides soon began due to the persistence of DDT and its toxicity to aquatic animals and other non-targets **(Jukes, 1974)**.

Humans try to control harmful insects with the help of pesticides. This can have some difficulties. One is that the pesticides developed were too broad in their effect. They affect not only the target pests but also other insects. Also, by persisting in the environment, they are magnified and passed along the food chain-they have created a hazard to organisms, including man. Two is that insects have shown an enormous ability to develop resistance to pesticides **(William, 1967)**.

Ancient Egypt, Greece, China, and India all followed the practice of employing plant compounds as insecticides, today known as botanical pesticides. Example, nicotene ryania, and sabadilla are other varieties with less widespread application **(Isman, 2006)**.

Pesticides can be found everywhere around us. Be it homes, workplaces, or schools. There are observed enough shreds of evidence that prove pesticide exposure causes health threats. Many reproductive health problems are seen affected by exposure to pesticides **(Gilden et al, 2010)**. Pesticides cause oxidative stress as an instrument of their toxic activity in the body. The stimulation of free radicals, lipid peroxidation, and disturbance of the body's antioxidant capability are mechanisms of toxicity observed in organophosphates, herbicides, and organochlorine pesticides **(Abdollahi et al., 2004)**.

Amongst the various pesticides, India has the maximum number of insecticides, while worldwide maximum herbicides are consumed, followed by insecticides **(Graph 1.2)**.

1.4. INSECTICIDE EFFICACY

"The farmer works the soil; the agriculturist works the farmer."

Eugene F. Ware

There are various shops present in the Vadodara districts which supply a commercial range of insecticides. Some of these found in the market were surveyed **(Table 1.1)**.

Table 1.1 Pesticide shops in Vadodara, Gujarat

Sr. no.	Location	Pesticide shops
1.	Khanderao market	Gujarat Agro Agency
2.	Dandia Bazar	Azad Agencies
3.	Channi	Sun Agro Sales
4.	Jubilee Baug	Krushiko Sales and Service
5.	Raopura	Shreeji Pesticides
6.	Kothi	Gayatri Pest control
7.	Kirtistumbh	A Saj Agricare PVT. Ltd.
8.	Sardar Patel market	Goverdhan Traders
9.	Gorwa	Ideal Pest Control Services
10.	Lehripura	Gujarat pest control
11.	Baroda Dairy	Pest World
12.	Tarsali	Patel pesticides
13.	Navapura	Dharti Pesticide
		Kanani Pesticides & Biochemical Pvt. Ltd.
14.	Kevda Baug	Bharat Traders
		Akshar Krushi Seva
15.	Kareli Baug	Narmada Pest Control Services
		Ashok Pesticides

Insects cause some problems. Control over different pests requires specific treatments. These vary as per the chemical composition as well as the amount required. There can be a pest causing a nuisance in the house of agriculture fields, or they might act as a vector of many diseases. Insects have been majorly a contributor to the spread of various severe and fatal diseases. The first-time use of insecticides gained importance from DDT usage during the World war. The application of DDT provided control against lice, mites, ticks, fleas, mosquitoes, and various prevented diseases caused by them, like scrub typhus and malaria. **(Bishopp, 1945)**. Insecticides must be processed into a form that is appropriate for a specific application method, known as formulation, in order to be effective in controlling insects. To increase the insecticide's efficiency and characteristics, several chemical solvents or diluents are added **(Rathburn, 1985)**.

1.5. RESISTANCE DEVELOPMENT IN INSECTS TO INSECTICIDES

"Natural selection certainly operates. It explains how bacteria will gain antibiotic resistance; it will explain how insects get insecticide resistance, but it does not explain how you get bacteria or insects in the first place."

William A. Dembski

Resistance in insects to insecticides is a phenomenon that occurs when populations of insects become less sensitive to the toxic effects of insecticides over time. This can happen because of several factors, including genetic mutations, adaptation, and changes in behaviour. When insects are repeatedly exposed to a particular insecticide, such individuals have genetic mutations that provide resistance to the toxic effects of the insecticide.

To mitigate the development of resistance, it is important to employ integrated pest management strategies that incorporate a variety of control methods.

It's important to note that once resistance has developed, it can be difficult to reverse, and new insecticides may need to be developed to control the resistant pests. Furthermore, the spread of resistance between populations of insects can occur through the movement of insects or the exchange of genetic material, making the management of resistance a challenging and ongoing task.

As soon as seen, insect pests are tried to be controlled by spraying chemicals, namely pesticides. The proper usage and limits are usually not followed, leading to the severe insecticide resistance problem in most insects. The issue has gotten so bad that even exposure to herbicides has an impact on an insect's ability to withstand insecticides, especially those used to control agricultural pests **(Sun et al., 2019)**.

Cross-resistance is another challenge where an increased tolerance to a type of insecticide never used for selection occurs due to cross-resistance between the insecticides. This can be because insecticides have the same mode of action or create a target-insensitive mutation. Asymmetrical cross-resistance has been observed between abamectin and tebufenozide in *Plutella xylostella*, a lepidopteran pest, where cross-resistance is significantly influenced by cytochrome P450 monooxygenase. **(Yin et al., 2019)**.

The inability of insecticides to control the pest population, which it was previously capable of counteracting, lies in the concept of resistance. Various behavioural, genetic, and molecular studies are conducted to understand insect resistance development.

Many lepidopteran pests like *Plutella xylostella* and *Spodoptera litura* have already shown resistance against insecticides. One such insect is *Spodoptera litura*. Each year, insects on different crops are exposed to a range of pesticides, which has led to their rapid development of resistance to a number of these insecticides. **(Saleem et al., 2008)**. The *S. litura* has stopped responding to many of the chemicals. Although a lot of pesticides have been used to manage the DBM, the pest has become resistant to practically all insecticides, even formulations made with *Bacillus thuringiensis* Berliner (Bt) bacteria. **(Liu & Tabashnik, 1997)**.

1.6. MOLECULAR BASIS OF RESISTANCE

"Genes are like the story, and DNA is the language that the story is written in."
Sam Kean

The molecular basis of resistance development in insects is largely due to genetic mutations that affect the target site of the insecticide or the metabolic pathways that detoxify the insecticide.

One common mechanism of resistance is the alteration of the target site of the insecticide. For example, many insecticides target specific enzymes in the nervous system of insects, such as acetylcholinesterase. When insects are exposed to these insecticides, those individuals with mutations in the gene encoding acetylcholinesterase that reduce the binding of the insecticide to the enzyme are more likely to survive. Over time, these resistant individuals can become dominant in the population, leading to resistance.

Another mechanism of resistance is through the upregulation of metabolic pathways that detoxify the insecticide. For example, some insects have evolved the ability to increase the expression of cytochrome P450 enzymes, which can metabolize and detoxify certain insecticides. The catabolism and anabolism of exogenous and endogenous substances depend on the cytochrome P450-dependent monooxygenases. As a result of this monooxygenase-mediated metabolism, insects frequently develop pesticide resistance **(Scott, 1999)**.

When insects are repeatedly exposed to a particular insecticide, those individuals that have increased expression of cytochrome P450 enzymes are more likely to survive. This can lead to the development of resistance, as the increased expression of these enzymes can detoxify the insecticide and reduce its toxicity.

The upregulation of cytochrome P450 enzymes in response to insecticide exposure can occur through various mechanisms, including changes in gene expression, increased enzyme activity, and altered substrate specificity. Some insects have even evolved genetic mutations that increase the expression of these enzymes, providing a permanent mechanism of resistance.

The significance of cytochrome P450 enzymes in the development of pesticide resistance is emphasize the importance of targeting multiple metabolic pathways in the development of new insecticides. This can reduce the selection pressure for resistance development and improve the longevity of insecticides. Additionally, understanding the molecular mechanisms of cytochrome P450-mediated resistance can also aid in the development of novel strategies to overcome or mitigate resistance.

Through the use of functional genomic technologies like the CRISPR/Cas9 gene-editing tool, resistance mechanisms in insects should be examined not just in terms of a single gene's expression but also in terms of numerous gene interactions **(Wei et al., 2019)**.

A study suggests, there is a specific molecular mechanism underlying the resistance. From a total of 32 D. melanogaster genes and proteins involved in insecticide resistance, for resistance 21 genes have been recognized **(Zhang & Zhang, 2019)**.

Sometimes a combination of processes, such as modifications to the target site and enhanced detoxification, can lead to resistance. The genetic foundation of resistance can differ amongst insect populations, and even within populations, there may be different mechanisms of resistance. This is a crucial point to remember. In order to create new pesticides and adopt integrated pest management techniques that can stop the emergence and spread of resistance, it is crucial to understand the molecular basis of resistance.

1.7. LEPIDOPTERA

"Just when the caterpillar thought – I am incapable of moving, it became a butterfly."

Annette Thomas

Lepidopterans (butterflies & moths) depend highly on crops for survival. These are holometabolous. Lepidopterans' longest and most economically important stage is the larval stage, also called the caterpillar stage. It is important as it is the damaging stage of these types of insects.

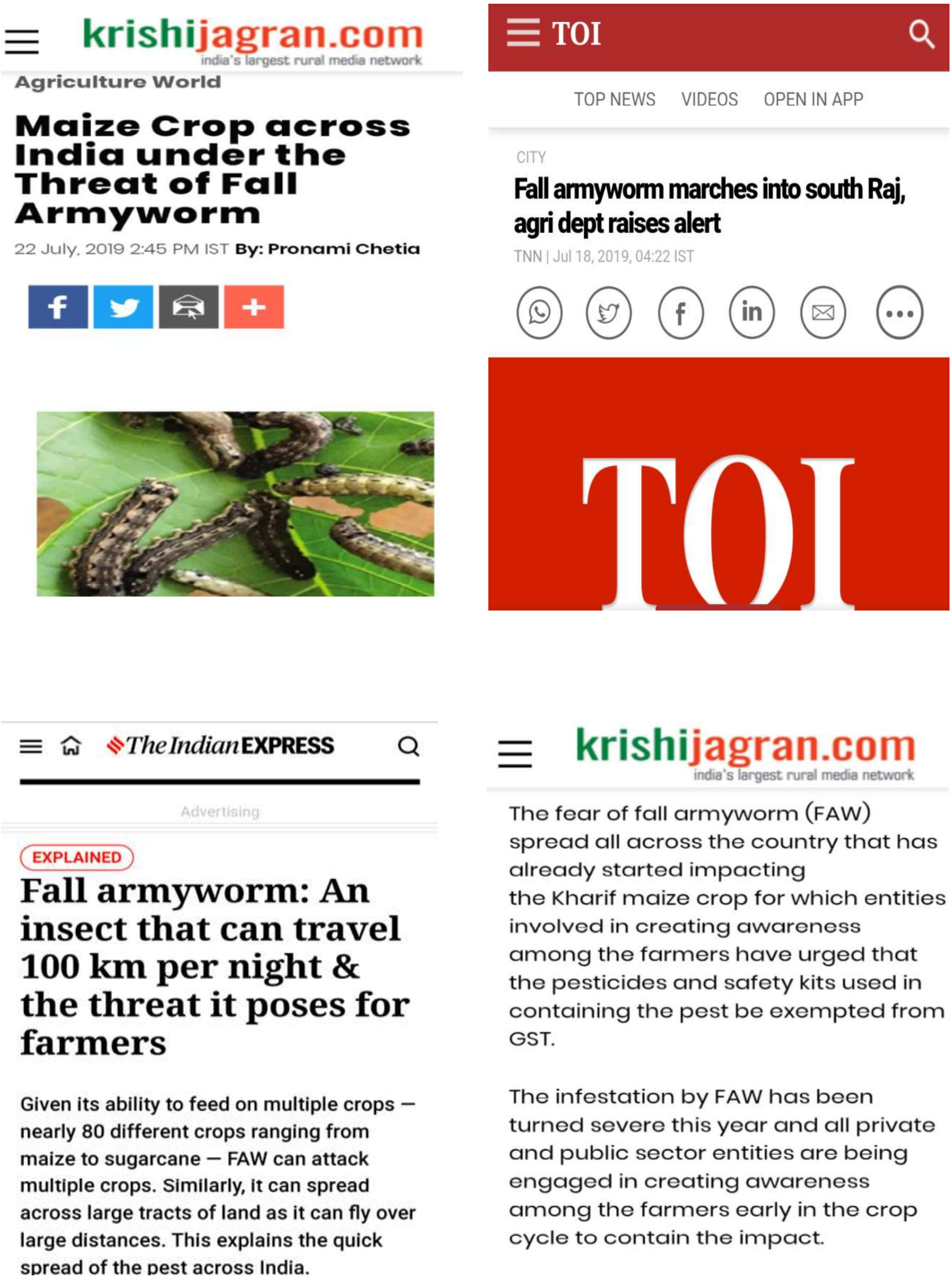
Although many caterpillars from the moth group are identified as agricultural pests, few are widespread, such as *Spodoptera litura*, *Plutella xylostella*, and *Helicoverpa armigera* **(Kataria & Kumar, 2012)**.

There occurs huge monetary loss in the control and management of the Lepidopteran pest. One such pest is DBM. Management costs and lost production with diamondback moth are approx US$4 to US$5 billion **(Zalucki et al., 2012)**.

One such important moth caterpillar is *Spodoptera frugiperda.* Smith. The pest is commonly called a fall armyworm or FAW. The pest has been causing severe damage since the time of its discovery on the American continent. Nowhere else was fall armyworm seen until 2016, when the first-ever report outside America was observed in Africa. The first report of FAW from India was also the first report from Asia, which was seen in the Karnataka state of India in 2018 **(Deshmukh, 2018)**. After this, several reports of fall armyworm from various Indian states, such as Maharashtra **(Chormule et al., 2019)**, Gujarat **(Sisodiya et al., 2018)**, Rajasthan, came **(Babu et al., 2019)**.

Spodoptera frugiperda is a polyphagous insect pest. However, its most severe infestation is seen in maize. Apart from maize, the pest is known to damage sorghum, sugarcane, paddy, spinach, mango, coriander, cucumber, melon, castor, peanut, chickpea, banana, barley, and pepper. **(Montezano et al, 2018)**.

The *Spodoptera frugiperda* (Fall armyworm) has been much in the news in recent years, since its invasion of the country **(Figure 1.7 & 1.8)**. It is found difficult to control in every corner of India. It is not responding to various insecticides recommended for the control of lepidopteran pests. The reason can be known from the study done in America from where the pest came from. It was observed that FAW has already become resistant to all the older groups of insecticides **(Yu, 1991)**. Therefore, a more detailed study for fall armyworm control is the need of the hour.



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Agriculture World

Maize Crop across India under the Threat of Fall Armyworm

22 July, 2019 2:45 PM IST By: Pronami Chetia

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Fall armyworm marches into south Raj, agri dept raises alert

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EXPLAINED

Fall armyworm: An insect that can travel 100 km per night & the threat it poses for farmers

Given its ability to feed on multiple crops — nearly 80 different crops ranging from maize to sugarcane — FAW can attack multiple crops. Similarly, it can spread across large tracts of land as it can fly over large distances. This explains the quick spread of the pest across India.

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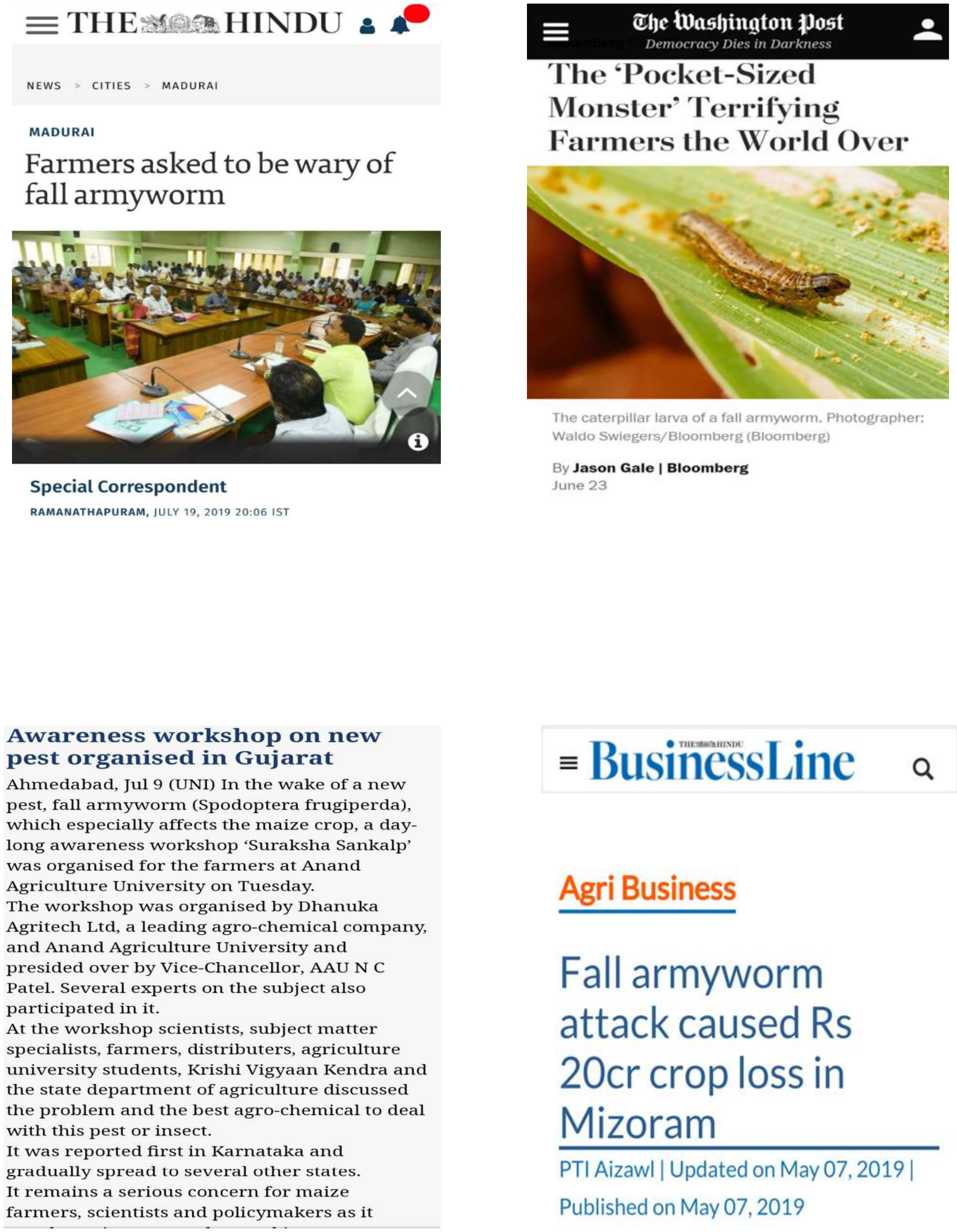
The fear of fall armyworm (FAW) spread all across the country that has already started impacting the Kharif maize crop for which entities involved in creating awareness among the farmers have urged that the pesticides and safety kits used in containing the pest be exempted from GST.

The infestation by FAW has been turned severe this year and all private and public sector entities are being engaged in creating awareness among the farmers early in the crop cycle to contain the impact.

Figure 1.7: FAW in News



THE HINDU

NEWS > CITIES > MADURAI

MADURAI

Farmers asked to be wary of fall armyworm

Special Correspondent

RAMANATHAPURAM, JULY 19, 2019 20:06 IST

The Washington Post
Democracy Dies in Darkness

The 'Pocket-Sized Monster' Terrifying Farmers the World Over

The caterpillar larva of a fall armyworm. Photographer: Waldo Swiegers/Bloomberg (Bloomberg)

By Jason Gale | Bloomberg
June 23

Awareness workshop on new pest organised in Gujarat

Ahmedabad, Jul 9 (UNI) In the wake of a new pest, fall armyworm (Spodoptera frugiperda), which especially affects the maize crop, a day-long awareness workshop 'Suraksha Sankalp' was organised for the farmers at Anand Agriculture University on Tuesday.
The workshop was organised by Dhanuka Agritech Ltd, a leading agro-chemical company, and Anand Agriculture University and presided over by Vice-Chancellor, AAU N C Patel. Several experts on the subject also participated in it.
At the workshop scientists, subject matter specialists, farmers, distributers, agriculture university students, Krishi Vigyaan Kendra and the state department of agriculture discussed the problem and the best agro-chemical to deal with this pest or insect.
It was reported first in Karnataka and gradually spread to several other states.
It remains a serious concern for maize farmers, scientists and policymakers as it

BusinessLine

Agri Business

Fall armyworm attack caused Rs 20cr crop loss in Mizoram

PTI Aizawl | Updated on May 07, 2019 | Published on May 07, 2019

Figure 1.8: FAW in News

1.8. THE PEST- SPODOPTERA FRUGIPERDA

"I get inspiration from a lot of things around me - nature, hills, people, and even insects."

Ruskin Bond

The insect which has been in the headlines in India and the world in recent years is – The fall armyworm **(Figure 1.7 & 1.8)**. Its highly destructive nature is a cause of concern for the country. The agricultural pest *Spodoptera frugiperda* (J. E. Smith) causes problems. Many host crops of *S. frugiperda* are of economic relevance to humans. There are two strains of fall armyworm known, Rice and Corn strains. The most devastating effects are observed in the maize fields. It causes leaf-feeding severe damage and direct injury to multiple crops eg. Barley, sorghum, rice, potato, tomato 353 plant species from 76 plant families **(Montezano et al., 2018)**.

Lepidopteran pest *Spodoptera frugiperda*, belongs to America and has an explosive reproductive rate all year long **(Sparks, 1979)**. Reports from several West and Central African countries highlighted sudden and severe outbreaks of fall armyworm populations due to their vast distribution and ability to take to the air; however, this is the first occurrence of invasion outside of the Americas continent. **(Goergen et al, 2016)**. Fall Armyworm has become a significant pest in Africa in a brief period. Its sudden arrival was around 2016, and by 2018 affected most maize farmers, about 86% quickly spread over two years in the country **(De Groote et al., 2020)**.

In 2018, *Spodoptera frugiperda* was discovered for the first time in India and Asia **(Deshmukh et al., 2018)**. Using phylogenetic analysis of biological macromolecules, it was recently determined that this invasive pest is present in China **(Jing et al., 2019)**.

Moreover, the Anand district's Gujarati maize fields were where the FAW invasion was initially detected **(Sisodiya et al., 2018)**. FAW infestation on maize and paddy has already been noted in Karnataka. **(Deshmukh et al., 2018) (Kalleshwaraswamy et al., 2019)**

FAW, is a pest of significant economic importance that is currently known to affect crops such as maize, rice, and sorghum. This insect not responding to chemicals in field becomes a subject of research because of its significant impact on agricultural production. This insect does not response to phosphorous compounds, carbamates and synthetic pyrethroids.

In some cases, resistance has been associated with changes in the target site of the insecticide, such as alterations in the gene encoding acetylcholinesterase. In other cases, resistance has been linked to the upregulation of metabolic pathways, such as increased expression of cytochrome P450 enzymes.

Additionally, studies have also investigated the genetic basis of resistance development in *Spodoptera frugiperda*. For example, some studies have identified specific genes and mutations that are associated with resistance to insecticides, providing important insights into the molecular mechanisms underlying this phenomenon.

1.9. MAIZE:

"A light wind swept over the corn, and all nature laughed in the sunshine."

Anne Bronte

Maize (*Zea mays* L.) is a significant cereal food crop that has the maximum productivity and output. It is a crucial crop for producing fodder, food, feed, and other industrial goods. Because of the crop's susceptibility to weeds, insect pests, and pathogens, it experiences significant biotic stress. The amount of these elements varies greatly depending on the area, season, and cultivar that is employed. Reduce agricultural loss by estimating crop loss in a timely manner.**(Kumar et al., 2018)**.

After rice and wheat, maize is the third-most significant cereal produced in India in terms of economic importance. According to a report from Mizoram in May 2019, the fall armyworm invaded 122 districts with maize agriculture, resulting in an estimated loss of 200 million INR. Fall armyworm is one of the world's worst agricultural pests. It has been known to cause severe damage to maize fields all over the world. Besides maize, it also destroys many other crops because of its polyphagous nature. Such herbivorous polyphagous insects possess notable adaptations to identify, detoxify and digest several host plants. The noctuid moth *Spodoptera frugiperda* Smith ranks has two morphologically indistinguishable strains ("C" and "R") that have different host-plant ranges **(Gouin et al., 2017)**. However, the invasion of FAW in recent years has caused the most profound effect on the maize crops and caused a severe decline in production.

Since 2008, over 80% of soybean and maize are grown in the USA are genetically engineered. Corn (or maize) seeds are transformed into two genes: one eliminates insects that feed on seeds, and the other allows tolerance in seeds to glyphosate. The soybeans contain only the gene that is consisting resistance to glyphosate **(Campos et al., 2019)**.

1.10. CHALLENGES WITH FAW:

"Opportunities to find deeper powers within ourselves come when life seems most challenging."

Joseph Campbell

The fall armyworm (*Spodoptera frugiperda* Smith*)* is a highly destructive insect pest that feeds on tender leaves and stems of maize, rice and various other crops. Studying insecticide resistance in fall armyworms presents a number of challenges, including:

Rapid Evolution of Resistance: Fall armyworms have a short generation time and high reproductive potential, which means that resistance to insecticides can evolve rapidly. This makes it difficult to stay ahead of the development of resistance, as new populations may emerge that are resistant to multiple insecticides.

Lack of Standardized Testing Methods: There is no standardized method for testing the susceptibility of fall armyworms to insecticides.

Difficulty in Identifying the Mechanisms of Resistance: The mechanisms of insecticide resistance in fall armyworms are not well understood, making it difficult to develop effective strategies for controlling resistant populations.

Limited Information on Population Dynamics: The population dynamics of fall armyworms, including the dispersal of resistant populations, are not well understood. This makes it difficult to predict the spread of resistant populations and develop effective management strategies.

High Cost of Monitoring and Control: Monitoring and controlling fall armyworms is an expensive and time-consuming process, especially in large-scale agriculture.

Despite these challenges, it is important to continue researching insecticide resistance in fall armyworms, as this information can be used to develop more effective and sustainable pest management strategies.

Further, *S. frugiperda* has been found to be resistant to earlier insecticide classes that are frequently used, such as pyrethroids, organophosphates, and carbamates, which cause Florida crops to fail. Because the most widely used insecticides are inefficient at controlling the pest, managing it has therefore become more challenging **(Yu, 1991)**. There is currently no surefire way to control FAW sustainably in Asia or Africa. **(Padhee & Prasanna, 2019)**. In order to successfully rear insect pests in the lab, artificial diets are used as a substrate. The diet studies also advance knowledge of the biology, behaviour, and dietary needs of insects, knowledge that is essential for creating effective Integrated Pest Management strategies. **(Pinto et al., 2019)**.

Developing ways to manage crop management strategy would require a thorough understanding of physiology, which is why it is recommended to raise them artificially in a lab. According to Kalleshwaraswamy and colleagues in 2019, the insects that need to be raised in a lab have unique traits that may be easily detected in the separate larval and adult stages **(Sharanabasappa et al., 2018)**.

1.11. INSECTICIDES USED IN THE STUDY:

"It is important to concede that modern pesticides have helped to make farming more productive and to increase yield."

Chuck Norris

The use of a combination of Chlorantraniliprole and Emamectin benzoate is one approach that has been proposed to combat pesticide resistance in insects. Chlorantraniliprole and Emamectin benzoate are insecticides that target different sites in the insect's nervous system and have different modes of action, making it more difficult for insects to develop resistance to both compounds.

When used in combination, these insecticides can provide a more effective and sustainable control of pests, as they reduce the selection pressure for the development of resistance to either compound. This approach is based on the principle of using insecticides with different modes of action to slow down the evolution of resistance.

Studies have shown that the combination of Chlorantraniliprole and Emamectin benzoate can provide effective control of a variety of insect pests, including Lepidoptera, Coleoptera, and Hemiptera species. However, it's important to note that the efficacy of this combination will depend on the specific pest species, the dose and application method, and the environmental conditions.

While the use of a combination of Chlorantraniliprole and Emamectin benzoate can help to reduce the risk of resistance development, it's important for us to know these insecticides in detail.

CHLORANTRANILIPROLE & EMAMECTIN BENZOATE

Chlorantraniliprole (Chemical formula-$C_{18}H_{14}BrCl_2N_5O_2$) is a novel insecticide belogs to the diamide class, discovered by Dupont, and which is used to control lepidopteran pests. It falls into IRAC MOA group 28 and functions as a Ryanodine receptor modulator. Emamectin benzoate, on the other hand, is a unique semi-synthetic derivative of the natural substance abamectin that belongs is of avermectin family and has potency against a wide range of lepidopteran pests (Chemical formula: $C_{56}H_{81}NO_{15}$). It falls into IRAC MOA group 6 and acts as a Glutamate-gated chloride channel (GluCl) allosteric modulator. Both

Chlorantraniliprole and Emamectin benzoate are new-age insecticides used against various lepidopteran pests like *Spodoptera litura*. In recent years, resistance development against these insecticides has also been studied. Both of them working through different modes cause paralysis and ultimately cause death in the organism **(Figure 1.9 & 1.10)**.
Higher resistance against Emamectin benzoate was seen than Chlorantraniliprole in the field populations of *Spodoptera litura* **(Wang et al, 2019)**.

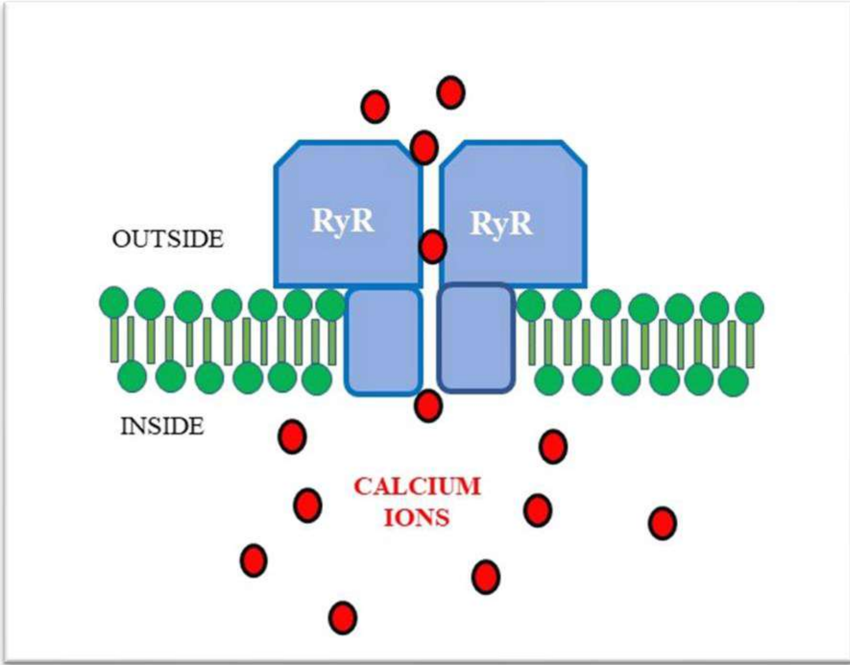


Figure 1.9: Diamide family (Chlorantraniliprole)

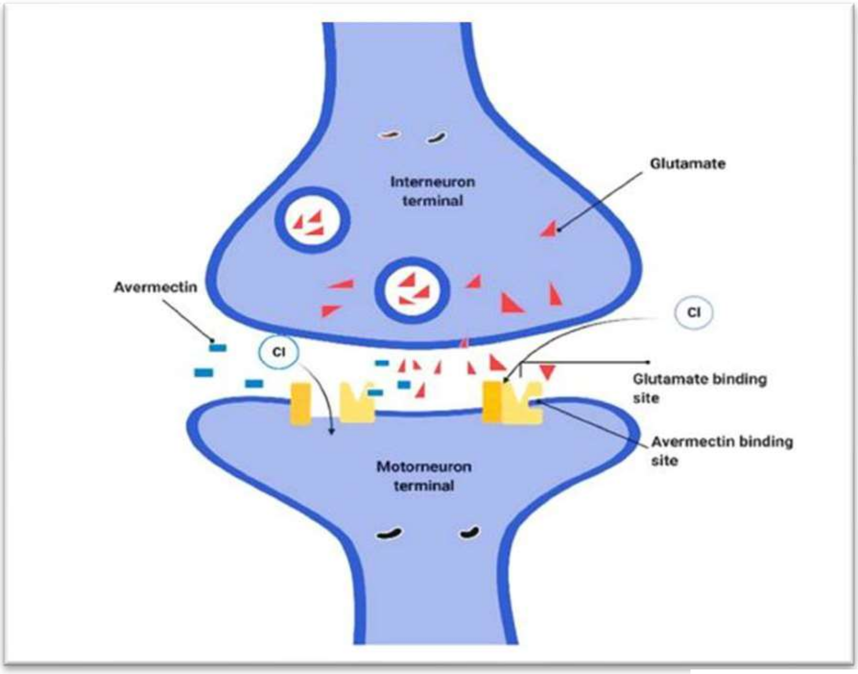


Figure 1.10: Avermectin family (Emamectin benzoate) Source: **El-Saber Batiha et al., 2020**

The need to take up this work arises from the ongoing scenario. Gujarat agriculture fields have a wide range of crops and are present in abundance, mainly due to the alert, aware farmers here. While I was visiting fields, I found severe destruction by this pest *Spodoptera frugiperda* Smith. It has been widely present in the news ever since it invaded India. The reason is its high capacity to cause a nuisance in the agriculture fields in various parts of India. Farmers are helpless in controlling it. Farmers have been facing huge losses because of this pest. Insects can act both ecologically beneficial and harmful to us. I collected insects and interviewed farmers from cotton, castor, maize, tobacco, and other fields in Vadodara, Anand, and Navsari fields. But as there is no planned control program for farmers so, is highly required.

One such important pest I observed in the field is the fall armyworm. I saw farmers overusing insecticides and still not getting control. Hence, the need to rear and breed it in the lab and find why it is not showing a response to the insecticide used by the farmers. The reason could be resistance. With previous experiences working on Lepidopteran insect pests *S. litura, and P xylostella,* I thought of checking Chlorantraniliprole and Emamectin benzoate insecticides. Toxicity of the selected insecticides, how controlling this pest, the extent, over time capacity. These insecticides were chosen due to their novel characteristics.

ORIGIN OF THE PROBLEM

Spodoptera frugiperda Smith is a massive pest invading a large part of the Indian subcontinent and is observed to be resistant to older insecticides, used in other parts of the globe. On the other hand, two drugs, namely Chlorantraniliprole and Emamectin benzoate, have been invented in recent decades to combat lepidopteran manifestations, but their efficiency to control *S. frugiperda* has not been studied in detail. Further, whether this pest develops resistance against the two drugs is unknown. As a result, this study is an attempt to investigate the combat potential of these drugs against *S. frugiperda*, with an eye toward potential drug resistance that may develop across multiple generations of the insect. The approach here is to decipher the mechanisms through which the resistance might develop in order to find a rescue operation beforehand. The same was attempted to be achieved through collection and effective rearing of the pest in the lab, followed by insecticide testing and observations, which were later confirmed by RNA-sequencing.

AIMS AND OBJECTIVES

"A goal without a plan is just a wish."

Antoine de Saint-Exupery

Overall aim:

The purpose of the research was to find out the effectiveness of two new generation insecticides against *Spodoptera frugiperda* Smith, 1797. To fulfil the aim, the following objectives were undertaken:

Objective 1:

A survey of agricultural fields in Vadodara district to find out the damage caused by *Spodoptera frugiperda*

Objective 2:

Evaluating natural and artificial diets for the biology study of *Spodoptera frugiperda.* Different artificial diet ingredients are compared to find a better lab-reared diet.

Objective 3:

Checking insecticide efficacy (Chlorantraniliprole and Emamectin Benzoate) for the control of *Spodoptera frugiperda*

Objective 4:

Comparing control and insecticide-treated insect midgut tissue by histology.

Objective 5:

Understanding resistance development in *Spodoptera frugiperda* against the insecticides Chlorantraniliprole & Emamectin Benzoate: The molecular basis of resistance