

Introduction

The growing population and increasing urbanization at the expense of agricultural resources lead to continuous shrinking of arable land, which poses a critical challenge to ensuring food and nutritional security for the nation. According to a United Nations review on the global population, India will surpass China's heavily populated world's nation by 2022. With a present size of 1.32 billion, India currently supports nearly 17.84% of the world population, with 2.4% land resources and 4% water resources (FAO , 2018; Ravi and Fulekar, 2018). Indian agriculture requires to ensure food and nutritional security for the nation by improving its slow pace of food production and agricultural produce loss due to pest attacks. Therefore, it becomes imperative to implement measures to enhance crop production and crop protection. It is noted that annually average, 45% of the world's total food productivity was lost due to pest infestations (Abhilash and Singh, 2008). Food security is intimidated by an alarming increase in the number of outbreaks of transboundary pests and plants and animals' diseases. These pests and diseases jeopardize food security and have broad economic, social, and environmental impacts (Misselhorn *et al.*, 2012). Hence, for Keeping pace with the growing population and their increasing demand for food, chemical crop protection products, commonly referred to like pesticides and fertilizers, have become a need to increase agricultural production and protection from pests to ensure food and nutrition security the nation.

India is a global agricultural powerhouse. The agriculture sector has remained the Indian economy's backbone from earlier and presently accounts for ~15% of its entire Gross Domestic Product (GDP) and holds prime importance in India's socio-economic foundation. About 44% of India's geographical area is used for agricultural purposes and is the principal source of livelihood for about 58% of its population (Singh and Nair, 2012). The agriculture sector has faced many challenges like high monsoon dependency, unpredictable weather patterns, reduction in arable land, low per hectare yield, pest attacks, etc. However, after the green revolution, agricultural practices have changed, having great yielding crop varieties, intensive pesticides, and applied irrigation leading India, a global crop-producing country. Although yield per hectare has doubled in the past few years, Indian agriculture is still grappling with challenges

(Iqbal, 2018). In recent years, climate change has threatened Indian food security by a negative effect on agriculture.

Climate is the primary determinant of agricultural production, directly impacting food production across the globe. Although the effect of increasing CO₂ concentrations increases the net primary productivity of plants, variation in climate affects the soil moisture, groundwater recharge, frequency of flood, or drought (Pasupalak and Pasupalak, 2009; Priyadarshi, 2009; Rai, 2010) that leads to decreased net food productivity. Indian agriculture consumes about 80-85% of the nation's available water (Eriksson *et al.*, 2008) The effect of climate change affects the water cycle (Reddy *et al.*, 2009) and the groundwater level in different areas. An increase in the mean seasonal temperature will reduce many crops' duration and reduce the final yield. In regions where temperatures are already close to the physiological maxima for crops, warming will impact yields more immediately (Solomon, 2007). Any alteration in the climatic parameters such as temperature and humidity, which govern crop growth, will directly impact the quantity of food produced.

Gujarat is a very unique and blessed state with various natural resources. Gujarat is located on the west coast of India, with the longest sea coast of 1600 km of the Arabian Sea. It is situated between 20°1' and 24°7' North Latitude and 68° 4'to 74°4' East Longitude covering a geographical area of 196 lakh hectares. This is 6 % of the country. The State is comprised of 33 districts having 246 talukas and 18569 villages. Agriculture is an essential sector in Gujarat, as it is one of the primary sources of livelihood for more than half of its workforce. Among all states of India, especially Gujarat, has drawn attention by its spectacular agricultural growth due to meticulous planning and implementation of programs to increase water availability, helping farmers increase productivity. Due to modern agricultural practices, Gujarat has witnessed an agricultural growth rate of over 9% per annum in the last decade (Dholakia and Datta, 2010) Gujarat's climatic conditions allow the cultivation of a variety of crops in different areas of the State. The State tops the country's agriculture growth table with a Compound Annual Growth Rate of 10.7% over the last decade. Around 65% of the total geographical area is under cultivation. The State has five regions having wide varieties of soil and agricultural diversity viz., Kutch, North Gujarat, Central Gujarat,

Saurashtra, and South Gujarat. The Central Gujarat region has Ahmedabad, Anand, Kheda, Panchmahal, Chota Udaipur, Mahisagar, Dahod, and Vadodara.

Vadodara is in the eastern part of the State of Gujarat in western India. Geographically Vadodara district with 7548.50 sq km area, is located the central part of Gujarat lies between latitude 21 ° 49 "19" and 22 ° 48 "37" north and longitude 72 ° 51 "05" and 74 ° 16 "55" east. The district's total area is 7,77,000 ha, out of which 177622 ha area is cultivated land (Krishi Vigyan Kendra). The district is composed of 12 talukas. The district boasts four agro-ecological zone. The major crops of the Vadodara districts include Rice (*Oryza sativa*), Maize (*Zea mays*), Wheat (*Triticum spp.*), Jowar (*Sorghum Vulgare*), Bajri (*Pennisetum typhoidis*), Gram (*Cicer arietinum*), Arhar (*Cajanus cajan*), Cotton (*Gossypium hirsutum*), Groundnut (*Arachis hypogaea*) and Banana (*Musa sp.*). The main horticulture crops in the Vadodara district are vegetables (27581 ha), fruits (21447 ha), and spices (mainly chili). The main vegetable crops are brinjal, Lady's Finger, and Tomato. Citrus, Ber, Guava, and mangoes are the main fruits. There are medicinal crops, too, grown over an area of 90 ha. Agriculture plays an essential role in Vadodara's economy as it is a leading manufacturer of pulses, crops, fruits, and flowers in the State of Gujarat. The total area under food grain cultivation is in the Vadodara district. The district is the biggest producer of pulses in Gujarat, contributing 14.7% to the total production. It is also among the State's significant fruit-producing districts, contributing 11.25% to the total fruit production. The district is the major cultivator of flowers in the State, contributing 16% to the total production (Suvagiya *et al.*, 2017). Vadodara, being one of the agriculturally essential districts, the challenge is to assure high and quality yields and ensure that crop production is environmentally sustainable. To reach this goal, the role of insects in agricultural ecosystems is also equally important.

As drivers of ecosystem functions, transect plays a significant role in agroecology, managing agricultural systems in an ecologically sound and sustainable way by encouraging beneficial organisms (Woodcock *et al.*, 2014). Ecosystem services are the benefits that humans derive from ecosystems. In terrestrial ecosystems, insects play vital ecological roles in diverse ecological processes such as nutrient cycling, seed dispersal, bioturbation, pollination, and pest control (Landis *et al.*, 2000; Brewer *et al.*, 2005; Replansky and Bell, 2009; Lonsdorf *et al.*, 2009; Jankielsohn, 2018) In

conventional agriculture, production practices focus on a few preferred species and their specific requirements, yet many other species' potential services are ignored (Hoehn *et al.*, 2008). Agricultural production systems are boosted by increased use of external inputs to high-level yield, but at the cost of diversity, causing ecosystems to become weakened. Diversity is a primary factor of natural ecosystems as it facilitates the systems to become more resilient and makes it survive significant changes. Because of the lack of diversity in those systems, agricultural systems cannot survive significant disturbances. Understanding insects' function in ecosystems enables us to recognize their importance in the sustainable functioning of agricultural systems and their future food security role. The insect-plant relationship is the dominant biotic association, and about 50 percent of insect species are herbivorous, with most herbivorous species feeding on plants in one or more associated plant families. Herbivorous insects damage 18% of the world's agricultural production, mainly controlled by chemical methods. Despite these damages, not more than 1% can be classified as a pest (Schoonhoven *et al.*, 2005; Losey and Vaughan, 2006; Ghazali *et al.*, 2014).

Pest control is an inevitability in agriculture. Insect pests are produced by exploiting human environments, where crops are selected for a more extensive scale, higher yields, nutritional value, and maximum monoculture production. In turn, monocultures create "biological deserts," where only a small number of organisms can live, and besides, they provide a highly favourable habitat for the growth of some herbivorous insects.

In turn, these herbivorous insects can evolve, adapt to new situations, Surmount the effects of toxic materials such as pesticides or circumvent the natural or artificial resistance of plants (Schwagerl, 2016). However, natural predators are killed using pesticides, leaving no control for the herbivorous insects' population growth. Among the many challenges involved in preserving crop productivity and nutritional protection, insect pests' direct and indirect damages are of paramount importance. Populations of insect pest outbreaks have enormous potential to damage the agricultural economy. Recognition of initial symptoms of pests and diseases to deal with the problem is of crucial importance. Therefore, the accurate taxonomic identification is the pivotal issue in biological research to implement adequate measures to contend with agricultural importance (Karthika *et al.*, 2016). However, significant knowledge gaps

remain as far as the pest status of the Vadodara District is concerned. **Hence, the present study's first objective was to Study the Diversity of insect in agricultural fields of Vadodara (Chapter I)** as studies of pest population dynamics within regions may be useful for developing management strategies.

Pests are essential reasons for declines in crop yield. As per the U.N. Food and Agriculture Organization (FAO), it decreases annually between 20 and 40 percent of global crop yields due to plant pests (FAO, 2018). Climate change is exacerbating food insecurity, which will intensify its negative impacts over time. It is happening via several pathways, among which plant pests are a leading cause. Climate change can affect plant pests through several potential mechanisms, including ecology, spatial distribution, and food chains. Climate changes have a significant bearing on insects' behaviour, as insects are cold-blooded organisms and are particularly sensitive to temperature changes. Climate change impacts the distribution and severity of crop infestations by direct effects on the life cycle of insects, in addition to indirect climatic effects on hosts, natural enemies, rivals, and insect pathogens. Owing to their alteration of pest activity and population dynamics, climate change has given rise to pest control and prediction difficulties. Predicting the direct impact of climate change on pests was further complicated by overlapping impacts of growing concentrations of atmospheric carbon dioxide, evolving climate regimes, and shifts in the frequency and severity of severe weather events. Also questioned were forecasts that climate change would indirectly exert its effects on pests (Puri and Ramamurthy, 2009; Dhaliwal *et al.*, 2010; Ratnadass *et al.*, 2012; Allinne *et al.*, 2016; Chaya, 2019). Herbivorous insects are responsible for destroying one-fifth of the world's total crop production annually. One primary reason why there are pests is the creation of man manipulated habitats, agroecosystems that fulfil man's needs, where crops are selected for their large size, high yield, nutritious value, and clustered confined area.

Losses of crops caused by plagues and diseases pose a significant threat to the income and food security of thousands of rural families worldwide (Savary and Willocquet, 2014; Allinne *et al.*, 2016; Avelino *et al.*, 2015). Implications of crop losses have reach levels far beyond farms, given that a reduced production affects entire rural communities and regions, national markets and exportations, and at the broadest level, the food availability for the world population.

The severity of pest problems has been changing with agricultural technology developments and modifications of farming practices. The changing scenario of insect pest problems in agriculture as a consequence of green revolution technology has been well documented (Dhaliwal and Arora, 2001; Dhaliwal *et al.*, 2002; Singh *et al.*, 2002; Puri and Mote, 2003 ; Kumar, 2005; Satpathy *et al.*, 2008; Koul and Dhaliwal, 2010; Usman, 2017). There has been a further shift in several insect pests' status after introducing transgenic crops and the current climate change scenario. Stress in plants on account of climate variations results in pest outbreaks as the plant defense system is lowered due to physiological processes (Sharma *et al.*, 2019). Along with native insect pests, global climate change has led to invasions of some exotic insect pests in India, proving devastating to indigenous crops. Invasions by alien species upset the balance of native ecosystems, and many of them cause considerable economic loss (Rathee and Dalal, 2018). Hence, if the pests and diseases of fruit vegetables are not properly managed, it could have an economic impact on production level by reducing crop yield, quality, and, subsequently, low return. Accurate estimates of agricultural losses caused by pest insects are difficult to obtain because the damage caused by these organisms depends on several factors related to environmental conditions, the plant species being cultivated, the farmers' socio-economic conditions, and the level of technology used. In Vadodara, data on insects' agricultural losses are incredibly scarce and scattered in the scientific literature. ***This research's second objective was to identify the common pests and look into Vadodara's agricultural fields' infestation rate and severity (Chapter II).***

Thousands of pest species either directly attack economically important plants or transmit viral and bacterial diseases, daunting enormous agroecosystem costs. The economic losses due to pests are increasing as new species gain pest status, often following human-mediated range expansions that, in the absence of natural enemies (Liebhold *et al.*, 2013), can lead to population detonations that move a species from non-pest in its native range to pest in newly colonized areas (Aukema *et al.*, 2011). The accurate identification of pest species is a prerequisite for deploying appropriate management strategies; it is critical to accurately identify pest species. Equally crucial for the implementation of effective pest control measures is the accurate identification of the species stage. However, uninformative morphological characteristics and a lack

of usable molecular data, such as species-specific DNA barcodes, frequently hinder the rapid identification of pests. Moreover, pest species are difficult to identify based on morphology because the frequently elusive immature stages are often responsible for the bulk of crop damage, and they exhibit very few diagnostic morphological characters. They are often mistaken for less destructive congeners (Chattopadhyay, 2017). These complexities have provoked growing interest in adopting DNA-based approaches for species recognition, creating exciting challenges for traditional approaches to regulatory compliance (Jörger and Schrödl, 2013).

Furthermore, insects' identification is crucial to managing endangered species, protected species, and invasive species. This management is essential for environmental quality indicators, basic research on evolutionary biology and ecology, agricultural pests/beneficial species and disease vectors/pathogens, and biodiversity study and conservation research. Until now, insect identification has been based on classical morphological and taxonomic studies. Eventually, difficulty in morphological identification has led to the use of molecular datasets instead of morphological analysis for identifying and characterization of different taxa (CBOL, Consortium for the Barcode of Life).

DNA barcoding is a diagnostic technique in which short DNA sequence(s) are used for species identification and has been proposed as a standardized approach to the characterization of the life forms in various groups of living organisms, including insects (Hajibabaei *et al.*, 2007; Floyd *et al.*, 2009). In the last three decades, mitochondrial DNA has been extensively analyzed (Ballard and Rand, 2005), and confirmed to be an essential tool in species delimitation as it possesses biological properties making it suitable as a marker for molecular biodiversity (Hebert *et al.*, 2003; Karthika *et al.*, 2016). Molecular identification and phylogeny using species identification markers COX 1 of the mitochondrial region are regarded as efficient. Insect mitochondria contain two ribosomal RNA (rRNA) genes, 12S rDNA and 16S rDNA. 12s rDNA is highly conserved in insects and used for genetic diversity in phyla, and 16S rDNA) is often used for studies at the low and intermediate levels such as in families or genera (Gerber *et al.*, 2001; Mandal *et al.*, 2014). Like other animals, insect mitochondrial genome is a double-stranded molecule with a range of 14,503 bp to 19,517 bp in size (Grewal *et al.*, 1994). It consists of 37 genes encoding the large and small subunit ribosomal RNAs; However, pests comprise of 1% of the total Insects,

pest species remains to be discovered and described (Mora *et al.*, 2011), the discipline of finding, describing, and naming pest species pest Taxonomy currently faces a vital deficit in term of funding and human resources (Godfray, 2002). **Hence, the third objective of the present study was to Study the Species Level identification of the economic essential pest insect species using the DNA Barcode Approach (Chapter III).**

There exists a close ecological link between pest and their host plants. Host associations can be established by direct observations of feeding or by morphological or chemical studies of gut content (Post, 2002; Jurado-Rivera *et al.*, 2009), but require precise identification of host plants. In plants, several 'barcode' loci have been proposed (Chase *et al.*, 2007; Kress and Erickson, 2007; Taberlet *et al.*, 2007; Fazekas *et al.*, 2008; Lahaye *et al.*, 2008) for which representation in databases increases rapidly, improving the accuracy and speed of host plant identification. When used in comparative studies, e.g., for the analysis of host plant associations, the sequence fragments are used by linking them to a named species or DNA-based group to which ecological information from literature or field observations has been associated (Hebert *et al.*, 2003). These groups and their host information provide the starting point for analyzing co-evolutionary relationships of plants and pests. A vital aspect of these studies is the authentication of the feeding source, whereby the most substantial evidence linking an individual to the host plant is provided through analysis of ingested host tissue (Jurado-Rivera *et al.*, 2009).

Host plant selection by insect pests is often divided into 'host plant finding' and 'host plant acceptance.' While the two are easy to separate conceptually, they are part of a continuum of three, rather than two, inextricably bonded links. Nevertheless, the central component of host plant discovery, previously thought to be controlled by volatile chemicals, has proven to be intractable to scientific experimentation until now. On the other hand, to combat this problem, a new scientific approach in the 21st century has been developed where barcodes of plants and individual insect species are used to find the homology between the two. Above 50% of all known species on earth are plants and their associates' insect herbivores. The first step in understanding the mechanisms generating and maintaining this vital component of biodiversity is identifying plant-

herbivore associations (García-Robledo *et al.*, 2013). Hence, we hypothesize that there has to be some sequence homology between various genes (conserved region), leading to a specific intrinsic interaction.

At the international level, DNA-based field studies on intra-guild predation have been reported (Gagnon *et al.*, 2011; Aebi *et al.*, 2011 and Thomsen *et al.*, 2012). Reports documenting predation on exotic pests in the field via molecular gut-content analysis are also available (Chen *et al.*, 2000; Hoogendoorn and Heimpel, 2001; Symondson *et al.*, 2002; Sheppard and Harwood, 2005; Gardner *et al.*, 2013; Greenstone *et al.*, 2014; Opatovsky *et al.*, 2012; Grasswitz, 2016). Further, the importance of abiotic factors, as well as human interference with relation to plant-insect interaction at the molecular level, is well documented at the national level (Ali and Agrawal, 2012; Dawkar *et al.*, 2013; Kumar and Usmani, 2014; Kumar Shah *et al.*, 2015). At the regional level, a series of work has been contributed by Kumar and co-workers (Kumar, 2012; Kumar, 2015; Kataria and Kumar, 2012, 2017) as far as the diversity of agroecosystem (Banana, Cotton, and Rice) is concerned where they have focused mainly on spiders, Termites, and Ants. However, there is a lacuna as far as genetic studies on insects of agricultural fields and its host plant interaction are concerned. **Hence, the present study's fourth objective was to identify the host plants and pest interaction with particular reference to Coleopterans and evaluate the Correlation of insect DNA with the plant DNA sequence.**

