CHAPTER 1

INTRODUCTION

1.1. TEA: JOURNEY FROM THE WILDERNESS TO THE CUP OF CIVILIZATION

Tea [*Camellia sinensis* (L.) O. Kuntze] is an evergreen plant that is cultivated in tropical and sub-tropical climates for its leaves, which are dried, fermented, processed and consumed as much-loved beverage. For centuries tea has been an integral part of people around the globe for its refreshing aromatic flavor which invigorates billions of life every morning with its first sip. In fact after water, tea is the second most consumed beverage in the world (van der Wal, 2008). It was discovered in around 2700 BC, crowning it to be one of the oldest beverages in the world. It has been an integral part of human civilization for having tremendous medicinal, commercial and cultural value.

The genus *Camellia* belongs to the family Theaceae. It was first elaborately described by Sealy in 1958 with reported 82 species, classified into 12 sections. Chang (1998) later rearranged the native Chinese *Camellia* into 280 species under four subgenera and 22 sections. All *Camellia* spp. does not produce the globally renowned beverage ‘tea’ (Benerjee, 1988), in fact many species are cultivated to produce ‘tea tree oils’ and some others like *Camellia japonica, Camellia sasanqua* etc. are grown as ornamental plants (Benerjee, 1992). A free grown tea tree can reach a height of 30-40 feet if left un-pruned (Carr and Stephens, 1992). However, for the ease of harvesting young shoots they are either pruned or skiffed time to time to maintain a bed of reachable height. From these beds freshly grown shoots (comprising two leaves and a bud) are hand plucked to prepare tea. Once harvested, these leaves (two and a bud) are brought back to factory where they are processed through various steps to prepare different forms of teas like '*green tea*', '*CTC* (cut, tear, curl) tea', '*black tea*', '*orthodox tea*' and etc. In India, geographical location of a plantation has been an important and determining factor for developing unique tea varieties. A bag of tea leaves coming from a particular place like *Darjeeling* will have a specific aroma and taste that is hard to reproduce in any other place in the world.

Tea is grown in an area with different types of porous, well-drained, acidic soils (pH 3.3 to 6.0). The optimum range of acidity for growth of tea is in between 5.0 – 5.6. Soil with pH 5.7 or above usually requires acidity fixing by adding aluminium sulphate, sulphate of ammonia, elemental sulphur etc (Sinha, 2010; Sengupta, 2007). Varieties of tea can thrive in diverse agro-ecological conditions experiencing a wide range of climatic parameters such as temperatures from −8°C to 35°C, annual rainfall from 938 mm to 8000 mm, radiation intensity from 0.3 to 0.8 cal/cm^2/min, and relative humidity from 30% to 90% (Sinha, 2010; Sengupta, 2007).

Historically, tea plants are native to East and South-East Asia and probably originated around the point of confluence of the lands of North-East India, north Burma (present Myanmar) and South-West China. Although there are tales of tea's first use as a beverage, no one is sure of its exact origins. The first recorded drinking of tea is in China, with the earliest records of tea consumption dating back to the 10^{th} century BC. The first authentic account of tea was documented in the book ‘Cha Ching’ (Tea Book) by Lo-Yu describing the preparation of a cup of tea from made tea and its manufacture (Weatherstone, 1992). Tea had also been known to Japanese as a beverage since 13^{th} century. However, paleographic record suggests that the Japanese tea dates back from early 9^{th} century (Okano, 1993). There are suggestive evidences of tea being consumed in different form viz. as drink, as vegetables, or even chewed by tribals and village folks of Bhutan, Nepal, North East India, Tibet, Myanmar, Laos, Vietnam, Thailand and Cambodia (Sinha, 2010). Trade of tea by the Chinese to western nations in the 19th century spread tea and the tea plant to numerous locations around the world (Sinha, 2010).

Today, around the world tea is cultivated in over 50 countries including China, India, Malaysia, Sri Lanka, Bangladesh, Taiwan, Iran, Malawi, Japan, Thailand, Kenya and Uganda etc. The national economy of many of these countries is largely dependent upon production and export of tea (Hazarika et al., 2009). As of 2014, China alone dominates the list by producing over 40% (2.1 million tonnes) of the total world tea production which is followed by India (24%) (1.2 million tonnes) and then Kenya (9%) (0.45 million tonnes) (FAO, 2017) (Figure 1.1 and 1.2). In recent decade tea production has gone manifold higher owing to advancement in cultivation techniques but mostly due to an increase in tea cultivating countries. Even more area is being included for tea cultivation. FAO statistics show a steep growth in the production of tea alongside more area being used to cultivate tea (Figure 1.3). China shows steady growth in production as well as more area being used for cultivation; however, India has not much accessed extra land for harvesting though an incline in the production is very much prominent (Figure 1.3) (FAO, 2017).

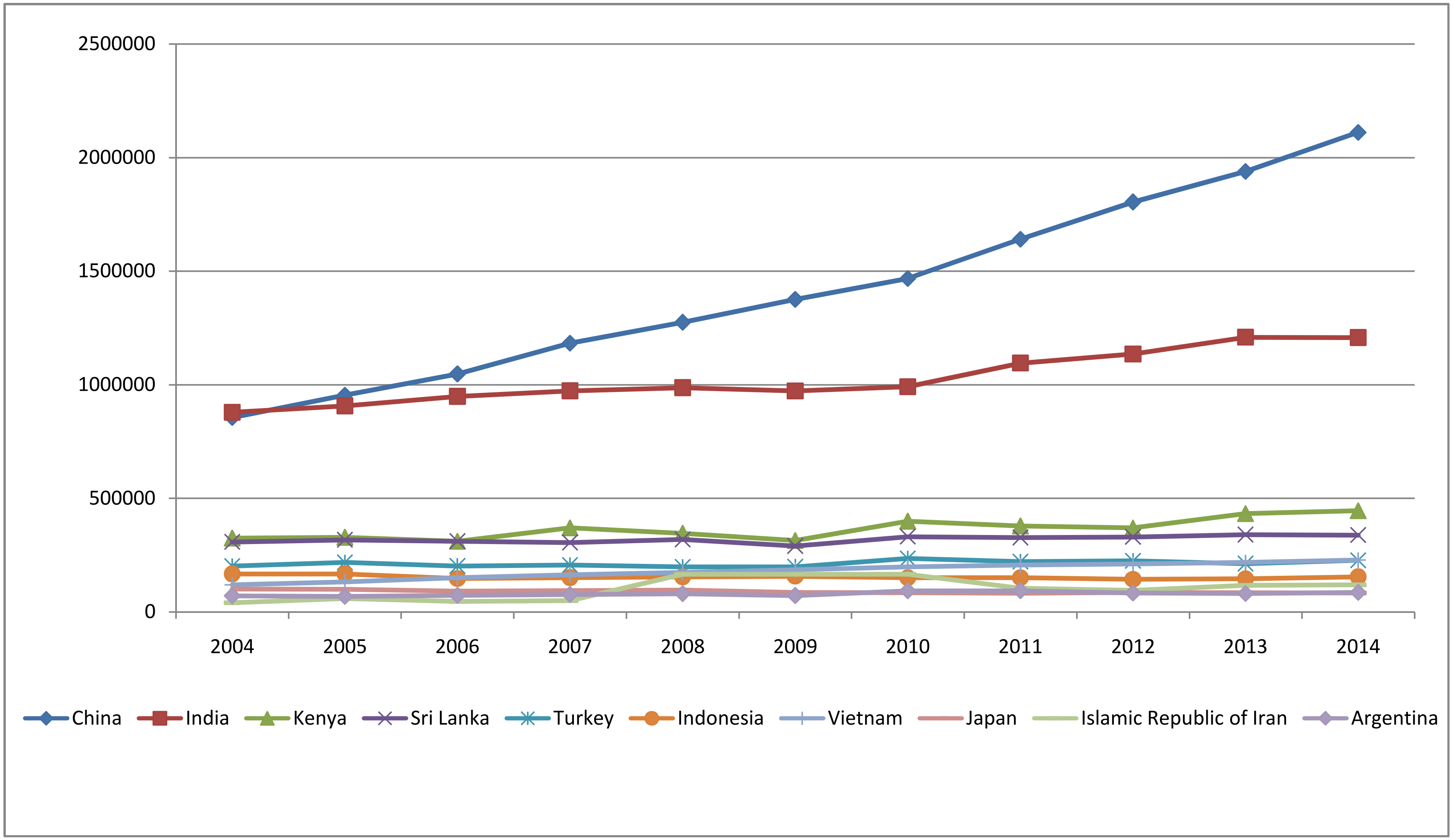

Figure 1.1: Graphical representation of total tea production from 2004 to 2014 by top ten tea producing countries of the world

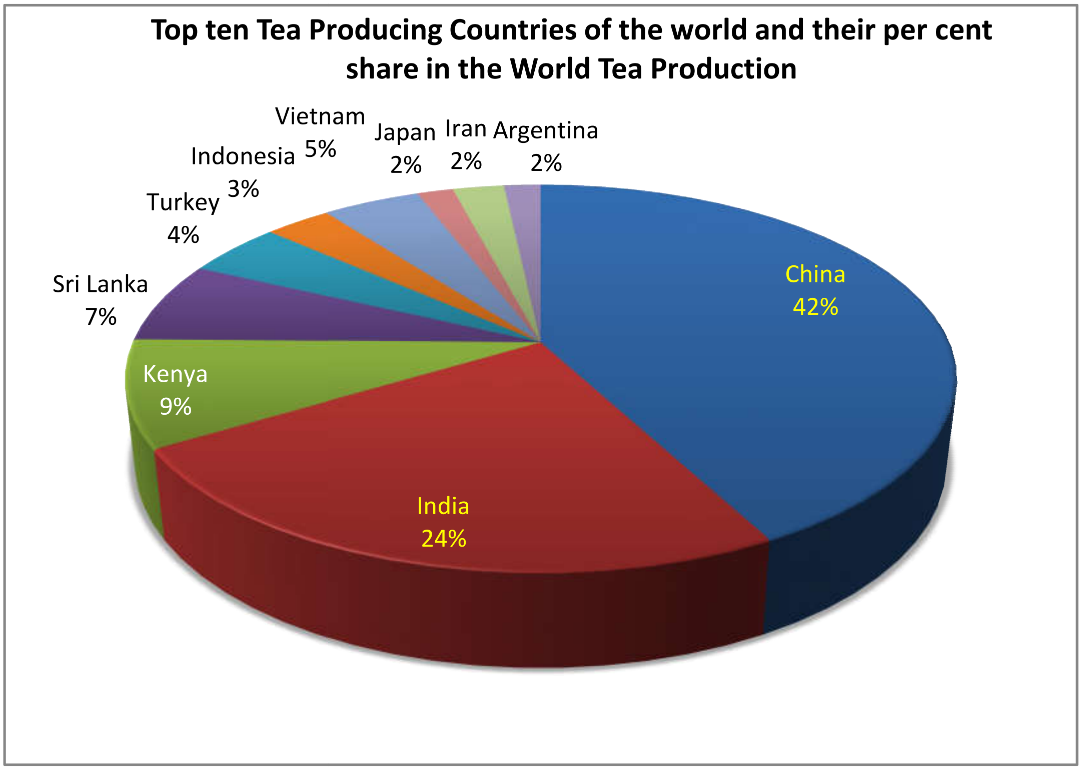

Figure 1.2: Pie diagram representing the percentile shares of top ten tea producing countries of the world (in tons) for the year 2014. China and India alone demands a lions' share of over 60% of total world tea production (data obtained from http://www.fao.org/faostat/en/#data/ QC' on 17/07/2017)

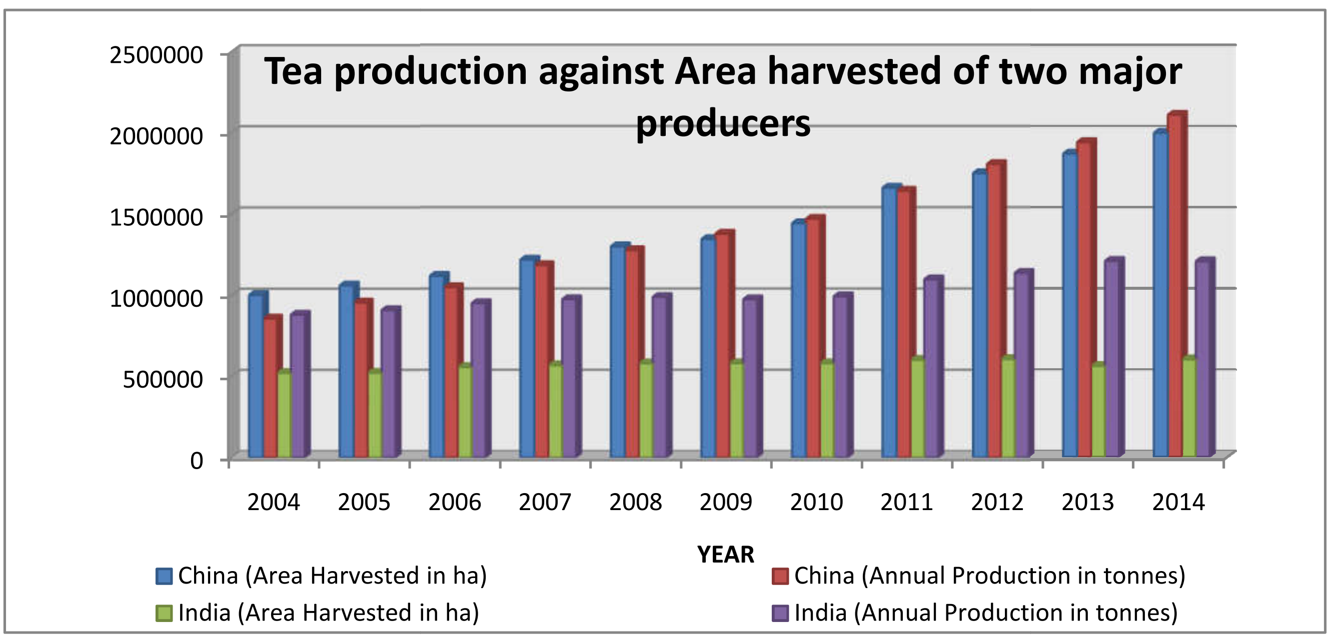

Figure 1.3: Comparative account of a trend in the increase of annual production of tea against harvesting area of two major producer of world. Till 2004 India was a leading producer, however, soon after China surpassed India in terms of production and became leading producer of made tea. (data obtained from http://www.fao.org/faostat/en/#data/ QC' on 17/07/2017)

In India, tea is cultivated at latitudes from 8° 12' N in Nagercoil in Tamil Nadu to 32° 13' N in Kangra in Himachal Pradesh and at altitudes ranging from near sea level in Assam to world record altitude of 2414 m (7920 ft) above mean sea level (msl) in Korakundha in the Nilgiris in south India. The Limca Book of Records for cultivating tea at the highest altitude was again reset by planting tea at the altitude of 2456.7 m (8060 ft) (Sundar, 2017a). In North East India, tea is planted in the Brahmaputra and Barak Valleys of Assam, plains of the Dooars and Terai and Darjeeling hills in northern part of West Bengal. In Brahmaputra Valley, it is planted in plain lands at elevations ranging from 50 to 120 m above msl (Hazarika and Muraleedharan, 2011). As mentioned, India produces about seven varieties of tea, out of which three specialty teas namely Darjeeling, Assam and Nilgiris, garner prime value. India is the second largest tea producers in the world (Figure 1.2). In total tea is grown in 13 states (Figure 1.4) among which Assam, West Bengal, Tamil Nadu and Kerala are the largest producers (Table 1.1). While CTC accounts for around 89 per cent of the production, orthodox/green and instant tea account for the remaining 11 per cent. There is a steady increase in the production over the years, which is due to extensive cultivation, improved technology, nutrition and fertility management (Saraswathy et al., 2007). As of December, 2013, India had around 563.98 thousand hectares of area under tea cultivation (Table 1.1) out of which Assam with 304.40 thousand hectares share the largest portion subsequently followed by West Bengal (140.44 thousand hectares), Tamil Nadu (69.62 thousand hectares) and Kerala (35.01 thousand hectares).

Country-wide 966 million kg of tea was produced in 2010, of which 76 percent was produced in the North-Eastern states alone. About 203.86 million kg tea is exported from India which brings about US $ 413 million as foreign exchange for the country per annum

(Hazarika, 2011). According to an article by Sundar (2017b) published in The Hindu BusinessLine, India has produced a record 1.233 mn tonnes of tea in the financial year of 2015-16. India is ranked fourth in terms of tea exports which reached 0.233 million tonnes (232.92 million kg) during the financial year 2015-16 and were valued at Rs 4,493 crore (US$ 686.67 million) (IBEF, 2017; Sundar, 2017b). Interestingly India is also the world's largest consumer of black tea with the domestic market. Being the largest consumer, it consumed 0.837 million tonnes of black tea in 2010 and almost over 1 million tonnes of tea during 2013-14.

The top export markets in volume terms for 2015-16 were Russian Federation (48.23 thousand tonnes), Iran (22.13 thousand tonnes) and Pakistan (19.37 thousand tonnes). In terms of value, the top export markets were Russian Federation (₹651.21 crore ≈ US$ 102.48 million), Iran (₹555.32 crore ≈ US$ 87.39 million) and UK (₹399.06 crore ≈ US$ 62.8 million). All varieties of tea are produced by India. As per records Indian tea industry is the second largest employer among organized sector after Indian Railway. It employs over 3.5 million people across some 1700 estates and 157000 small holdings, where majority of labourers are women (IBEF, 2017).

1.2. TEA PESTS AND THEIR VARIABILITY

Tea is grown as a perennial monoculture crop hence attracts a large array of arthropod pests leading to a substantial crop loss. According to Hazarika et al. (2009), globally there are 1031 arthropod species associated with tea, out of which 300 species of insect pests are recorded from India and specifically 167 species from North-East India (Das, 1965).

Table 1.1: Region wise tea cultivation area and production of tea in India

State / Districts	**Area under tea (in Thousand Hectares)**	**Production (Million kg)**
Assam Valley	270.92	581.03
Cachar	33.48	48.02
Darjeeling	17.82	8.91
Dooars	72.92	177.85
Terai	49.70	125.34
Other North Indian States (Includes Himachal Pradesh, Uttarakhand, Bihar, Sikkim, Arunachal Pradesh, Manipur, Nagaland, Tripura, Meghalaya, Mizoram and Orissa)	12.29	23.92
Tamil Nadu	69.62	174.71
Kerala	35.01	63.48
Karnataka	2.22	5.52
TOTAL=	**563.98**	**1208.78**

(Source: IBEF, 2017. Tea statistics. *https://www.teacoffeespiceofindia.com/tea/tea-statistics*)

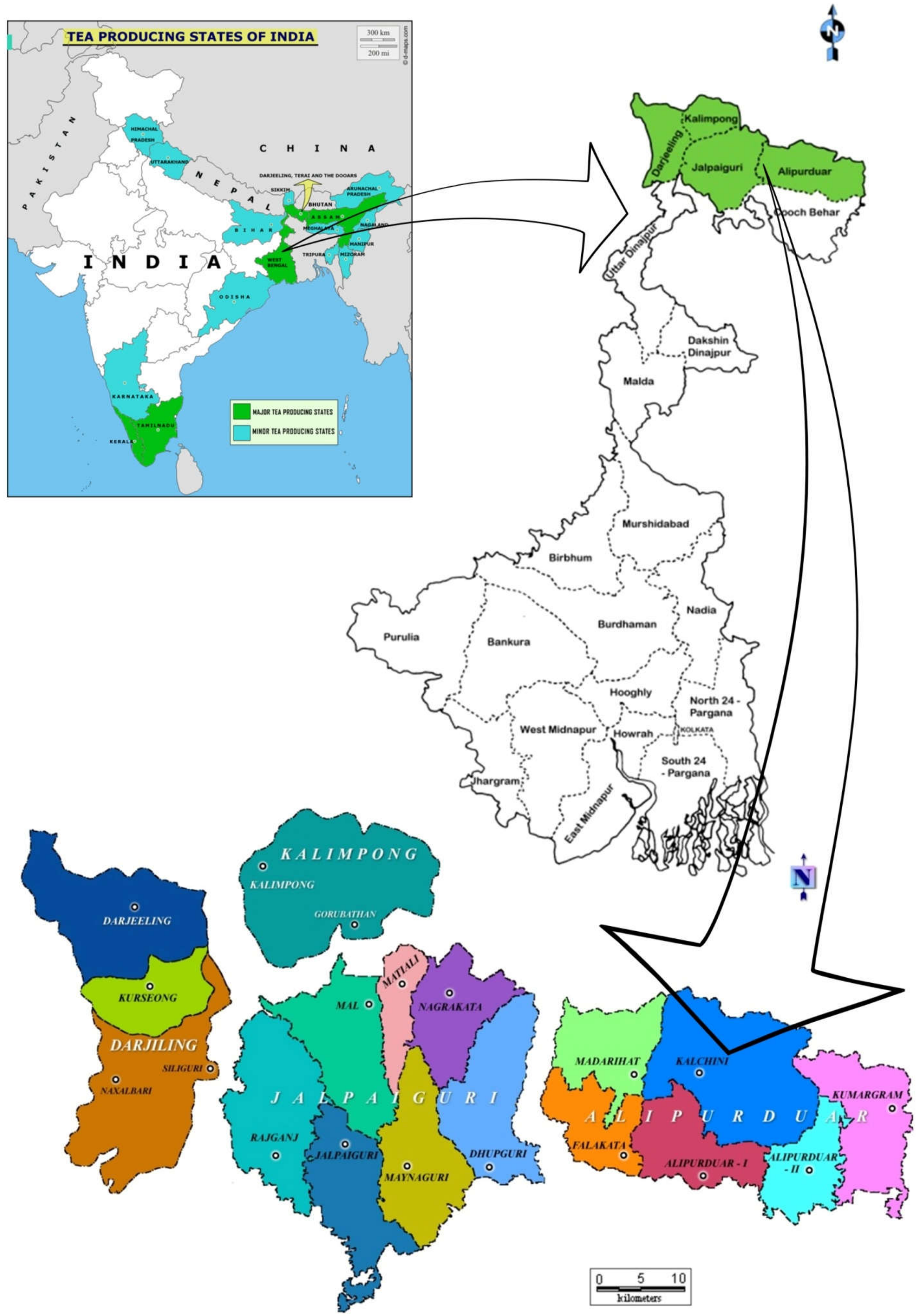

Figure 1.4: Tea growing areas of North Bengal region highlighting the major study area (Terai, Darjeeling and the Dooars).

Among these, insect and mite pests are the most damaging, causing on an average 5% - 55% yield loss (Muraleedharan, 1992; Rattan, 1992; Sivapalan, 1999). This loss reaches an approximate of U.S. $500 million to $1 billion (Agnihotrudu, 1999). In some cases yield loss can be 100% (Muraleedharan and Chen, 1997). As mentioned above there are 167 arthropod pests from North East alone which affect tea production, however, all of them do not inflict serious damage to the crop. There are insects which stand out as major pests owing to their sever attack on crop and rest remains occasional or minor visitor. The major insect and mite pests of tea that cause damage to tea industry are red spider mites (*Oligonychus coffae*), looper pests (*Hyposidra talaca, H. infixaria*), termites (*Odontotermes obesus, Microtermes obesi*), cockchafer grubs (*Holotrichia* sp.), black hairy caterpillar (*Arctornis submarginata*), Darjeeling hairy caterpillar (*Euproctis latifacia*), bunch caterpillar (*Andraca bipunctata*), leaf roller (*Caloptela theivora*), shot-hole borer beetle, (*Xyleborus fornicatus*) *etc*. (Figure 1.5) (Mukhopadhyay et al., 2015). Some of these can cause havoc if not checked on time with proper control measures. Pests like *Helopeltis theivora* has been recorded to cause crop loss of 11-100% (Muraleedharan, 1992). In Malawi, thrips, termites, carpenter moth and mosquito bug are the most important tea pests (Peregrine, 1991). Problems with scale insects, aphids, jelly grub, beetles and red spider mite were also reported but were considered as minor pests. In Zimbabwe termites are the major pest causing considerable damage. In Sri Lanka adult female shot-hole borer beetle, *Xyleborus fornicatus*, make galleries into tea stems. Attack by this beetle results in damage to the frame of the tea bush, a loss in yield of the valuable leaf and also makes the bushes vulnerable to attack by other pests, such as termites (Danthanarayana, 1968). Back in India, termite problem is well known from upper Assam

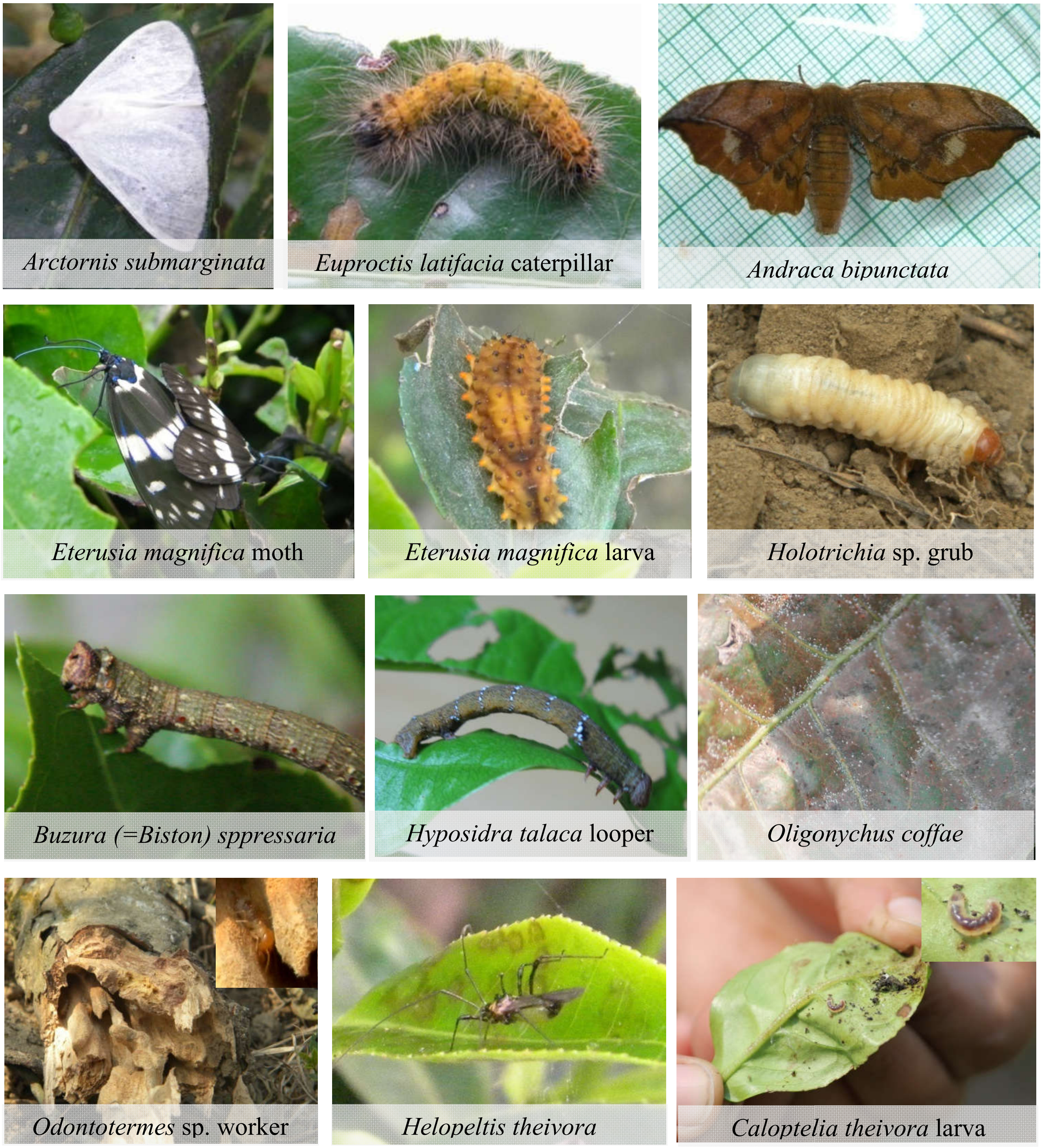

Figure 1.5: Some of the serious pests of tea

and Barack valley tea plantations. Nevertheless termite populations also cause serious damage in parts of Terai-Dooars plantations.

Pests which attack the shoot system of tea bush deserve more attention because of their perceptible and permanent damage symptoms. Therefore acting against them with appropriate control measures is imperative. There are pests like termites or cockchafer grubs who often surreptitiously attack tea plants underground without facing any trouble from planters. As for example termite, a subterranean pest, hollows the plant by devouring pith from inside leaving minimum vigor left for the plant to sustain with some green leaves on surface. By the time a planter realizes termites' existence in tea garden, the damage is already beyond recovery. Mere killing few of these surreptitious pests doesn't recover the plant to its actual production potential as the entire colony of thousands of insects remains hidden underground. Therefore, damage potential of these tiny little creatures is difficult to quantify exactly until the plant starts showing the symptoms of dying above ground.

These pest problems originating whether from surface or subterranean have been a major challenge to planters. Controlling pest problem requires a systematic and holistic approach. There are kaleidoscopic measures for controlling pests, but, none can offer a complete control against a pest. Therefore, often amalgamation of different approaches to control pests is a common practice amongst planters.

1.3. PEST MANAGEMENT PRACTICES AND EFFECTIVENESS

1.3.1. Cultural Practices:

Cultural pest control practices are the oldest methods that have been used to manage pest populations. Cultural control measures include monitoring the population dynamics of pests by regular field assessment, shade/weed tree/plant management and removal of alternate host plants (*Bidens* sp., *Ageratum* sp., *Conyza* sp., *Crassocephalum* sp., etc.) (UPASI TRF, 2017). These practices are primarily preventative in nature rather than curative, therefore, are dependent on long-range planning. Also, because they are dependent on detailed knowledge of the bio-ecology of the pests and their relationships with the natural-environment, which were poorly understood in the past, the results were much varying, and often difficult to evaluate effectiveness of the control practice. With the recent developments of synthetic pesticides these control practices have been considered obsolete consequentially largely discontinuing the research and development programs in these practices. It is understandable that most farmers eventually got attracted to the more reliable and less knowledge and skill-dependent toxic chemical application for dealing with pest problems.

Manual Practice is another form of the Cultural Practice which includes mainly maintenance, preventive measures and curative measures performed by humans with simple tools rather than using heavy machinery. In tea plantation, manual pest control is not just limited to killing of pests but also includes timely pruning and skiffing of plants, mulching, spraying fertilizers and pesticides, locating infested sections and so on. For example, monitoring the infestation level of pests in field, plucking damaged leaves, weed control and removal of shoots containing eggs of insect pests like tea mosquito bugs are some important manual control methods. Manual practice is an add-on practice, which alone cannot control the pest insurgence. It can only provide an additional support system to pest control strategy.

1.3.2. Modern Practices (Chemical Approach):

To defend the tea crop against pest attack, in recent time large quantities of chemical agents are being used. Organosynthetic pesticides are commonly used for controlling recurrent pest problem. This application is a burden to planters as well as to environment and can result in a resurgence of primary pests (Sivapalan, 1999) or mite syndrome (Cranham, 1966), secondary pest outbreak such as the *Totrix* outbreak (Cranham, 1966), resistance development (Kawai, 1997; Sivapalan, 1999), and environmental contamination, including undesirable residues on made tea (Choudhury, 1999; Sivapalan, 1999). During the last several decades, the control of pests, diseases and weeds in tea fields is predominantly by the use of synthetic chemicals. Pesticides have evolved tremendously from mere sulfur fumigants to the recent most advanced broad spectrum toxicants. In fact post world war II (WWII) chemical pesticides have largely took over natural products to control various pest problems (Table 1.2). Though broad-spectrum pesticides offer powerful incentives in the form of excellent control, increased yield and high economic returns, they have serious drawbacks such as development of resistance to pesticides, resurgence of pests, outbreak of secondary pests, harmful effects on human health and environment and presence of undesirable residue (Das, 1959; Gurusubramanian et al., 2005; Sarnaik et al., 2006).

Bunch caterpillar, red slug and looper caterpillars are controlled by spraying profenophos/phosalone/quinalphos at 1:400/neem formulations 5% at 1:1500 /diflubenzuron at 1:1000 in early instars, however, in late instars, deltamethrin at 1:2000 is used. Lower part of the shade tree trunk is treated with insecticides in case of red slug infestation. Organophosphates (profenophos and quinalphos) are highly effective

Table 1.2: Historical evolution of pesticide

1000 BC	Chinese used sulfur as a fumigant
1800s	Europeans used sulfur as a fungicide to control powdery mildew on fruit
16th century	Japanese mixed poor quality whale oil with vinegar to spray on rice paddies to prevent development of insect larvae by weakening their cuticle
17th century	Water extracts of tobacco leaves were sprayed on plants to kill insect *Nux vomica*; the seed of *Strychnos nux-vomica* (strychnine) was used to kill rodents
19th century	Insecticides isolated from plants included rotenone from the root of *Derris elliptica* and pyrethrum extracted from flowers of chrysanthemums Arsenic trioxide was used as a weed killer, especially dandelions. Copper arsenite (Paris Green) was used for control of Colorado beetle Bordeaux mixture (copper sulfate, lime and water) was used to combat vine downy mildew
20th century	Sulfuric acid (10%) was used to destroy dicotyledonous weeds without harming monocotyledonous cereal grains and other cultivated plants with waxy coat on leaves
1920s	Public concerns because some treated fruits and vegetables were found to contain pesticide residues
Post WWII	Pesticide development and use increased dramatically in agriculture and public health sectors. Widespread use of pesticides for insect control to prevent transmission of diseases such as typhus, malaria, and use in controlling pests of different crops

against the early larval stages of tea looper in terms of time mortality, reduction in food consumption and nutritional indices, leaf area protection and preference index than synthetic pyrethroids, organochlorine and neonicotinoids (Bora et al., 2007a).

Report suggests that some of the second and third generation pesticides have now become less effective against the defoliators in recent time (Sannigrahi and Talukdar, 2003). Among the tea growing area of North East India, pest attack activities has always been reported higher in North Bengal region (Barbora and Biswas, 1996; Sannigrahi and Talukdar, 2003). In recent times studies have shown gradual increase in pesticide use in this region. The consumption pattern of insecticides gives an indication that the insect pests are more dominant and problematic in North Bengal region. The preference of synthetic pyrethroids has probably increased because the conventional non-pyrethroid insecticides have become less effective against the target pests (Roy et al., 2008). The consumption of pesticide in India is one of the lowest in the world. India uses a low amount of 0.5 kg ha^{-1} pesticide compared to 7.0 kg ha^{-1} in USA, 2.5 kg ha^{-1} in Europe, 12 kg ha^{-1} in Japan and 6.6 kg ha^{-1} in Korea (Anonymous, 2003). The average use pattern of chemical pesticides in tea was estimated to be 11.5 kg ha^{-1} in the Assam valley and Cachar, 16.75 kg ha^{-1} in Dooars and Terai and 7.35 kg ha^{-1} in Darjeeling (Barbora and Biswas, 1996). Within the synthetic insecticides, organophosphate compounds (64% - 5 rounds per year) were most preferred followed by organochlorine (26% - 2 rounds per year) and synthetic pyrethroids (9% - 7 rounds per year) (Sannigrahi and Talukdar, 2003).

Environmental hazards, pest resurgence, variation in susceptibility, residue problems in made tea, impedance for natural regulatory agents and lethal and sub-lethal effects on non-target organisms, including humans are evident in India due to excelled use of pesticides (Gurusubramanian et al., 2005; Borthakur et al., 2005; Bora et al., 2007a,b). These side effects have raised public concern about the routine use and safety of pesticides. In the recent years, it has become a major concern to the tea industry as the importing countries are imposing stringent restrictions for acceptability of the made tea due to pesticide residues. Changes in pest management measures are resulting from- a) Environmental and human safety concerns, b) susceptibility change in insect pests and c) increased cost of pesticides (Rahman et al., 2005).

1.4. TERMITE: AN INHERITANT PEST OF PLANTATION

Termites are eusocial insects and belong along with cockroach to order Blattodea and infra-order Isoptera. Even few years back Isoptera was considered as order, however, based on recent molecular phylogenetic studies termites have been found to be closely related to wood feeding cockroaches and suppose to have diverged from their common ancestor about 170 million years ago (Bourguignon et al., 2015). Due to this reason termites have now been placed along with wood feeding roach, *Cryptocercus* under order Blattodea (Inward et al., 2007). About 2933 species of living and 173 species of fossil termites are recorded so far from all over the world, of which 269 species belong to Indian subcontinent (Kishna et al., 2013; Bignell et al., 2011). Termites play an important role in the cycling of carbon and trace elements in the biosphere through their degradation of wood, grasses and humus. They mostly depend upon cellulose base as their food due to which they are considered as primary pest of many crops and are marked as a serious pest of structural timber and buildings (Su and Scheffrahn, 2000). Most of these cause extensive damage amounting to several billion dollars per year worldwide (Kapur and Bose, 1972; Su and Scheffrahn, 1990, 2000; Flores, 2010). In April of 2011 wood-eating termites were blamed for reportedly consuming more than $220,000 worth of Indian rupee notes (Sacks, 2011).

In spite of the fact all termites are not pests. Of nearly 3000 living species, only 371 (12.4%) have been reported in the literature as destructive, and only 104 (3.5%) are considered serious threats (Krishna et al., 2013). In North America, nine subterranean species are pests; in Australia, 16 species have an economic impact; in the Indian subcontinent 26 species are considered as pests, and in tropical Africa, 24. In Central America and the West Indies 17 pest species of termites have been reported (Su and Scheffrahn, 2000). Among the termite genera, *Coptotermes* with 28 species has the highest number of pest (Su and Scheffrahn, 2000).

In these almost 200 years of tea production, as like any other tea pests, termite fauna has also adapted as per the conventional management practices of tea plantations. As the findings states that two species of termites are more prevalent in tea plantation then rest of the species (Singha et al., 2012, 2014). May be due to selection pressure of synthetic chemicals has facilitated these two species' adaptability to become dominant pest species. There have been many attempts of biological control measures being developed against termite pests (Verma et al., 2009; Singha et al., 2012, 2014; Debnath et al., 2012) however, they seem undeterred. As Chouvenc et al. (2011) claimed that in last 50 odd years despite boom in biological control research against termites, they have failed miserably and still have not been able to provide any substantial control strategy. This may be due to termites' multifaceted defense system that these biological control systems have failed to penetrate. May be in future one can come up with the efficient biological control agent against a termite pest, but for now despite of thousands of claim we still have to resort to chemical control system.

Kapur (1958) and Das (1962) reported wood-eating termite as a serious menace to tea industries causing an estimated loss of at least 15 per cent of the tea crop in North-Eastern India. According to Sands (1977) crop losses in agricultural fields could go up to 50% or more over a period of 10 years of infestation by termites. There are reports of widespread termite damage to tea bushes in most of the tea gardens in Darrang and Cachar where 50 to 100 percent bushes get affected, especially on the poorly shaded hot slopes of Cachar tillahs (Das, 1962; Das et al., 1982; Choudhury, 1999; Singha et al., 2012, 2014). The species *Odontotermes obesus* (*=assamensis*) Holmgren, *O. parvidens* Holmgren and Holmgren and some others of the genera *Coptotermes* and *Microcerotermes* are so far reported from tea gardens in India (Das, 1965). In Ceylon, five species, *Postelectrotermes militaris* (Desneux), *Neotermes greeni* (Bugnion and Popoff), *Coptotermes ceylonicus* Holmgren, *Odontotermes horni* (Wasmann) and *Odontotermes redmanni* (Wasmann) are reported to infest tea plantation (Das, 1965). It is possible that some more wood termites will be found to be associated with tea if a proper survey is undertaken. In recent time not much information on termite diversity is available from North East India including Terai and the Dooars regions of Darjeeling foothills.

1.5. ABOUT THE CONTEMPLATED WORK

The present research study is undertaken to determine the diversity of termite species associated with the tea plantation of Darjeeling Terai and the Dooars plantation and relationship among these species both at morphological and molecular levels. Further, studies were conducted on bio-ecology of some of these termite pests, especially with their tolerance status to commonly used pesticides. The knowledge generated through this study is expected to be useful for mapping distribution of tea termites for the first time from tea plantations of Darjeeling Terai. The study will also provide with handy information on termite pest status from the area. Findings of termite pest species response against pesticides can help to undertake “resistance management program”, and the basis for developing effective control measures against these surreptitious subterranean pests of tea.