SPECIES DIVERSITY, INFESTATION INTENSITY AND MANAGEMENT OF MANGO FRUIT WEEVIL IN THE HILLY AREAS OF BANGLADESH

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CERTIFICATE

This is to certify that thesis entitled, "**SPECIES DIVERSITY, INFESTATION INTENSITY AND MANAGEMENT OF MANGO FRUIT WEEVIL IN THE HILLY AREAS OF BANGLADESH**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **ENTOMOLOGY**, embodies the result of a piece of bona fide research work carried out by **Md. Abdullah Al Mumin**, **Registration No. 10-03776** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated: December, 2016
Dhaka, Bangladesh

Prof. Dr. Md. Abdul Latif
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Dedicated

To My

Beloved Parents

.

LIST OF ACRONYMS

AEZ	:	Agro-Ecological Zone
BARI	:	Bangladesh Agricultural Research Institute
BBS	:	Bangladesh Bureau of Statistics
Cm	:	Centimeter
CV%	:	Percentage of Coefficient of Variation
EC	:	Emulsifiable Concentrate
et al.	:	And others
Etc	:	Etcetera
G	:	Gram
H	:	Hour
Ha	:	Hectare
IPM	:	Integrated Pest Management
j.	:	Journal
kcal	:	Kilocalorie
Kg	:	Kilogram
L	:	Liter
M	:	Meter
ml	:	Milliliter
mm	:	Millimeter
MP	:	Muriate of Potash
no.	:	Number
RCBD	:	Randomized Complete Block Design
SP	:	Soluble Powder
T	:	Ton
TSP	:	Triple Super Phosphate
Vit-C	:	Vitamin-C
%	:	Percent
^{0}C	:	Degree Celsius
a.i	:	Active Ingredient
@	:	At the rate of

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ABSTRACT

The present study was conducted at the farmer's orchard in Bandarban, Rangamati and Khagrachari districts, during the period from January to July, 2017 to study the species diversity, infestation intensity and management of mango fruit weevil. The treatments of the experiment were T_1 = Improved pest management practices (5 times spraying of Ripcord 10EC @ 1.0 ml/Liter water on 30 January, 28 February, 30 March, 28 April, 30 May along with cultural practices), T_2 = Farmer's practice (2 times spraying of Ripcord 10EC @ 1.0 ml/L water from January to May) and T_3 = Untreated control. The experiment was laid out in a Randomized Complete Block Design (RCBD) with ten replications. Among weevil species only *Sternochetus frigidus* was found at three hill districts. The lowest number of fruit infestation (19.62% at Bandarban, 19.73% at Rangamati and 19.22% at Khagrachari districts) was recorded from improved management practice of the plant. On the other hand the highest number of fruit infestation (81.46% at Bandarban, 80.40% at Rangamati and 80.19% at Khagrachari districts) was recorded from untreated control. Improved management practice decreased more than 70.00% infested fruits over control (75.91% at Bandarban, 75.44% at Rangamati and 76.02% at Khagrachari districts). Among three treatments improve management practice was the most effective against mango fruit weevil.

CHAPTER I

INTRODUCTION

Mango (*Mangifera indica* Linn.) is the most popular fruit in the oriental region. It has great economic importance in the tropical and subtropical region (Atwal and Dhaliwal 2007). It is regarded as the King of the fruits of the world (Mollah and Siddique 1973). It is considered to be the choicest of all indigenous fruit and one of the important fruits in Bangladesh. In area, production, nutritive value and popularity of appeal, no other fruit can compete with it. Mango is now the most important fruit item by tonnage production and widely cultivated in all the districts of Bangladesh. Mango contributes 0.945 million MT from local production. The fruit has really of immense value in respect of money and prosperity. Bangladesh is one of the major mango producing countries along with India, Pakistan, Mexico, Brazil, the Philippines, etc. (Alexander 1989). In Bangladesh, mango occupies about an area of 61,997 ha with a production of 1018112 metric tons during 2014-15 (BBS 2015).

In nutritional aspects, both ripe and unripe mango is rich in several vitamins as well as minerals (Paramanik 1995). Besides, mango contains appreciable quantity of iron, vit-C, carotene and soluble sugar. Moreover, it provides a lot of energy (as much as 74 kcal/100g edible portion) which is nearly equals the energy values of boiled rice of similar quantity by weight (Hossain 1989). The mango is generally consumed as a fresh fruit but is also processed into various products such as jam, squash, mango juice, chutney, and pickle (achar) (Anon 2006, Morton 1987). In addition to the nutritive value, the seed kernel is used as feed for poultry and cattle, the wood for rafters and joists, window frames, shoe hills and crates, the bark for tannin extraction, the gum as a substitute for gum Arabica where it is employed as an adhesive, surfactant and emulsifier in food, chemical and textile industries. The dried flowers serve as astringents for diarrhoea, chronic dysentery, catarrhal of the bladder and chronic urethritis (Kiarie 1986).

Over 175 species of insects have been reported damaging mango trees (Fletcher 1970; Nayar *et al.*1976). Out of these the *Sternochetus frigidus* (Fabr.) is one of the serious and specific pest of mango. *Sternochetus frigidus* is spread mainly by infested fruits because the weevil develops within the mango pulp (Griesbach 2003). Lefroy (1906) was the first to report *Sternochetus frigidus* as a pest of mango in Bangladesh and at present the pest is quite serious in south eastern part of Bangladesh. The mango fruit weevil is considered a major pest as it causes significant damage to the mango fruit contaminating the edible portion.

However, profitable mango production is hampered by several challenges, including inappropriate agronomic practices, lack of adequate true-to-type planting materials, inappropriate pest and disease management technologies, poor extension support systems, poor post-harvest handling technologies and poor marketing infrastructure as well as lack of appropriate credit support facilities (Braimah *et al*. 2010). Currently, the key problem is in the area of insect pest management. Notable among these insect pests are mango hoppers, fruit flies, fruit weevil, mealybugs, thrips etc.

Proper management of the mango fruit weevil is a prerequisite to meet the quality demanded in the competitive export market (Braimah *et al.* 2010). The use of synthetic insecticides to manage insect pests has arguably been the mainstay of fruit crop production. However, the increasing demand for organically grown foods in the face of environmental and health concerns has downplayed reliance on synthetic pesticides to manage pests and the identification of eco-friendly and reliable alternatives would be an incentive to minimize reliance on synthetic insecticide use. Effective management of mango weevil using indigenous technical knowledge at the farm level will serve as an incentive to increase mango production for the local market and export (World Bank 2011).

A fragmentary work has been done on biology and control of this pest by different workers like Subramanyam (1925), Balock and Kozuma (1964), Seshagiri *et al*. (1971) in different parts of the world but in Bangladesh research work on mango fruit weevil is scanty. Thus, the research work on Pest Management Analysis of mango fruit weevil in hilly areas of Bangladesh is required to be under taken aiming to identify pests concern for the mango cultivation and evaluate their risk as well as to identify suitable management options.

Specific Objectives of the Study

- To study the species diversity of mango fruit weevil in Bandarban, Rangamati and Khagrachari districts.
- To determine the infestation intensity by mango fruit weevil at hilly areas in Bangladesh
- To evaluate the performance of management approaches against mango fruit weevil in farmers field.

CHAPTER II
REVIEW OF LITERATURE

2.1 Origin and distribution of mango

The centre of origin and diversity of the genus *Mangifera* is regarded as Southeast Asia but the origin of the mango *Mangifera indica* L. has been a matter of speculation for years (Douthett 2000). Available records, however, indicate that *M. indica* is probably native to Southern Asia, especially eastern India, Burma and the Andaman Islands (Anon. 2007, Anon. 2006, Douthett 2000, Mukherjee 1997, Morton 1987).

Cultivation of mangoes in the Indian sub-continent has been ongoing for over 4000 years and the fruit has been a favourite of kings and commoners because of its nutritive value, taste, attractive fragrance and health promoting qualities (Anon. 2007). Organized cultivation of mangoes in India is associated with the Mughal Emperor Akbar (1556-1605) who planted about 100,000 mango trees in an orchard near Darbhanga in Lakh Bagh, India (Anon. 2007, Snyman 1998, Mukherjee 1997).

The distribution and spread of mangoes to other parts of the world occurred at different times through the agency of travelers and traders (Mukherjee 1997). Hwen Sang a Chinese traveler, visited India between 632 and 645 AD and was the first person to take mango to the outside world (Anon. 2007). Previously, Buddhist monks are believed to have taken the mango on Voyages to Malaya and eastern Asia in the 4^{th} and 5^{th} centuries B.C (Morton 1987). Introduction of the mango to East Africa is believed to have been done by the Persians about the 10^{th} century A.D. It is recorded to have been grown in Eastern Somalia by AD 1331 (Anon. 2007, de Villiers 1998, Snyman 1998, Morton 1987). Later on, the mango spread to the rest of the world such as Philippines (1600), Mexico (1778), Hawaii (1809), Florida (1861), West Africa (1864) and California (1880) (Anon. 2007, Anon. 2006, Rey *et al.* 2006, Griesbach 2003, Snyman 1998, Morton 1987, Kiarie 1986).

2.2 Pests of mangoes

The mango, like all cultivated crops is attacked by some very key pests, others secondary and a large number of occasional pests in localized areas where the crop grows (Pena and Mohyuddin 1997). Worldwide, the mango is a host to 260 species of insects and mites among which 87 are fruit feeders, 127 foliage feeders, 36 inflorescence feeders, 33 bud feeders and 25 branch and trunk feeders (Toledo *et al*. 2006, Joubert 1998, de Villiers and Steyn 1998, Pena and Mohyuddin 1997, Morton 1987). In the different parts of the world where mango is cultivated, the spectrum of pests has been identified and listed. Some of these lists contain both the life histories and control measures for the different pests (Pena and Mohyuddin 1997).

In India, South Africa and Hawaii, the Mango seed weevil *Sternochetus Cryptorhynchus*) *mangiferae* (Fabricius) and the Pulp weevil *Sternochetus frigidus* (Fabricius) are both major Coleopteran pests while the fruit flies *Bactrocera ferrugineus* (Fabricius) and *Dacus zonatus* (Saunders) are both major Dipteran pests (Toledo *et al*. 2006, Morton 1987). In Bangladesh, major mango pests include the Mango hoppers *Idioscopus atkinsoni* (Lethierry), *Idioscopus clypealis* (Lethierry) and *Idioscopus niveosparsus* (Lethierry), (Cicadellidae: Homoptera); the Mango fruit weevils, *Sternochetus frigidus (*Fabricius), *Sternochetus gravis* (Fabricius) and *Sternochetus mangiferae* (Fabricius) (Curculionidae: Coleoptera) and then mango fruit fly *Bactrocera dorsalis* (Tephritidae: Diptera).

Both the Dipteran and Coleopteran pests attack the fruits while the homopterans infest the foliage (Anon. 2006). In Queensland, Australia, the fruit fly *Bactrocera tryoni* (Froggatt) and the mango seed weevil *Sternochetus mangiferae*are major pests, the latter being widespread in all mango growing areas of the country (Peng and Christian 2007, Morton 1987). In Kenya, the recorded key pests are mango seed weevil, *S. mangiferae* and the fruit flies *Ceratitis corsyra* (Walker), *Ceratitis capitata* (Wieldemann) and *Ceratitis rosa* (Karsch) (Toledo *et al*. 2006, Griesbach 2003, Morton 1987, Hill 1975). In the rest of the mango growing areas including South America, the Carribean, Florida (USA), the Philippines, Indonesia etc all have their share of key, minor and occasional pests across many insect taxa (Pena *et al.* 1998; Pena and Mohyuddin 1997, Hill 1975).

2.3 Diversity of mango fruit weevil

Occurrence of mango fruit weevil species at Bandarban, Rangamati and Khagrachari districts have been shown in Figure 1. The graph expresses that 100% weevil population were *S. frigidus* at the three hill districts, which attack mango pulp. No seed weevils, *S. mangiferae* was found in this region. This result agrees with the reports of Alam (1962) who reported that of *S. frigidus* was a major pests of mango in eastern side of the Jamuna river in Bangladesh. EPPO (2014) also reported the widespread distribution *S. frigidus* attacking the flesh of mango in Bangladesh. However, *S. mangiferae* was also reported in Bangladesh, India, Mayanmar, Srilanka, Nepal and some other Asian countries with no detail information. (CABI 2015).

2.4 Nomenclature of mango fruit weevil

Kingdom: Animalia

Phylum: Arthropoda

Class: Insecta

Order: Coleoptera

Family: Curculionidae

Genus: *Sternochetus*

Species: *Sternochetus frigidus* (Fabricius)

Sternochetus mangiferae (Fabricius)

2.5 Morphological characteristics of the weevil species

Mango weevils are identified based on their morphological characteristics such as elytra, strial punctures, shape of whitish macula, pronotum, aedeagus and also adult size. Their behavior also illustrates the species. Both mango weevils (MPW and MSW) look similar to each other but the MPW infests mango flesh or pulp and the MSW eats the seeds (Anon. 2015). Morphologically, MPW is a small stout hardened weevil. The antennae, sternum and tarsi in both male and female are morphologically identical. However, sexual difference can be seen at the tergite. Females have seven visible tergites and the last tergite is more strongly sclerotized. However, males have 8 tergites and the 7^{th} and 8^{th}tergites are separated from each other. Tergite 8^{th} is smaller than tergite 7^{th}. Anon. (2015) reported that there are several differences between *S. frigidus* and *S. mangiferae.* The size of *S. frigidus* is 3.8 to 5.9 mm smaller than *S. mangiferae* 7.5 mm to 10.0 mm.

The elytra of *S. frigidus* is narrowing starting from its base to the apex while the odd inter striae except sutural one distinctly costate-tuberculate. The adults have round strial punctures. Whitish macula is fragmented but usually forming a vague anterior inverted triangle inscribing a similar. This insect have smaller black median triangle and a broken posterior band on declivity while the pronotum has erect black scales arranged in medial pair of loose clusters. Male of *S. frigidus* has aedeagus with pair of internal sclerites overlapping apically.

In *S. mangiferae,* the sides of elytra are nearly parallel starting from its base to beyond middle. The strial punctures are rectangular to square in shape. Whitish macula forms a more or less distinct V and transverse posterior band; pronotum with erect black scales scattered over basal part of its pronotal disk. The aedeagus has a pair of internal separate sclerites, not touching apically.

2.6 Biology and ecology of mango fruit weevil

The Mango stone weevil is an insidious pest that spends most of its life cycle inside the mango seeds (Pena *et al*. 1998). Adult female weevils oviposit into boat-shaped cavities on the fruit (Follet 2002, Smith 1996).

The larvae burrow through the pulp to the developing seed on hatching. The tunnel made by the larvae becomes undetectable after a short time (Woodruff and Fasulo 2006, Joubert 1998). The subsequent larval and pupal stages occur in the seed (Follet and Gabbard 2000). The larvae feed on the seed and makes extensive tunnels on the seed surface. A copious amount of frass is deposited in these feeding tunnels. The strategy of feeding inside the seed capsule makes it difficult to control the pest by use of such conventional methods as a foliar application of chemical pesticides. Newly emerged grubs bore through the pulp, feed on seed coat and later cause damage to cotyledons. Pupation takes place inside the seed. Pulp is discolored around the affected portion.

The adult weevils become reproductively active when mango flowers begin to bloom (Hansen *et al.* 1989). Small or marble-size fruits are preferred, but nearly full-grown fruit may also be attacked. The female makes a boat shaped cavity in the skin (epicarp) in which an egg is deposited. She then covers each egg with a brown exudate and cuts a crescent-shaped area 0.25 - 0.50 mm in the fruit, near the posterior end of the egg. The wound creates a sap flow, which solidifies and covers the egg with a protective opaque coating (Hansen 1993). One female may lay 15 eggs per day, with a maximum of almost 300 over a three-month period (Balock and Kozuma 1964). The oviposition data suggested that the female weevils randomly select fruit for egg-laying and, hence, do not mark the oviposition site (Hansen *et al.* 1989). Hansen *et al.* (1989) concluded that the mango seed itself must be a nutritious resource, considering that five or more individuals can successfully complete development within one seed. After hatching, the small larva burrows through the pulp to the young developing seed. Generally, only one larva develops into a seed, but as many as five have been found. Larval development usually occurs within the seed and only very rarely in the pulp (Hansen *et al.* 1989). Hansen *et al.* (1989) believed that the larvae excavate cavities within the seed and pupate. Balock and Kozuma (1964) calculated the larval period at 22 days. However, larval developmental period may be influenced by climate, location, host cultivar, and non-biotic site characteristics, for example, soil chemistry and humidity (Hansen *et al.* 1989). The pupal stadium lasts for about a week (Balock and Kozuma 1964).

Adults generally emerge from the seed about one or two months after the fruit has dropped and the fruit pulp has been consumed by various organisms (Balock and Kozuma 1964). Upon maturation, the adults rapidly move out of the seed and find hiding places. The weevils hide under loose tree barks, in the crotches of trees, under loose material beneath the trees and are able to hibernate inside the seed of the mangoes. Schoeman (1987) found weevils in crotches of trees after harvest, whereas soil samples and samples of loose material under the trees produced no weevils. According to Griesbach (2003), once the mango stone weevils have left the fruit, they search for a hiding place such as beneath loose bark of trees or in waste material under the trees where they spend the time of the year that is unfavorable for them. According to Balock and Kozuma (1964), the weevils remain in the sheltered locations until the fruiting season of the following year.

The factors which break diapause and motivate the weevils to seek oviposition sites are unknown (Hansen *et al.* 1989). Balock and Kozuma (1964) suggested that the onset of diapause seems to be associated with long-day photoperiod, and the break with short-day photoperiod. Mango weevils possess well-developed wings, but are poor fliers and fly only 50 to 90 cm at a time (De Villiers 1983, Kok 1979). However, Schoeman (1987) observed the weevils fly from tree to tree with ease and quickly disappear into the foliage. In India the adult weevils were found to feed on the leaves and tender shoots of mango trees during March and April. They are nocturnal, fly readily and usually feed, mate and oviposit at dusk. After emergence, adults enter a diapause, which varies in duration according to the geographic area (Shukla and Tandon 1985).

In a similar study in Ghana it was argued that the adult weevils fed on both honey and cotyledons of the mango seed in the laboratory and the adult weevils were attracted to mango flowers and appeared to feed on nectar and pollen. The attraction of mango stone weevils to flowers probably explains how it moves out of its hideout into flowering and fruiting mango trees and odours of flowers provide cues that direct the weevils to the host tree (Braimah *et al*. 2009).

2.7 Damage severity and economic importance of mango fruit weevil

Mango weevil is considered an important pest of mango fruit worldwide (Pena *et al.* 1998). It is considered a serious pest because its development in the fruit causes damage to the pulp rendering it unmarketable, reduces the germination of seeds and causes premature fruit drop. Contrasting reports are found in literature regarding pulp feeding by the mango seed weevil; however, pulp feeding is considered to be rare (Follet and Gabbart 2000, Hansen *et al.* 1989). Pulp feeding was observed in South Africa, but the incidence was considered to be low in the cultivar "Kent" but not in the early maturing cultivar "Tommy Atkins". Pulp feeding might have resulted from eggs laid late in the season when seed husks had already hardened and thus prevented penetration by larvae (Louw 2006). Pulp damage is also caused when adult weevils emerge from the fruit on the trees in late season cultivars (Kok 1979, Milne *et al.* 1977).

Louw (2006) found emergence holes on the cultivar "Kent" but the incidence was low. Exit holes were not present on the early maturing cultivar "Tommy Atkins". Studies conducted in Hawaii to assess the effect of mango weevil infestation on seed viability showed that mango seed can withstand substantial damage and still germinate successfully (Follett and Gabbard 2000). Follett (2002) studied the effect of mango seed weevil infestation on premature fruit drop and reported that mango weevil infestation can increase fruit drop during early fruit development. When infestation by mango seed weevil was reduced by chemical sprays, fruit drop also decreased (Verghese 2005).

2.8 Host plant search process of an insect pest

Host plant's location is known to begin with some form of movement and orientation in space (Miller and Strickler, 1984). Insects may be in flight, walking in a random dispersal mode, or even moving in response to a particular stimulus when they come in contact with a stimulus that they follow to enter a host plant patch (Kennedy 1978). Most insects which rely upon specific resources are challenged by habitat heterogeneity at several spatial scales. This is highly important for herbivorous insects which may depend on specific host plants for feeding and oviposition (Schoonhoven *et al.* 2005). Insects that move in a landscape can detect and locate host plants that often occur in scattered patches which may differ in size, isolation and plant density (Tscharntke *et al*. 2002). At smaller scales, when insects have entered patches, they also must be able to distinguish host plants among non-host plants. The habitat heterogeneities have constraints on the host finding ability of insects, which has to rely upon different sensory cues in order to find patches and host plants (Schoonhoven *et al*. 2005). Once within the boundaries of a habitat, direct or random oriented movements occur in response to visual, olfactory or other stimuli generated from either a host plant habitat or the host plant (Hsiao 1985). The stimuli emanating from the resources are assessed in terms of quality, so that the foraging insect searches in the best habitat, patch or resources unit (Bell 1990). The mango weevil occurs on mangoes only and no alternative host crops are known (Hansen *et al*. 1989). Complete development was only achieved in mangoes. In the laboratory, oviposition was obtained on potatoes, peaches, litchi, plums, beans and several cultivars of apples, but larvae failed to reach maturity (Balock and Kozuma 1964). In a study in the laboratory when feeding preferences between mango and other substances (protein, sugar, plant volatile) were compared, the adult weevils only visited mango (Louw 2006). The weevils preferred to feed on very young and soft flush and did not feed on old leaves and stems. Portions of the lamina were consumed on soft flushes while in slightly older flushes feeding occurred along the veins or on stems. Weevils fed in large numbers on mango fruit, especially when it was cut in half. Weevils did not respond to mango juice (Bell 1990).

2.9 Attractiveness of mango plant parts to the mango weevil

Schoeman (1987) found large numbers of adult seed weevils in tree crotches directly after harvest, although these numbers did not correlate to fruit infestation levels prior to harvest. During the course of the season he observed only a small number of adult weevils, either walking along tree branches within trees (Schoeman 1987), or flying to adjacent trees where they landed with ease, disappearing into the foliage (Schoeman 1987). He also collected soil and debris samples from beneath infested trees to investigate for the presence of mango seed weevils. These samples, however, yielded no adult weevils. The mango seed weevil (MSW) is a monophagous pest (Follett and Gabbard 2000) with mango the only known host (Follet 2002, Hansen and Armstrong 1990).

2.10 Management of mango weevil

Recommended practices for management of the mango stone weevil include orchard hygiene, application of pesticides (such as Lebaycid, Azinphos, Endolsulfan, Malathion and Carbosulfan) adherence to quarantine regulations and treeing resistant cultivars (Pinese and Holmes 2005, Griesbach 2003, Hill 1975, Joubert 1998, Smith 1996). Pesticides are applied either as foliar sprays or as trunk paint bands (Griesbach 2003). The reduction in infestation levels that results after using the recommended practices varies from one region to the other. Griesbach (2003) argued that most of these insecticides have been uneconomical and ineffective. He argued that the combination of sanitation of the orchard, treatment of the trunk and branches with insecticides and fruit treatment with pesticides usually reduces the weevil population in the orchard better than the application of single insecticide.

Habitat disruption of the mango pulp weevil population (MPW) by the removal of 25% of the canopy diameter of MPW-infested mango trees, or open centre pruning, an improved component of integrated pest management (IPM). The IPM mango trees yielded an average of 175 kg fruit/tree and a net income of 1,729.50 pesos/tree in contrast to traditionally (farmers) managed trees, which yielded only 4 kg or an income of only 20.00 pesos/tree (Lorenzana 2013).

Verghese (2005) found that intervention with a single spray of monocrotophos 0.05% or fenthion 0.08% at pea to marble size (middle of March) showed 13 to 15% infestation as compared to 34% in the control in 1997. Two sprays of monocrotophos 0.05% at a 10 day interval, in 1998, and destruction of fallen fruits (at and just before harvest of the previous year) resulted in 97.5% and 100% control in Banganpalli and

Alphonso. In the farmers field in Andhra Pradesh, South India, two experiments with three sprays of monocrotophos 0.05% or fenthion 0.08% at pre-flowering, at pea size and at marble size gave 100% control, thus ensuring pest-free fruits for export and processing.

It was found that four synthetic insecticides - deltamethrin, acephate, carbaryl and ethofenprox - obtained levels of infestation of between 3.3% and 14.8% at harvest, in contrast with a level without control of 33.0%. Two biological-origin insecticides - azadirachtin (of tree origin) and fish oil rosin soap (of animal origin) - obtained intermediate levels of control, of 27.4 and 23.0% respectively, which were not significantly superior to no-treatment (Verghese 2005).

2.10.1 Effect of pesticide application

According to Ntow (2008), worldwide pesticide usage has increased tremendously since the 1960s. It has largely been responsible for the “green revolution”, when there was massive increase in food production obtained from the same surface of the land with the help of mineral fertilizers (nitrogen, phosphorus, and potassium), more efficient machinery and intensive irrigation. The use of pesticides helped to significantly reduce crop losses and to improve the yield of crops such as corn, maize, vegetables, potatoes and cotton. Notwithstanding the beneficial effects of pesticides, their adverse effects on environmental quality and human health have been well documented worldwide and constitute a major issue that gives rise to concerns at local, regional, national and global scales (Cerejeira *et al*. 2003, Kidd *et al*. 2001, Ntow 2001, Huber *et al*. 2000, Planas *et al*. 1997). Residues of pesticides contaminate soils and water, persist in the crops, enter the food chain, and finally are ingested by humans with foodstuffs and water. Furthermore, pesticides can be held responsible for contributing to biodiversity losses and deterioration of natural habitats (Sattler *et al.* 2006). There have been reported instances of pest resurgence, development of resistance to pesticides, secondary pest outbreaks and destruction of non-target species. Despite the fact that pesticides are also applied in other sectors, agriculture can undoubtedly be seen as the most important source of adverse effects (Sattler *et al.* 2006).

Dash *et al*. (2011) revealed that cultural control along with two sprays of Sumithion 50 EC @ 2 ml/L of water gave the highest fruit infestation reduction over control (96.62% and 93.94% in 2008-09 and 2009-10 respectively). Two times spray of fenitrothion and dimethoate @ 2.5 ml/L of water at an interval of 15 days starting from the pea size stage of mango was reported to have effective result (Rashid and Rahman 2010).

2.10.2 Local technology and government intervention

Nzomoi *et al*. (2007) reported that numerous problems are associated with technologies that are not locally developed. Common difficulties include inappropriateness, lack of qualified personnel to implement them, and high costs associated with the acquisition and utilization of such technologies.

On the role of government in the horticultural industry, Nzomoi *et al*. (2007) observed that government plays a significant role that enables firms or farms to enhance their production and marketing strategies. For technologies to be utilized there is a need for government involvement in making it possible for the users to conveniently benefit from the availability of the new technology. Nzomoi *et al*. (2007) further stated that failure to utilize technologies by the various intended beneficiaries can be blamed on the government's inability or reluctance to facilitate same, and that government's role should be minimized since excessive government meddling can actually curtail productivity in the horticultural industry.

2.11 The role of indigenous knowledge in Agriculture

Indigenous knowledge is the unique knowledge confined to a particular culture or society. It is also known as local knowledge, folk knowledge, people's knowledge, traditional wisdom or traditional science. This knowledge is generated shared and transmitted by communities, over time, in an effort to cope with their own agro-ecological and socioeconomic environments (Fernandez 1994). Indigenous knowledge is passed from generation to generation, usually by word of mouth and cultural rituals. It is anchored in actions, experiences and values of a particular social group. Indigenous knowledge is not just a compilation of facts drawn from local and remote environment, but a complex and sophisticated system of knowledge drawn from centuries of experience, testing and wisdom of local people (World Bank 1998).

Indigenous knowledge systems combine culture and religion, therefore making it compatible with indigenous environment and culture. Indigenous knowledge includes accumulated knowledge as well as the skills and technologies of the local people that are developed locally and handed down through the centuries (Khodamoradi and Abedi 2011). Dewalt (1994) states that even farmers who are part of the modern agriculture have an indigenous knowledge system. African communities have a vast array of Indigenous knowledge in food technology that is favourable to the supply, quality and safety of food and hence has a direct contribution to food security

(Aniang'o *et al.* 2003). According to Khodamoradi and Abedi (2011), indigenous knowledge is accessible, useful and cheap. This makes it important in supporting the poor farmers in the marginal areas who have no physical and economic access to scientific technologies.

2.12 Indigenous knowledge and insect pests management practices

There are several traditional pest management practices that risk being forgotten if they are abandoned for the sake of chemical pesticide usage. According to Morales (2002), such practices include site selection, soil management, timing of plantation and harvesting, crop resistance, intercropping, weed management, removal of fallen fruits from the orchard ground, harvest residue management, post-harvest management, management of natural, mechanical control and use of repellents and traps in the natural regulation of potential pests. This section discusses some of the practices and their application to mango production.

In the face of this continuing failure to control pest losses in Sub-Saharan Africa with synthetic chemical insecticides, Grzywacz *et al*. (2013) proposed that there is a need to explore more vigorously alternative, more affordable, appropriate and sustainable solutions to the current pest control model that focuses exclusively on the use of imported synthetic chemicals as the primary option. This would not seek to replace current pest control systems where they are effective, nor impede attempts to develop or disseminate modern pest control to a wider constituency, but it could have a useful role in providing an alternative, cheaper, locally-accessible option for the poor subsistence farmers who cannot afford the more expensive synthetic pesticides or lack the resources to use them.

CHAPTER III

MATERIALS AND METHODS

Experiment was conducted at the farmer’s orchard in Bandarban, Rangamati and Khagrachari districts during the period from January to July 2017. The detail materials and methods adopted for this study are discussed under the following sub-headings:

3.1 Location of the experiment

The experiment was conducted at the farmer’s orchard of three hill districts of Bangladesh. Experimental site at Bandarban (Plate 1), Rangamati (Plate 2) and Khagrachari (Plate 3) districts and farmer’s information are given below:

Sl.	Farmer’s Name	Location
1	Singpat Mro	Cramadipara, Bandarban Sadar, Bandarban
2	Hemokumar Chakma	Shukarchari, Manikchari, Rangamati
3	Bayes Mia	Borobil, Manikchari, Khagrachari

Plate 1. Experimental orchard at Cramadipara, Bandarban Sadar in Bandarban district.

Plate 2. Experimental orchard at Shukarchari, Manikchari in Rangamati district.

Plate 3. Experimental orchard at Borobil, Manikchari in Khagrachari district.

3.2 Characteristics of soil

The soils of the experimental sites are high land belonging to the Chittagong Hill tracts under the Agro Ecological Zone (AEZ) 29 (Northern and Eastern hills). The experimental sites are high hill.

3.3 Climate

The climate of the experimental site is sub-tropical characterized by heavy rainfall during April to September and sporadic during the rest of the year.

3.4 Variety of the mango

Mango variety, Amrapali or BARI Mango 3, was the cultivated variety for the experiment. Each of the orchards contained at least 30 mango trees which were considered an experimental unit.

3.5 Treatments

Three treatments were used in this study, which were same at Bandarban, Rangamati and Khagrachari districts. Details of treatments used in this study are shown in Table 1.

Table 1. Treatments for the management of mango weevil and their application time

Treatments	Description
T_1	Improved pest management practices (5 times spraying of Ripcord 10EC @ 1.0 ml/L water on 30 January, 28 February, 30 March, 28 April, 30 May along with cultural practices like clean cultivation through the removal of fallen mango fruits, leaves, weeds and parasitic plants, light pruning of the dead branches of previous year, avoidance of naturally grown forest plants with minimum economic value etc.)
T_2	Farmer's practice (2 times spraying of Ripcord 10EC @ 1.0 ml/L water from January to May)
T_3	Untreated control

3.6 Design and layout of the experiment

The experiment was laid out in a Randomized Complete Block Design (RCBD) with ten replications. Each mango tree was considered one experimental unit. Thus 10 mango trees were selected for 10 replications and a total of 30 mango trees were considered for this experiment in each district. Same treatments were used for each of three hill districts.

3.7 Intercultural operations

The experimental orchards were prepared by removing bushes and weeds followed by cleaning and weeding during December to January, 2017. Then, weeding was done as it grew higher through the period of experiment. Removing of dead twig and leaves was done during the preparation of experiment field.

3.8 Manure and fertilizer application

Age of all the mango trees using as a block in this experiment were within 4 (Four) to 10 (Ten) years. So, manures and fertilizers with their doses and their methods of application followed in the study have been recommended in Hand Book on Agro-technology by BARI (Mondal *et al.* 2014) and are shown in Table 2.

Table 2. Doses of manures and fertilizers and their methods of application used for this experiment

Manures and Fertilizers	Age of Tree (Year)		
	2-4	5-7	8-10
Compost (kg)	10-15	16-20	21-25
Urea (g)	250	500	750
TSP (g)	250	250	500
MOP (g)	100	200	250
Gypsum (g)	100	200	250
Zinc Sulphate (g)	10	10	15
Boric acid (g)	20	20	30

3.9 Treatment application

3.9.1 Improved management practices

For chemical insecticide spray, 10.0 ml of Ripcord 10EC was mixed with 10.0 liter water to make the spray solution. Spray mixture was applied with the help of foot pump sprayer for each treatment and Fungicide Tilt 250EC @ 0.5 ml/L was applied with each insecticidal spray as cover spray for the management of fungal disease. No control measure was applied in untreated control trees.

3.10 Harvesting

Harvesting of mango fruit was done during 20th June to 20th July, 2016. That time period was suitable for harvesting because the mangoes were matured and ready to sell in the local market. It was taken three to four days, to harvest all of the mangoes in a plot. Mangoes were harvested according to the treatments though each tree was treated as a treatment. After harvesting of one treatment, harvesting of another treatment was started. During the time of harvesting, mangoes were counted and mangoes were looked and tested thoroughly as it was infested or not. Then the mangoes were kept in a specific site.

3.11 Data collection

After harvest healthy and infested fruits/tree were sorted out visually and recorded separately for each treated and untreated tree in each district. Total number of fruits/tree was calculated by addition of healthy and infested fruits/tree.


Plate 4. Collection of Data.

Plate 5. Mango fruit weevil infested fruit pulp.

Plate 6. Collection of larva.

Plate 7. Collection of pupa.

Plate 8. Adult mango fruit weevil collection.

Plate 9. Larvae of mango fruit weevil.

Plate 10. Adults of mango fruit weevil.

3.11.1 Percent total fruit infestation

Percent total fruit infestation for each tree was calculated by using the following formula:

$$\text{Total fruit infestation (\%)} = \frac{\text{No. of infested fruits/tree}}{\text{Total no. of fruits /tree}} \times 100$$

3.11.2 Fruit infestation by fruit weevil

Twenty fruits were selected randomly from each tree and dissected longitudinally by knives. Number of healthy fruits and weevil infested fruits out of 20 fruits from each tree were recorded separately. Percent fruit infestation by fruit fly and fruit weevil was calculated separately for each treatment in each district:

$$\text{Fruit infestation by weevil (\%)} = \frac{\text{No. of fruit weevil infested fruits}}{20} \times 100$$

3.11.3 Percent increase of healthy fruits/tree

The percent increase of healthy fruits/tree in treated tree over untreated control tree was computed by using the following formula:

Increase of healthy fruits/tree over control (%)

$$= \frac{\text{healthy fruits in treatements} - \text{healthy fruits in control}}{\text{healthy fruits in control}} \times 100$$

3.11.4 Percent decrease of infested fruits/tree

The percent decrease of infested fruits/tree in treated tree over untreated control tree was computed by using the following formula:

Decrease of infested fruits over control (%)

$$= \frac{\text{infested fruits in control} - \text{infested fruits in treatments}}{\text{infested fruits in control}} \times 100$$

Percent decrease of fruit infestation

$$= \frac{\text{fruit infestation in control} - \text{fruit infestation in treatemetns}}{\text{fruit infestation in control}} \times 100$$

3.12 Statistical analysis of data

The recorded data were compiled and tabulated for statistical analysis. Analysis of variance was done with the help of computer package MSTAT program (Gomez and Gomez, 1976). The treatment means were separated by Least Significant Difference (LSD) Test.

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted at farmer's orchard at Cramadipara in Bandarban, Shukarchari in Rangamati and Borobil in Khagrachari districts during January to July 2017 to study diversity, damage assessment and management of mango fruit weevil. The results of the present study have been presented and discussed under the following sub-headings:

4.1 Species diversity of mango weevil

The result indicates that only pulp weevil, *S. frigidus* species was recorded at hilly areas of Bangladesh (Figure 1) and no stone weevil *S. mangiferae* was recorded in those areas. Alam (1962) reported both species of mango fruit weevil in Bangladesh with no detail information. CABI (2014) also reported incidence of both species of mango fruit weevil *S. frigidus* and *S. mangiferae* in Bangladesh.

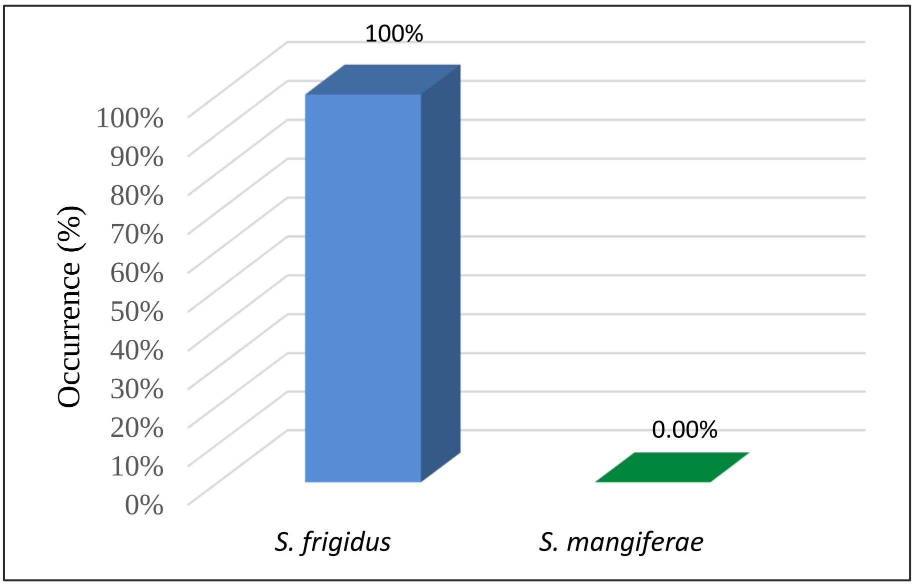

Figure 1. Weevil species attacking mango at Bandarban, Rangamati and Khagrachari.

4.2 Infestation intensity of mango fruit weevil at hilly areas in Bangladesh

Mango fruit weevil *S. frigidus* caused huge infestation of mango fruits at Bandarban, Rangamati and Khagrachari districts in 2017 (Figure 2). The figure demonstrated that the highest fruit infestation (81.46%) was recorded at Bandarban followed by 80.40% in Rangamati and 80.19% in Khagrachari districts. Results on infestation level of mango fruit weevil at three hill districts agree with the findings of other researchers. EPPO (2014) reported that damage level of mango fruit weevil *S. frigidus* may reach up to 100% in case of untreated control plot. Anon (2006) reported 60 to 90% fruit infestation of mango in India. But the result may vary with the findings of other due to several factors like weather, mango cultivars, age of the plant etc. Alam (1962) reported both species of mango weevil *S. frigidus* and *S. mangiferae* in south eastern part of Bangladesh with no detail information.

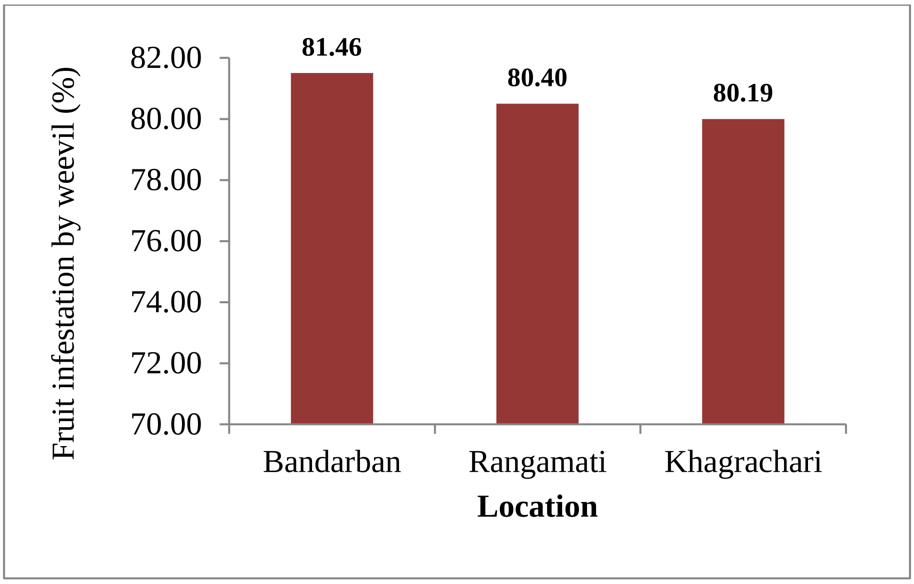

Figure 2. Percent fruit infestation by *S. frigidus* at experimental field in the hilly areas.

4.3 Effect of management practices on mango fruit production

4.3.1 Effect of different treatments on production of mango fruits

Total number of mango fruits/tree varied significantly in different treatments at Bandarban, Rangamati and Khagrachari districts. Data in Table 4 indicate that the highest number of total fruits/tree (458.90/tree) was recorded from T_1 treatments at Cramadipara (Bandarban) having significant difference with T_2 (405.60) and T_3 (370.00) treatments. In contrast the lowest number of total fruits/tree (370.00) was observed in T_3 (control) which was significantly different from other treatments. Similar trend of total number of mango production was found at Shukurchari (Rangamati) and Borobil (Khagrachari) for all treatments. However, the number of fruits/tree was recorded higher at Bandarban than Khagrachari and Rangamati for all treatments.

Table 3. Number of total fruits/tree under different treatments at Bandarban, Rangamati and Khagrachari districts in 2017

Treatments	Total No. of Fruits/Plant		
	Bandarban	Rangamati	Khagrachari
T_1	458.90 ± 18.06 a	254.90 ± 10.10 a	370.20 ± 16.42 a
T_2	405.60 ± 13.49 b	219.40 ± 8.37 b	311.70 ± 10.68 b
T_3	370.00 ± 13.92 c	208.30 ± 7.36 c	257.20 ± 9.55 c
CV (%)	3.72	4.38	3.36
$S_{\bar{x}}$	4.84	3.15	3.33

In a column, means having same letter(s) are statistically similar at 5% level of significance by DMRT.

4.3.2 Effect of different treatments on healthy mango fruits production

Significant variation was observed for total number of mango fruits/tree at three hill districts. Data (Table 5) indicate that the highest number of healthy fruits/tree (368.90) was recorded from T_1 treatments at Cramadipara (Bandarban) having significant variation with all other treatments. On the other hand, the lowest number of healthy fruits/tree (68.70) was observed in T_3 (control) which was significantly lower than other treatments. Similar trend of healthy mango fruits/tree production was found at Shukurchari (Rangamati) and Borobil (Khagrachari) for all treatments. This result may be explained by the findings of Schoeman (1987) who reported that the weevils flew from tree to tree during March to April fed on leaves and deposited eggs at dusk. Moreover Braimah *et al.* (2009) observed that smell of mango flower provided cues which attracted weevils to the host tree. Thus routine application of Ripcord 10EC may cause mortality of adult weevil that might infest the mango fruit resulting higher percentage of healthy fruit.

Table 4. Number of healthy mango fruits/tree at Bandarban, Rangamati and Khagrachari in 2017

Treatments	**Total No. of Healthy Fruits/Tree**		
	Bandarban	**Rangamati**	**Khagrachari**
T_1	368.90 ± 15.49 a	204.70 ± 11.09 a	299.10 ± 14.92 a
T_2	237.50 ± 10.19 b	131.70 ± 6.41 b	183.40 ± 8.17 b
T_3	68.70 ± 8.34 c	40.80 ± 5.01 c	51.00 ± 5.39 a
CV (%)	**5.32**	**6.87**	**4.74**
$S_{\bar{x}}$	**3.79**	**2.73**	**2.67**

In a column, means having same letter(s) are statistically similar at 5% level of significance by DMRT.

Improved management practice increased more than 80.00% healthy fruits/tree over control at Bandarban, Rangamati and Khagrachari districts and T_3 (Untreated control) showed the lowest number healthy fruits/tree over control at Bandarban, Rangamati and Khagrachari respectively (Figure 3).

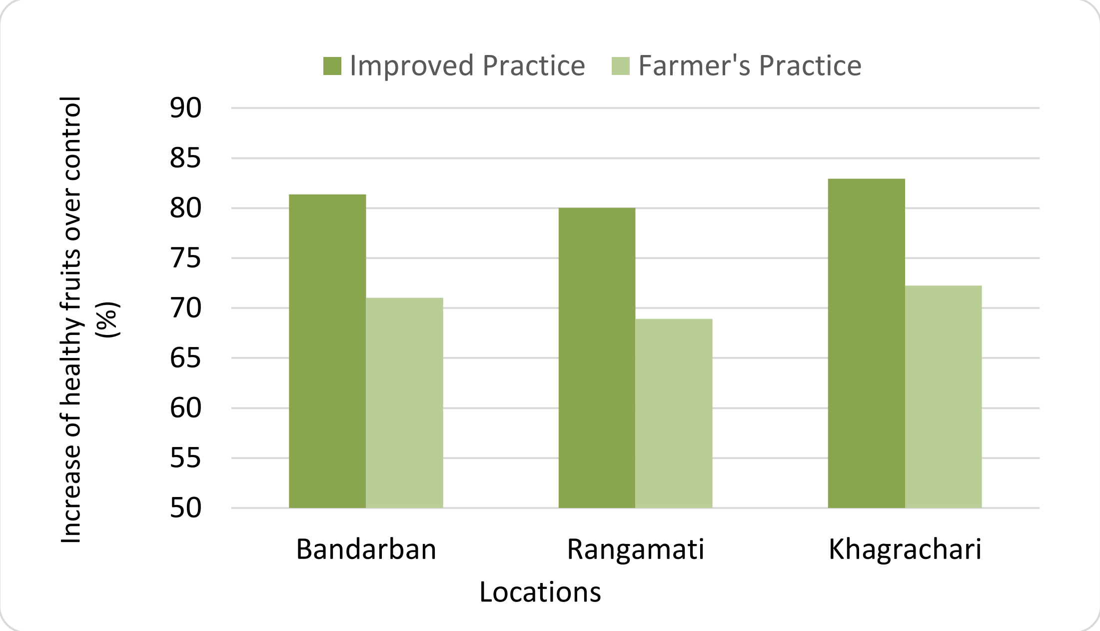

Figure 3. Percent increase of healthy fruits over untreated control at Bandarban, Rangamati and Khagrachari districts.

4.3.3 Effect of different treatments on mango fruits infestation

The lowest number of infested fruits/tree (34.40 fruits/tree at Bandarban, 21.30 fruits/tree at Rangamati and 30.80 fruits/tree at Khagrachari districts) was recorded from improved management practiced plant followed by farmer's practice (90.00 fruits/tree at Bandarban, 50.20 fruits/tree at Rangamati and 71.10 fruits/tree at Khagrachari districts) having significant difference between them(Table 6). On the other hand the highest number of infested fruits/tree (301.30 fruits/tree at Bandarban, 167.50 fruits/tree at Rangamati and 206.20 fruits/tree at Khagrachari districts) was recorded from untreated control which was significantly higher than all other treatments.

Table 5. Number of infested fruits/tree at Bandarban, Rangamati and Khagrachari in 2017

Treatments	No. of Infested fruits/Tree		
	Bandarban	**Rangamati**	**Khagrachari**
T_1	90.00 ± 3.56 c	50.20 ± 2.35 c	71.10 ± 3.78 c
T_2	168.10 ± 5.32 b	87.70 ± 4.27 b	128.30 ± 5.69 b
T_3	301.30 ± 10.36 a	167.50 ± 8.24 a	206.20 ± 7.28 a
CV (%)	**3.84**	**4.95**	**4.09**
$S_{\bar{x}}$	**2.26**	**1.59**	**1.75**

In a column, means having same letter(s) are statistically similar at 5% level of significance by DMRT.

Improved management practice decreased more than 60.00% infested fruits over control (70.09% at Bandarban, 69.99% at Rangamati and 65.46% at Khagrachari districts)and farmer's practice decreased more than 35% infested fruits over control at three hill districts (Figure 4).

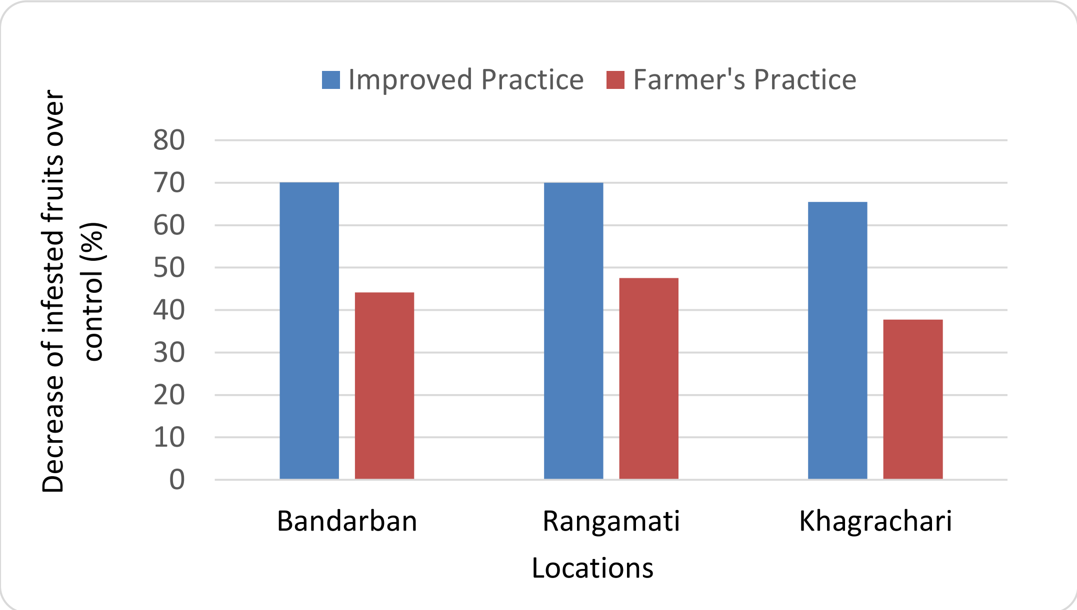

Figure 4. Percent decrease of infested fruits over untreated control at Bandarban, Rangamati and Khagrachari districts.

4.3.4 Effect of different treatments on percent fruits infestation

The lowest percent of fruit infestation (19.62% at Bandarban, 19.73% at Rangamati and 19.22% at Khagrachari districts) was recorded from improved management practiced plant followed by farmer's practice (41.46% at Bandarban, 39.98% at Rangamati and 41.17% at Khagrachari districts) having significant difference between them(Table 7). On the other hand the highest percent of fruit infestation (81.46% at Bandarban, 80.40% at Rangamati and 80.19% at Khagrachari districts) was recorded from untreated control which was significantly higher than all other treatments.

Table 6. Percent fruit infestation at Bandarban, Rangamati and Khagrachari in 2017

Treatments	Percent Fruit Infestation		
	Bandarban	**Rangamati**	**Khagrachari**
T_1	19.62 ± 0.52 c	19.73 ± 1.37 c	19.22 ± 0.98 c
T_2	41.46 ± 0.97 b	39.98 ± 1.48 b	41.17 ± 1.42 b
T_3	81.46 ± 1.81 a	80.40 ± 2.36 a	80.19 ± 1.72 a
CV (%)	**2.69**	**3.47**	**3.09**
$S_{\bar{x}}$	**0.40**	**0.51**	**0.46**

In a column, means having same letter(s) are statistically similar at 5% level of significance by DMRT.

Improved management practice decreased more than 70.00% infested fruits over control (75.91% at Bandarban, 75.44% at Rangamati and 76.02% at Khagrachari districts) and farmer's practice decreased more than 45% infested fruits over control at three hill districts (Figure 5).

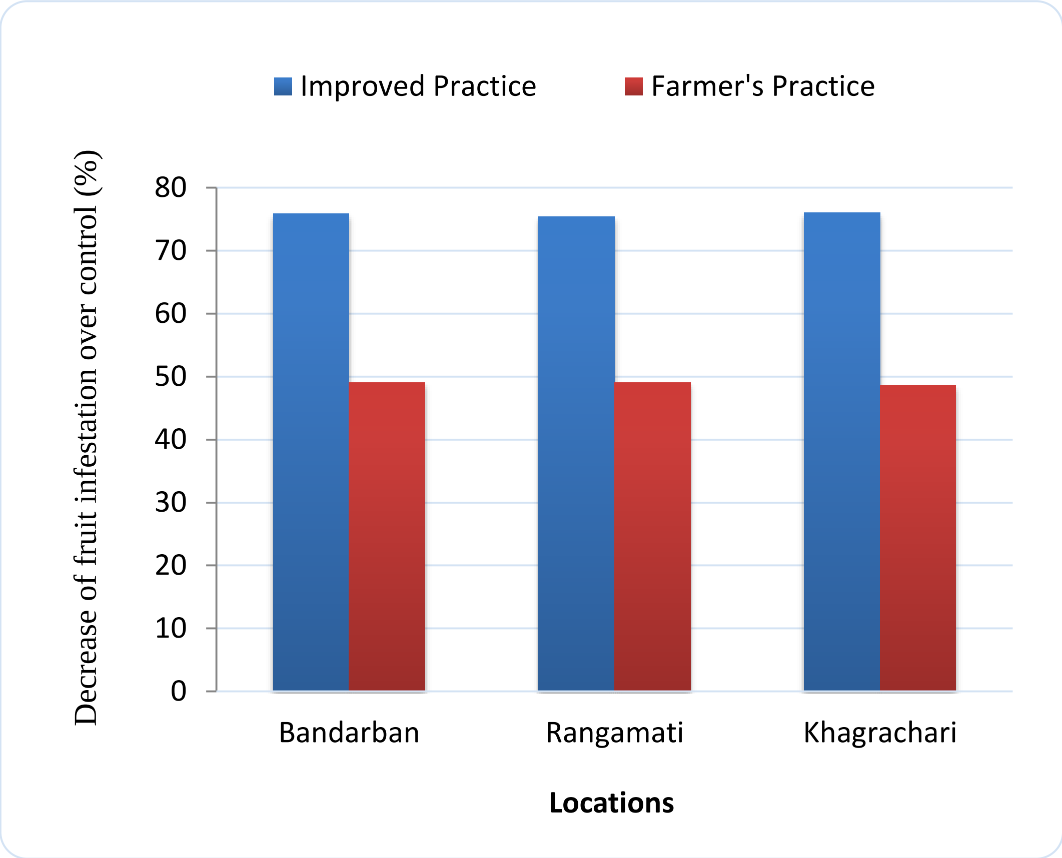

Figure 5. Percent decrease of fruit infestation over untreated control at Bandarban, Rangamati and Khagrachari districts.

CHAPTER V

SUMMARY AND CONCLUSION

The present study was conducted at the farmer's orchard in Bandarban, Rangamati and Khagrachari districts, during the period from January to July, 2017 to study the species diversity, infestation intensity and management of mango fruit weevil. The treatments of the experiment were T_1 = Improved pest management practices (5 times spraying of Ripcord 10EC @ 1.0 ml/L water at 30 January, 28 February, 30 March, 28 April and 30 May along with cultural practices like clean cultivation through the removal of the fallen mango fruits, leaves, weeds and parasitic plants, light pruning of the dead branches of previous year, avoidance of naturally grown forest plants with minimum economic value etc), T_2 = Farmer's practice (2 times spraying of Ripcord 10EC @ 1.0 ml/L water from January to May), T_3 = Untreated control. The experiment was laid out in a Randomized Complete Block Design (RCBD) with ten replications. Each mango tree was considered one experimental unit.

Occurrence of mango pulp weevil *S. frigidus*, species at Bandarban, Rangamati and Khagrachari districts was 100% and no seed weevils, *S. mangiferae* was found in this region.

Total number of mango fruits/tree was highest at improved management practices in Bandarban (458.90), Rangamati (254.90) and Khagrachari (370.20) districts respectively. Again, the lowest number of total fruits/tree was found in untreated control at three hill districts.

The highest number of healthy fruits/tree was found in T_1 treatments at Bandarban, Rangamati and Khagrachari districts (368.90, 204.70 and 299.10 respectively) and the lowest number of healthy fruits/tree was found in untreated control in three hill districts. Improved management practice increased more than 80.00% healthy fruits/tree over control at three locations and T_3 (untreated control) showed the lowest number healthy fruits/tree over control at Bandarban, Rangamati and Khagrachari respectively. The lowest number of infested fruits/tree was found in T_1 treatments at Bandarban, Rangamati and Khagrachari districts (90.00, 50.20 and 71.10 respectively) and the highest number of infested fruits/tree was found in untreated control (301.30, 167.50 and 206.20) in three hill districts. Improved management practice decreased more than 60.00% infested fruits over control (70.09% at Bandarban, 69.99% at Rangamati and 65.46% at Khagrachari districts) and farmer's practice decreased more than 35% infested fruits over control at three hill districts.

The lowest number of fruit infestation (19.62% at Bandarban, 19.73% at Rangamati and 19.22% at Khagrachari districts) was recorded from improved management practice plant. On the other hand, the highest number of fruit infestation (81.46% at Bandarban, 80.40% at Rangamati and 80.19% at Khagrachari districts) was recorded from untreated control which was significantly higher than all other treatments. Improved management practice decreased more than 70.00% infested fruits over control (75.91% at Bandarban, 75.44% at Rangamati and 76.02% at Khagrachari districts) and farmer's practice decreased more than 45% infested fruits over control at three hill districts.

Considering the result of the present study it may be concluded that improved pest management practices (5 times spraying of Ripcord 10EC @ 1.0 ml/L water on 30 January, 28 February, 30 March, 28 April, 30 May along with traditional cultural practices like clean cultivation through the removal of fallen mango fruits, leaves, weeds and parasitic plants, light pruning of the dead branches of previous year, avoidance of naturally grown forest plants with minimum economic value etc.) was the most effective management practices against mango fruit weevil. This treatment may be used for the overall management of mango insect pests but needs further trial for validation in large area.

CHAPTER VI

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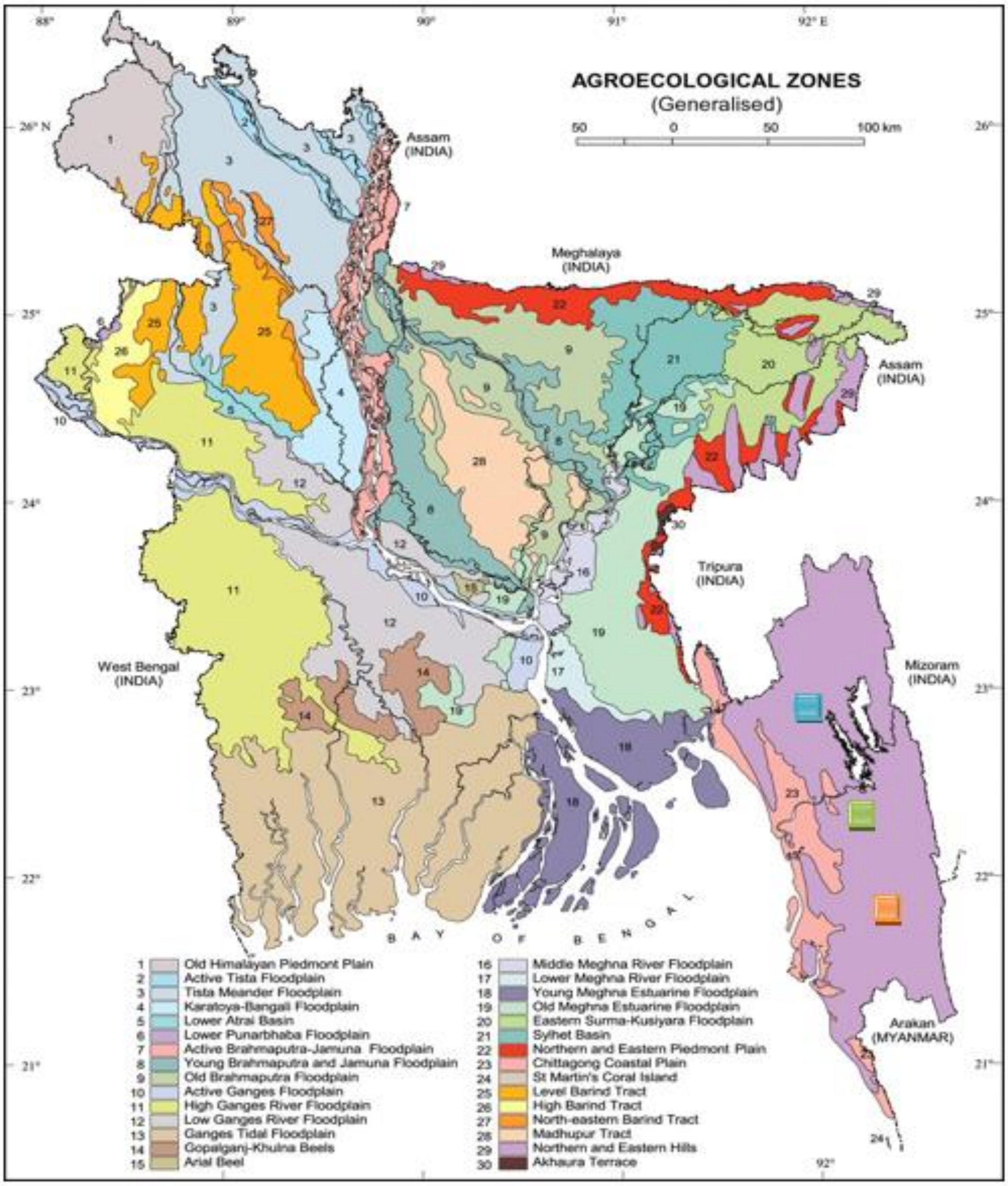
APPENDIX

Appendix I. Map Showing the Location of farmer's orchard under the study



Kramadipara, Bamdarban Sadar, Bandarban

Shukarchari, Manikchari, Rangamati

Borobil, Manikchari, Khagrachari