ABUNDANCE OF INSECTS IN MAIZE FIELDS AND DEVELOPMENTAL BIOLOGY OF FALL ARMYWORM, *SPODOPTERA FRUGIPERDA* (LEPIDOPTERA: NOCTUIDAE) ON MAIZE VARIETIES

A THESIS

BY

MOHAMED FARAH JIMALE

Student No. 1805497

Session: 2018-2019

Thesis Semester: July-December, 2019

MASTER OF SCIENCE (MS)
IN
ENTOMOLOGY

DEPARTMENT OF ENTOMOLOGY

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
DINAJPUR, BANGLADESH

DECEMBER, 2019

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Submitted to the Department of Entomology. Hajee Mohammad Danesh Science and Technology University, Dinajpur in partial fulfillment of the requirements for the degree of

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DEDICATED

TO MY

BELOVED PARENTS

ACKNOWLEDGEMENTS

For the very first of all, the author expresses his gratitude to the almighty Allah, the most gracious and supreme authority of the universe for his kind blessings to fortunate the author to accomplish this research work and complete this thesis successfully. Words actually will never be enough to express how grateful the author is nevertheless will try his level best to express his gratitude towards some respected persons for their advice, direction and cooperation in completing the research work and thesis.

The author would like to express heartfelt gratitude to his honorable Supervisor, Dr. Md. Abdul Alim, Professor, Department of Entomology, Hajee Mohammad Danesh Science and Technology University, Dinajpur for his cordial supervision, innovative suggestions, scholastic guidance, helpful comment, inspiration and timely instructions throughout the entire period of the research.

The author expresses his deep indebtedness to his Co-Supervisor, Dr. Hasan Fuad El Taj Professor, Department of Entomology, Hajee Mohammad Danesh Science and Technology University, Dinajpur for his cordial supervision, innovative suggestions, scholastic guidance, helpful comment, inspiration.

I express my gratefulness to all the teachers of the Department of Entomology, Hajee Mohammad Danesh Science and Technology University, Dinajpur, for their assistance, for improving academic skills in entomology during course of MS. The author also acknowledges the Institute of Training and Research (IRT), HSTU for their financial support.

Finally, the author expresses a deep appreciation to his parents, brothers, sisters, wife and son for their love, support, encouragement and prayer. They have always encouraged me in all of my pursuits and without them none of this would have been possible. I would like to give my thanks whole heartedly to all of my relatives, friends for their co-operations, inspirations and affectionate feelings towards the successful completion of my study.

Finally, I acknowledge Almighty Allah for bestowing blessing on me in partial fulfillment of the requirements for the MS. Degree.

The Author

ABSTRACT

Spodoptera frugiperda (Lepidoptera: Noctuidae) is a newly introduced destructive pest of maize in Bangladesh which causes substantial yield loss to different maize cultivars. Experiments were conducted to study the abundance of insects in the maize fields and development of fall armyworm, *S. frugiperda* on three maize varieties BISCO51, KOHINOOR1820 and M. GOLD. The study was carried out in three different locations of Dinajpur district such as Noshipur, Sadipur and Karnai. Study revealed that maize aphids *Rhopalosiphum maidis* (Aphididae: Hemiptera) were most abundant in three different locations. Fall armyworm *S. frugiperda*, maize earworm *Helicoverpa zea* (Noctuidae: Lepidoptera), maize stem borer *C. partellus* (Noctuidae: Lepidoptera) and black cutworm *Agrotis ipsilon* (Noctuidae: Lepidoptera) were also found in the studied fields during March to May. Ladybird beetle *Coccinella septempunctata* (Coccinellidae: Coleoptera) and lacewing *Chrysoperla carnea* (Chrysopidae: Neuroptera) were found as natural enemies. Development of *S. frugiperda* showed no significant differences while fed on three maize cultivars. The highest longevity of adult female was 39.0 days on the cultivar BISCO 51 while shortest 36.5 days on M. GOLD. The daily fecundity showed significant differences among the three maize cultivars. The maximum number (63.78) of eggs was laid on BISCO 51, while minimum (32.9) oviposited on M. GOLD. The sex ratio (proportion of male) was found maximum on BISCO51 (0.56) while minimum in M. GOLD (0.45). The net reproductive rate (Ro = 195.85), intrinsic rate of natural increase (r_m =0.185), finite rate of increase (λ= 1.3) were maximum in BISCO51 Population doubling time (T= 29.42) were maximum in KOHINOOR1820 but minimum in M. GOLD. Therefore, maize aphid (1489), fall armyworm (265), maize stem borer (167) maize earworm (156), and black cutworm (66), were observed as major maize pest. Fall armyworm can develop faster in M. GOLD cultivar than KOHINOOR1820 and BISCO51while in terms of reproductive phase and fecundity.

Keywords: *Spodoptera frugiperda,* development, reproduction, life table, maize cultivars.

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FAW:	Fall armyworm
MA:	Maize aphid
MSB:	Maize stemborer
BC:	Black cutworm
MEW:	Maize earworm
LB:	Ladybird beetle
LW:	Lacewing

CHAPTER I

INTRODUCTION

Maize (*Zea mays L.*) is the third most important grain crop of the world which is widely cultivated all over the world in different agro-climatic zones (Smith & Rajasthan *et al.*, 2019).Worldwide, it is popularly known as "Queen of cereals" due to its wider adaptability and highest genetic yield potential among cereal crops. It has a wider genetic base and extraordinary level of genotypic diversity which makes it most versatile and adaptive under different agro-climatic conditions. Maize is a storehouse of various nutrients such as carbohydrates, proteins, minerals, vitamins, iron etc. and particularly supplying a high energy of 365 Cal/100g (Kumar and Bhatt *et al.*, 2016). It serves many purposes such as source of human food, livestock and poultry feed. Besides, maize has its wider applications in milling industries for starch and oil extraction. Its large-scale application lies in bio-fuel or ethanol production in many developed countries especially USA and Brazil. Maize was originated from central Mexico and is currently one of the most widely distributed crops. It is cultivated in tropical, subtropical as well as temperate parts of the world ranging from 0 to 4000 meters' height from sea level. It is grown in more than 160 countries of the world and USA, China, Brazil, Mexico, France and India are the major producers. In the beginning of 17th century, it was introduced into India from Central America (Mango *et al.* 2018). In India, it is cultivated over an area of 9.63 million hectares with annual production of 25.90 million metric tons and average productivity of 2.69 metric tons per hectare. Throughout the year, it is cultivated both as food and fodder crop in different seasons (Kharif, Rabi and spring) in different parts of the country. It is cultivated throughout the country in diverse habitats, though Karnataka, Andhra Pradesh, Maharashtra, Bihar, Punjab, Rajasthan and Haryana are the major producers. In Haryana, it is cultivated over an area of 5000 hectares having annual production of 17000 tons with average productivity of 3.40 metric tons per hectare (Singh and Jaglan 2018).

Maize known as corn, a kind of cereal crop (Poaceae: Poales) and commonly known as Bhutta in Bangladesh is the third most important cereal crop after rice and wheat (IRRI and CIMMYT, 2006).

Maize is the third largest planted crop after wheat and rice. It is mostly used and traded as a leading feed crop but is also an important food staple. In addition to food and feed, maize has wide range of industrial applications as well; from food processing to manufacturing of ethanol. This report discusses the significance of maize in the global context. It begins by providing an overview of the different origins/types of maize as well as describing its planting characteristics (Mollah *et al.*, 2018). Estimated corn production is 2.8 MMT in MY 2016/17. Assuming normal growing conditions, in MY 2017/18 corn planted area is forecast about 440,000 ha and production at 3.1 MMT on expectation of increase in feed demand from poultry and aquaculture industries. This 8.6 percent increase in planted area over MY 2016/17 also reflects farmers' desire to utilize less fertile sandy soil (char land)(Wallace *et al.*, 2017).The production area of maize is increasing day by day due to increase day by day due to increase poultry and dairy farms in the country (Kaul and Rahman, 1983).

In Bangladesh it is cultivated to a limited extent in *Kharif* and *Rabi* seasons. But its cultivating area is increasing day by day. The northern part of Bangladesh mainly Rajshahi and Rangpur, divisions are suitable for cultivation of maize. It can be grown throughout the year because of its photo insensitiveness's. Maize is a unique crop because of its versatile use and per unit cost of production is low (Iqbal *et al.*, 2000). It has gained much popularity among the farmers of Bangladesh because of three reasons; (i) its yield is high, (ii) It is high protein content, and (iii) good to use as poultry feed and also in bakery (e.g. corn flake, corn flour). Maize grains have high nutritive value containing 66.2% starch, 11.1% protein, 7. l2%

oil and 1.5% minerals (Choudhury and Islam, 1993). Maize is an economically important food and feed crop being recognized recently in Bangladesh and has gained an increasingly important attention by the government. It accounts for 18% of the world cereal acreage and about, 25% of the world cereal production (Hague *et al.,* 1 999).

The demand for maize in Asia is expected to grow in the next 20 years mainly driven by the growth of the livestock and poultry feed industry as regional income increase and the consumers shift towards animal-based diets. The rapid expansion of the biofuel industry in recent years and high fossil energy costs also influence global maize demand and supply, pushing maize prices to a historic high. The increasing demand for maize is rapidly transforming cropping systems in certain parts of Asia. Where the biophysical and socioeconomic conditions are favorable, significant shifts from rice monoculture to more profitable rice maize systems have either occurred or are emerging (IRRI and CIMMYT, 2006).

In other areas, future potential for rice-maize systems exist but recent increases in maize demand have primarily been met by imports because knowledge and technologies for rice-maize systems are lacking. Cropping systems-based approaches to crop, nutrient, and other management practices are needed to ensure a sustainable, ecologically-sound diversification and intensification of rice-based systems for increased productivity and profitability to benefit farmers (Pasuquin *et al.,* 2007).

Current maize productivity is below its potential, although still higher than that of other major cereal crops. The low yield is attributed to a combination of several production constraints mainly lack of improved production technologies such as pest management practices, moisture stress, low fertility and poor cultural practices (Tufa and Ketema, 2016). Maize stalk borer (*Busseola fusca*), maize aphid, *Rhopalosiphum maidis,* maize earworm *Helicoverpa zea*, spotted stalk borer (*Chilo partellus*), Fall armyworm (*Spodoptera* *frugiperda),* shoot fly, *Atherigona nuquii* and various termite species have long been recognized as key pests, but a more recent invasive species (*Macrotermes* and *Microtermes spp*.) *(*Assefa, 2018 Singh and Jaglan, 2019).

Fall Armyworm (*S. frugiperda*), FAW, is an insect native to tropical and subtropical regions of the Americas. Its larval stage feeds on more than 80 plant species including maize, rice, sorghum, millet, sugarcane, vegetable crops and cotton. FAW can cause significant yield losses if it is not well managed. Its modality of introduction, along with its biological and ecological adaptation across Africa, are still subjects of speculation (Kfir *et al.,* 2002).

FAW was first detected in Central and West Africa in early 2016. Today, it is present in all countries of sub-Saharan Africa except Lesotho. At the end of July 2018, FAW was detected in Yemen and in India: the first occurrence in Asia. As at January 2019, it has been reported in Bangladesh, Myanmar, Sri Lanka, Thailand and China. The map on page vi illustrates the spread of the pest to date (Lanka, 2019). There is no study about fall armyworm in maize crops in Bangladesh. So, we designed the study to know about the insect complex in maize field specially fall armyworm development. Therefore, the objectives of this study were to find out the insect pest abundance in maize (Rabi maize) field and development of fall armyworm in three maize cultivars.

CHAPTER II

REVIEW LITERATURE

Maize or corn (*Zea mays L*) is a plant belonging to the family of grasses Poaceae. It is cultivated globally being one of the most important cereal crops worldwide. Maize is not only an important source of human nutrient, but also a basic element of animal feed and raw material for manufacture of many industrial products (Kumar and Bhatt, 2016).

Fall armyworm

Fall armyworm (FAW), *S. frugiperda* (JE Smith) (Lepidoptera: Noctuidae), is native to tropical and subtropical regions of the Americas and is the key insect pest of maize in tropical regions. The occurrence of FAW was reported in Africa for the first time in late 2016 in West Africa. Subsequently, FAW has rapidly spread throughout Sub-Saharan Africa (SSA) and it has been reported at January 2019, in Bangladesh, Myanmar, Sri Lanka, Thailand and China (Lanka, 2019). FAW is a highly polyphagous insect pest that attacks more than 80 plant species, including maize, sorghum, millet, sugarcane, and vegetable crops; nevertheless, maize is the main crop affected by FAW in Africa. Given the importance of maize in Africa as a primary staple food crop, the recent invasion of FAW threatens the food security of millions of people in a region that will likely have an aggravated drought due to climate change/El Nino in SSA. According to a recent estimate, in the absence of control methods, FAW has the potential to cause losses of an estimated 8.3 to 20.6 m tons of maize per annum (valued at US$2481–6187 m) in 12 maize-producing countries in SSA, which accounts for approximately 20% of the total production in the region (Wallace *et al.*, 2017).

Biology of fall armyworm *Spodoptera frugiperda*

Understanding the biology of insect pest in general and fall army worm particularly is essential to take any action and also hasten scientific investigations to bring immediate solutions. Even though new agricultural pests are periodically introduced into the African agricultural environment and pose some degree of risk, a number of characteristic factors make FAW a more devastating pest than many others, including FAW consumes many different crops, spreads quickly across large geographic areas and it can persist throughout the year (Prasanna *et al.,* 2018).

The Life cycle of fall armyworm

Recognizing FAW is the first step for management. The pest is new to Africa, and farmers need to be able to recognize FAW, and distinguish it from other pests. The Fall Armyworm life cycle includes egg, 6 growth stages of caterpillar development (instars), pupa and moth (FAO, 2018). The FAW life cycle is completed in about 30 days (at a daily temperature of ~28°C) during the warm summer months but may extend to 60-90 days in cooler temperatures. FAW does not have the ability to diapause (a biological resting period); accordingly, FAW infestations occur continuously throughout the year where the pest is endemic. In non-endemic areas, migratory FAW arrive when environmental conditions allow and may have as few as one generation before they become locally extinct. For example, FAW is endemic in south Florida (latitude ~28°N) and populates the entire eastern USA each summer by migration (Prasanna *et al.,* 2018).

The egg is dome shaped: the base is flattened and the egg curves upward to a broadly rounded point at the apex. The egg measures about 0.4 mm in diameter and 0.3 mm in height. The number of eggs per mass varies considerably but is often 100 to 200, and total egg production per female averages about 1,500 with a maximum of over 2,000. Duration of the egg stage is only 2 to 3 days during the warm summer months (Prasanna *et al.,* 2018). The FAW typically has six larval instars. Larvae tend to conceal themselves during the brightest time of the day. Duration of the larval stage tends to be about 14 days during the warm summer months and 30 days during cooler weather. Mean development time was determined to be 3.3, 1.7, 1.5, 1.5, 2.0, and 3.7 days for instars 1 to 6, respectively, when larvae were reared at 25°C (Pitre and Hogg, 1983; Prasanna *et al.,* 2018). It pupates in the soil at a depth 2 to 8 cm. The larva constructs a loose cocoon by tying together particles of soil with silk. The cocoon is oval in shape and 20 to 30 mm in length. Duration of the pupal stage is about 8 to 9 days during the summer, but reaches 20 to 30 days during cooler weather. The pupal stage of FAW cannot withstand protracted periods of cold weather (Prasanna *et al.,* 2018). For example, Pitre and Hogg (1983) studied winter survival of the pupal stage in Florida, and found 51% survival in southern Florida, but only 27.5% survival in central Florida and 11.6% survival in northern Florida. Adult FAW moths have a wingspan of 32 to 40 mm. In the male moth, the forewing generally is shaded gray and brown, with triangular white spots at the tip and near the center of the wing. The forewings of females are less distinctly marked, ranging from a uniform grayish brown to a fine mottling of gray and brown. Adults are nocturnal, and are most active during warm, humid evenings. After a pre oviposition period of 3 to 4 days, the female moth normally deposits most of her eggs during the first 4 to 5 days of life, but some oviposition occurs for up to 3 weeks. Duration of adult life is estimated to average about 10 days, with a range of about 7-21 days (Luginbill *et al.*, 1928; Sekul and Sparks,1976; Prasanna *et al.,* 2018).

Origin and distribution of fall armyworm *S. frugiperda*

Native to the Americas, the fall armyworm; *S. frugiperda* (JE Smith); Lepidoptera, Noctuidae) was first reported as present on the African continent in January 2016 in Nigeria, Sao Tome, Benin and Togo (CIPV,2016; Goergen *et al.*, 2016; CABI, 2017) and causes significant damage on maize crops. According to (Georgen *et al.,* 2016), the FAW is originated from the tropical regions of the Americas going from the United States to Argentina and the Caribbean region. It is a prime noctuid pest of maize and has remained confined there despite occasional interceptions by European quarantine services in recent years. It has been recently introduced into the African continent and has already moved to many countries where the pest has been reported for the past two years (Abraham *et al.,* 2017; Stokstad, 2017; Prasanna *et al.,* 2018). The genus *Spodoptera* comprises 31 species with seven species previously recorded from the Afrotropical region while six species are known to occur in West and Central Africa (Pogue *et al.*, 2002). The crop pest has since been found in over 30 African countries, posing a significant threat to food security, income and livelihoods (Prasanna *et al.*, 2018). Like other moths in the genus *Spodoptera*, FAW moths have both a migratory habit and a more localized dispersal habit. In the migratory habit, moths can migrate over 500 km (300 miles) before oviposition. When the wind pattern is right, moths can move much larger distances (Rose *et al.*, 1975; Prasanna *et al.*, 2018). In most areas of North America, FAW arrives seasonally and then dies out in cold winter months, but in much of Africa, FAW generations will be continuous throughout the year wherever host plants are available, including off-season and irrigated crops, and climatic conditions are favorable. Although the patterns of population persistence, dispersal, and migration in Africa are yet to be determined, conditions in Africa, especially where there is a bimodal rainfall pattern, suggest that the pest can persist throughout much of the year (Prasanna *et al.*, 2018). Adequate management strategy could not be developed without assessing its current distribution and elucidating its bio-ecology in this new environment (Tindo *et al.,* 2017). To-date, FAW has been detected and reported in almost all of Sub-Saharan Africa, except in Djibouti, Eritrea, and Lesotho. Since the pest was detected in Sudan, Egypt and Libya must be on alert (Goergen *et al.,* 2016; FAO, 2018). It was first detected in Central and Western Africa in early 2016, Sao Tome, Nigeria, Benin & Togo and in late 2016 and 2017 in many other countries, and it is expected to move further. FAW's presence in Africa is irreversible (FAO, 2017). Information was collated from all 54 countries in Africa through literature searches, personal communications and internet mining 30 countries have confirmed the presence of FAW, while other countries suspect its presence, or are awaiting official confirmation of the pest in the country (CABI, 2017). As at January 2019, it has been reported in Bangladesh, Myanmar, Sri Lanka, Thailand and China. The map on page illustrates the spread of the pest to date. FAW is a dangerous transboundary pest with a high potential to spread continually due to its natural distribution capacity and international trade. Farmers need significant support if they are to be able to manage FAW sustainably in their cropping systems through Integrated Pest Management (IPM) activities (Lanka, 2019).

Nature and extent of damage

Corn plants are susceptible to fall armyworm (*S. frugiperda)* attack during practically all stages of its development cycle, and severe losses occurs when the whorl is destroyed, reducing photosynthetic area and compromising the grain yield. It may also attack the basal portion of the ear, destroying the grain or favoring infection by microorganisms (Cruz *et al.*, 1999; Goergen *et al.*, 2016). In Africa the pest is causing huge damage to maize crop where the larger larvae can act as cutworms by entirely sectioning the stem base of maize seedlings (Goergen *et al.*, 2016).

Damage on maize may be observed on all plant parts depending on development stage. The extent of damage, however, depends on factors such as planting season, geographical region, cultivar planted and cultural practices inherent in and around the field (Sarmento *et al.*, 2002). Due to favorable environmental conditions, *S. frugiperda* can able to reproduce at a fast rate and caterpillars appear to be much more damaging to maize in West and Central Africa than most other African *Spodoptera* species (Goergen *et al.*, 2016; IITA, 2016). In the absence of proper control methods, FAW has the potential to cause maize yield losses of 8.3 to 20.6 M metric tons per year, in just 12 of Africa's maize producing countries. This represents a range of 21-53% of the annual production of maize averaged over a three-year period in these countries. The value of these losses was estimated at between US$2.48 billion and US$6.19 billion (Day *et al.,* 2017; CABI, 2017; Prasanna *et al.,* 2018). Authors are also mentioned that several seed companies in SSA have reported significant damage to their maize seed production fields over the past year, potentially impacting both the availability of seed to farmers over the coming rowing seasons and the economic viability of Africa's emerging private seed sector. CABI conducted a household socio-economic survey in Ghana and Zambia in July 2017. Survey questions examined farmers' perception of losses specifically due to FAW over the last full growing season. Accordingly, the estimated national mean loss of maize in Ghana was 45% (range 22-67%), and in Zambia 40% (range 25-50%). Using the data from Ghana and Zambia, CABI estimated the potential impacts on national yield and revenue in 10 other major maize-producing countries that are likely to occur in the maize producing seasons, assuming that the FAW will spread throughout all areas where it is predicted to survive (CABI, 2017).

Management practices

Fall armyworm (*S. frugiperda*) is likely to remain a significant agricultural pest across much of SSA for the foreseeable future. It is therefore essential to develop an effective, coordinated, and flexible approach to manage FAW across the continent. Such an approach should be informed by sound scientific evidence, build on past experience combating FAW in other parts of the world, and be adaptable across a wide range of African contexts, particularly for low-resource smallholders. An integrated pest management (IPM) approach provides a useful framework to achieve these goals (FAO, 2017; Prasanna *et al.,* 2018). Large scale eradication efforts are neither appropriate nor feasible. Below are presented with an overview of the managements that have been practiced so far in some African countries and needs to be adopted in other areas of the continent.

Cultural methods

Different cultural methods have been adopted and practiced by farmers in many African countries, including: Plant early, use early maturing varieties, intercrop maize and beans, remove weeds, remove/destroy crop residues, rotate with non-hosts, ploughing/cultivating to expose larvae and pupae, handpicking egg masses and larvae, applying sand sawdust or soil in the whorl (with ash/lime). Many of the measures recommended so far, therefore represent general agro-ecological best practices for pest control though where indicated, emerging evidence suggests efficacy against FAW in Africa, particularly for the “Push-Pull” intercropping approaches. The benefits of cultural and landscape management approaches often arise from the interplay of ecological factors across a range of spatial scales from plot to field to farm to landscape that disrupt and control the pest at multiple stages throughout its life cycle (Veres *et al.,* 2013; Martin *et al.,* 2016). For example, cultural practices such as intercropping, companion cropping, conservation agriculture, and agroforestry may simultaneously improve the health of the crop, provide shelter and alternative food sources for natural enemies, and reduce the ability of FAW larvae to move between host plants. Cultural and ecological management options are highly compatible with host plant resistance and biological control approaches (Martin *et al.,* 2016; Pumariño *et al.,* 2015; Stevenson *et al.,* 2012).

Mass trapping (Pheromone Control) of fall armyworm

Synthetic mimics of the female moth’s sex pheromone used to mass-trap males or disrupt their mate-finding. Set up 4-6 FAW Pheromone traps per hectare to suppress the moth population build up. The infestation is reduced by using different management options and continuous monitoring, and by using integrated fall army worm management method (cultural i.e. early planting, input used, hand picking) pheromone control, insecticide spraying together reduced this pest infestation (Tamiru *et al.,* 2017).

Host-plant resistance of fall armyworm

Historically, considerable effort was undertaken in the Americas to breed for FAW resistance, especially in maize. Similar efforts have only been recently initiated in Africa, following the identification of FAW on the continent in 2016 (Georgen *et al.,* 2016).

Biological control of fall armyworm

In its native range numerous parasitic wasps and flies have been recorded as natural enemies of the fall armyworm and some species, in particular egg and larval parasitoids, are frequently introduced, resulting in noticeable levels of control. The egg parasitoid *Telenomusremus* is frequently introduced to effectively control fall armyworm and other *Spodoptera* species. Natural levels of larval parasitism are often very high (20-70%), mostly by braconid wasps, larval parasitism by a tachinid and a *Cotesia spp*. has already been noted. A large number of isolates of nucleo-polyhedroviruses (NPV) have been obtained from the field and screening efforts only recently resulted in the detection of promising isolates. Similarly, the development of bio pesticides including the use of endophytic entomopathogenic fungi is still in its infancy and needs increased attention for providing viable alternatives to conventional insecticides. Indeed, laboratory experiments have demonstrated that evolution of insect resistance to pest-control measures can be delayed or prevented in the presence of natural enemies (Liu *et al.,* 2014).

However, indiscriminate spraying of toxic pesticides often adversely affects these natural enemies, reducing benefits from biocontrol (Meagher *et al.*, 2016) and potentially increasing the population of secondary pests (Tscharntke *et al.*, 2016).

Chemical control of fall armyworm

Chemical treatment has been the most frequently used control method against *S. frugiperda.* Management of the fall armyworm has been mainly affected through use of synthetic insecticides (Cook *et al.*, 2004). Twenty-nine active ingredients have been recommended for *S. frugiperda* (Gallo *et al.,* 2002). The pyrethroiddeltamethrin was often used in the past and remains as one of the most important available insecticides for insect pests' control of corn crops (Badji *et al.,* 2004). In addition, there have been reported cases of *S. frugiperda* resistance evolution in this insect to this group of insecticides used (Figueiredo *et al.,* 2005). Although some of these are both effective against the pests and less harmful to the environment, experience indicates that choice of insecticides is largely based on a farmer's knowledge and purchasing power, with a tendency to select cheaper products (Pogeto *et al.*, 2012). Interventions based on pest incidence thresholds are primarily meant to better protect young plants and reproductive stages of maize. Therefore, monitoring activities together with alternated application of insecticides such as pyrethroids, carbamates and organophosphates are recommended as immediate measure. Early detection is primordial, as the application of chemical insecticides is only efficient on young larval stages (Goergen *et al.,* 2016).

Integrated insect management of fall armyworm

The most common management strategy for the fall armyworm in the Americas has been the use of insecticides and genetically modified crop (Bt maize). However, the worm has evolved resistance both to several pesticides and to some kinds of transgenic maize (Adamczyk *et al.*

1999; Abraham *et al.,* 2017). It is also complicated by chronic poisoning of farmers in some localities due to incorrect use (Tinoco and Halperin,1998); use of insecticides as a pest management tool for small scale farmers in Africa is minimal, largely due to shortage of information, inaccessibility of appropriate and effective products, and high costs (Midega *et al.,* 2012). Hence, there is an urgent need for developing ecologically sustainable, economically profitable and socially acceptable IPM programs to fight the fall armyworm in Africa (Goergen *et al.,* 2016). Furthermore, challenges observed with the conventional control methods highlighted above, notably development of resistance by the pest to some insecticides and Bt-maize events, indicate that an integrated management approach for fall armyworm that fits within the mixed cropping nature of the African farming systems is necessary for resource constrained farmers (Midega *et al.,* 2018). Currently, integrated management strategies are thought to be the best options. These include monitoring (weekly plant inspection) for treatment decision making, good practices (early planting, use early maturing varieties, intercrop maize with legume, weeding, remove and destroy all crop residues, rotate maize with a non-host, ploughing/cultivating to expose larvae and pupae, handpicking egg masses and larvae, applying sand (mixed with lime or ash), sawdust or soil in the whorl (Tindo *et al.,* 2017). In addition, according to (Abraham *et al.,* 2017), government of countries with FAW presence should immediately promote awareness of FAW, its identification, damage and control, provide emergency/temporary registration for the recommended pesticides.

Origin and distribution of corn aphid

The corn leaf aphid, *R. maidis* (Fitch) (Homoptera: Aphididae), is a serious pest of maize with Asiatic origin but it is now distributed throughout the tropics and temperate regions of the world (Uo, Hiu and Erng, 2006b). This aphid is a polyphagous pest and can cause damage to many host plants species and weeds from Gramineae and occasionally Cyperaceae and Typhaceae. *R. maidis* damages its host plants by feeding, viral disease transmission and honeydew production. Aphid infestation occurs on seedlings, leaves, inside the whorl, the covers inflorescence of plants and produces plentiful honeydew which may result in deformed leaves as well as the sterilization of inflorescences(Azmjou and Olizadeh, 2010b). In addition, *R. maidis* is a vector of plant viruses and may transmit 10 viral diseases to cereals (Hill, Maize is an economically important crop in Iran and worldwide and is planted on nearly 300,000 ha annually (planted in 2006–2007). Few insect pests have been found to attack maize fields in Iran. Among these pests, the corn leaf aphid is prevalent in commercial fields of maize(Azmjou and Olizadeh, 2010a). Outbreaks of this aphid occur in the late growing season, when maize tassels appear. At this time, pesticide applications are generally no longer employed in maize fields; therefore, after this time, aphid control is necessary to produce a high yield of this crop. As is known, pesticide applications have several harmful influences, such as environmental and agroecosystems pollution, being detrimental to human health, as well as financial issues. Moreover, in recent decades, the resistance of different pest species against chemical compounds has considerably increased in the world(Pan *et al.*, 2017).

Environmental requirement

The corn leaf aphid may be the most important aphid pest of cereals in tropical and warm temperature climates (Hodgson, Neal, and Schmidt, 2009). Although corn leaf aphids are not tolerant of cold temperatures, they migrate northward in the spring from southern overwintering sites (Uo, Hiu, and Erng, 2006a).

The effects of six constant temperatures (11, 15, 19, 23, 26, and 29°C) and three fluctuating temperatures (average: 18, 22, and 29°C) on the development of corn leaf aphids on barley were studied in the US, but only the effects of the three fluctuating temperatures on population growth statistics were reported (Elliott and Kieckhefer, 1988).

Biology

Biology of maize aphid has been studied under uncontrolled, field and controlled conditions (Co, 1972). The aphid species undergoes 4 nymphal stages to maturity. The average durations of the instars reared on barley under field and controlled conditions were; (1) first instar, 1.30 and 1.88 days; (2) second instar, 1.36 and 1.29 days; (3) third instar, 1.16 and 1.00 days; and (4) fourth instar, 1.41 and 1.29 days for totals 5.23 and 5.46 days, respectively. Lifespan averaged 23.83 days and the aphids gave birth to an average of 61.33 offspring (Veg and Agr, 1967). Temperature is probably the most important environmental variable influencing rates of aphid development and reproduction (Elliott and Kieckhefer, 1988). For winged aphids, temperature can be regarded as the effective releaser of takeoff in the morning and light as the inhibitor in the evening (Johnson and Taylor, 1957).

Life cycle of corn leaf aphids

Corn leaf aphids reproduce solely by parthenogenesis. Females produce genetically identical offspring without mating. Sexual forms of corn leaf aphids have only been found in a few populations that are host specific to Himalayan prune cherries (*Prunus cornuta*) in Pakistan. Males are produced occasionally in other colonies, but they do not mate (Ben-ari, Gish, and Inbar, 2014).

Corn leaf aphids produce live young by parthenogenesis. Females produce genetically-identical clones, without fertilization by males. Female fecundity changes with temperature, optimal temperatures occur around 20 to 25 degrees Celsius. A single female can produce anywhere from 5 to 75 offspring during her lifetime. Corn leaf aphids can reach maturity in about 7 to 8 days. Colony size and parthenogenesis typically peaks in July, or later in the host crop's growing season, depending on the region (Kuo *et al.*, 2006).

Nature and extent of damage

Yield loss in maize by direct feeding of com leaf aphid is periodic and sporadic but considerable when it occurs (Foott, 1973)reported that when plants were lightly infected with com leaf aphid, about 10% of yield was reduced. However, significant reduction in yield by corn leaf aphid can be encountered when com plants suffer from drought stress (Hbn *et al.*, 1960). Foott *et al.* (1973) reported up to 91.8% yield reduction in heavily infected, drought-stressed maize.

Direct feeding by colonies of com leaf aphid may cause the followings ; (a) injury to the central tassel spike resulting in failure to shed pollen; (b) gumming up of the lateral branches of the tassel with honeydew which prevents pollen shedding; (c) failure of tassel to emerge completely; (d) development of molds and rots on the upper portion of the plant which often extends down to the ears; (e) yellow and red discoloration of com leaves especially under high level of infestation; (f) accelerated maturity with partially filled ears, an effect due to aphid feeding on kernels and silk; (g) a concomitant increase in the infestation of com earworm (*Helicoverpa zea*) (Boddie), which is attracted by the honeydew produced by com leaf aphids (Hbn *et al.*, 1960).

Corn leaf aphid management

Cultural

Rotation will help minimize the buildup of sorghum pests in the same field. Plant well-adapted, vigorous, high-yielding hybrids with good disease resistance and stand ability (Uo *et al.*, 2006b). Test soil and apply fertilizer and lime according to the University of Georgia

Cooperative Extension recommendations to maintain the proper soil fertility (Nandjui, Armand, Théodore, and Adjoafla, 2018). Maize planted in early May in South Georgia and by the middle of May in north Georgia often escapes major insect damage. Several maize pests, such as sorghum midge, do not usually reach damaging population levels until after early plantings are mature (Studebaker and Lorenz, 2013).

This practice helps reduce the incidence of damage from insects, which may establish infestations on weeds, volunteer grasses or grass sod. Also, cutworms are often a problem where previous-crop residue is present on the soil surface at planting (Elliott and Kieckhefer, 1988.

Biological

There are many effective natural enemies of aphids. Hoverfly larvae, lacewings, ladybird beetles and damsel bugs are known predators that can suppress populations. Aphid parasitic wasps lay eggs inside bodies of aphids and evidence of parasitism is seen as
Bronze-colored enlarged aphid 'mummies. As mummies develop at the latter stage of wasp development inside the aphid host, it is likely that many more aphids have been parasitized than indicated by the proportion of mummies. Naturally occurring aphid fungal diseases (*Pandora neoaphidis* & *Conidiobolyus obscurus*) can also suppress aphid populations (Hodgson *et al.*, 2009).

Chemical

Since 1990, a new class of synthetic chemicals, the neonicotinoids, has entered the pesticide market and its use has grown rapidly. The neonicotinoids have a systemic mode of action in the plant, which becomes toxic for insects sucking the circulating fluids or ingesting parts of it. They are effective in the control of a range of insect pests, including aphids. This group of insecticides is frequently applied to crops as seed treatments at sowing to protect seedlings (Han, Tian, & Shen, 2017). Conservation of natural enemies through using selective pesticides has been one of the main criterions for establishing an integrated pest management program (Mahmoud, Osman, and Mahmoud, 2017).

Origin and distribution of *Chilo partellus*

Chilo partellus originated in India and had since spread to East Africa, southern Africa it occurs in Botswana, Lesotho, Malawi, Mozambique, Swaziland, Zimbabwe and South Africa (Kfir *et al.,* 1992). *Chilo partellus* is found in warm, low-lying regions and restriction of *C. partellus* to low altitude was probably due to temperature limits (Ingram, 1954). In South Africa *C. partellus* was first reported by A. Barnard near Naboomspruit (24° 31S, 28° 41E), Transvaal on 12 March 1958 and has now become widely distributed throughout the Springbok Flats (Ingram, 1954). Its distribution also extends from western grain producing areas to coastal areas of Natal when host plants are available and temperature is favorable for the development of *C. partellus*, this species develops continuously throughout the year although Ingram (1958) found that it was restricted to altitudes below 1 500 m above mean sea level (amsl.) in Uganda, he speculated that *C. partellus* should be able to spread to regions higher than 1 500 ml (Africa, 2001).

Biology and life cycle

The corn stem borer *Chilo partellus* undergoes a complete metamorphosis. Each stage takes different number of days depending on prevailing abiotic and biotic factor prevailing growth and development involves the eggs hatching into larvae. The larva then changes into pupa stage and then finally adult. *Chilo partellus* lays 10-80 overlapping eggs per batch on both upper and lower leaf surfaces, usually close to the midrib (Y. Assefa, Conlong, Berg, and Mitchell, 2010).

These eggs hatch into larvae 3-5 days, Young larvae feed in the leaf whorl while older larvae tunnel into stems, eating out extensive galleries, within which they live, feed and grow for about 15-22 days (Tamiru, Getu, Jembere, and Bruce, 2012). When larvae are fully grown, they pupate and remain inside the maize stem for 7-14 days. Afterwards, adults emerge from pupae and come out of the stem through the exit windows. The moths usually mate soon after the female emerges and stay for 2-3 days before they oviposit on maize plants again and continue damaging the crop. During the dry season, *C. partellus* may enter a state of diapause for several months and will only pupate at the start of rains. Adults emerge from pupae in the late afternoon or early evening. They are active at night and rest on plants and plant debris during the day. They are rarely seen, during the day unless they are disturbed (Sétamou, Jiang, and Schulthess, 2005).

The whole life cycle takes about 25-50 days, varying according to temperature and other factors. Five or more successive generations may develop under favorable conditions. In regions where there is sufficient water and an abundant of host plants, the spotted stemborer can reproduce and develop all year-round (Bag and Africa, 1991).

Environment requirement

Generally, *C. partellus* has been known in low to mid altitudes (< 1500m) and warmer areas However, a growing number of studies indicate that the pest is expanding its geographic distribution to higher elevation(“18285-14798-1-PB.pdf,” n.d.2007). *C. partellus* presence in relatively high altitude zones (moist high and moist mid-altitude zones) where the pest used not to occur (Khadioli *et al.*, 2014). The pest has been reported to be highly invasive and partially displacing other indigenous stemborer species, such as *Busseola fusca* and *Chilo orichalcociliellus,* in several areas(“18285-14798-1-PB.pdf,” n.d. 2007). Evidence from laboratory studies conducted to examine the displacement of the indigenous stemborer *Chilo* orichalcociliellus has revealed that *C. partellus* had a higher fecundity than *C. orichalociliellus* at 25°C and 28°C (Ofomata, Overholt, Lux, and Huis, 2000).

Nature and extent of damage

In older maize plants *C. partellus* causes stem tunneling as well as tunneling and feeding on the grain inside the enclosed panicle in the case of sorghum and also tunnel the peduncle and move up to the panicle (Kumarl *et al.,* 1993). Tunneling not only weakens and causes breakage of stems of sorghum plants but also interferes with supply of nutrients to the developing grains by destroying the plant's vascular system and resulting in chaffy panicles (Agrawal *et al.* 1990; Kishore *et al.* ,1987). In Africa and Asia, the damage caused to maize and sorghum crops may lead to yield reductions of 50% or more (Walker and Walker, 1994).

Management practices of *Chilo partellus*

Cultural methods

Cultural methods are aimed at reducing population growth. The commonly used methods include: tillage, mulching, right spacing, manipulating planting time, crop rotation, fertilizer application and crop residue management (Taylor *et al.,* 2006). The disadvantage of using cultural methods are that crop residues have many uses, there is shortage of labor and finance (Bonhof, Overholt, Huis and Polaszek, 1997).

Use of resistant crop varieties is the most important and promising way to reduce damage and yield loss due to stem borer (Kfir *et al.,* 1997). Several mechanisms are utilized by resistant maize varieties against the attack by *C. partellus*. These include non-preference for oviposition, reduced feeding and tunneling, tolerance to leaf damage, dead heart and stem tunneling and antibiosis (Sharma, Nain, Lakhanpaul, and Kumar, 2011).

Biological control

Natural enemies are usually not sufficiently abundant to keep stemborer populations at low levels (Maniahia *et al.,* 1992). A combination of the different approaches of classical biological control, conservation of indigenous natural enemies, application of commercially produced micro-organisms and redistribution of locally important natural enemies may provide a suitable management strategy for the sustainable control of *C. partellus* in Africa (Bonhof *et al.,* 1997). Efforts have been made to introduce exotic 19 parasitoids, *C. flavipes*, for control of *C. partellus* and reports indicate that the parasitoid is currently established in Kenya, Tanzania, Uganda, Zambia and Ethiopia (Omwega *et al.*, 1995).

Chemical control

Maize stem borer *C. partellus* is most destructive one. In sever infestation at seedling stage it causes loss up to 75%. It attacks all parts of the maize plant except roots (Anonymous *et al.,* 1986). (Khan *et al.,* 1983) granular formulation of Carbofuran, Disulfoton, Diazinon and Fenthion at 0.60, 1.50 and 1.75 kg a.i./ha, respectively against the maize stem borer *C. partellus* and concluded that the systemic compound (Carbofuran and Disulfoton) applied in the furrow were more effective than the non-systemic compounds as foliar applications (Marwaha *et al.* 1984) reported that on the basis of percent dead -hearts and leaf injury, the soil treatment with Carbofuran granules at 1.0 kg a.i./ha and seed treatment with Carbofuran at 3.0 kg a.i./ha were superior to other treatments.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted at three farmers field to observe the abundance of major maize insect pests at 3 different growth stages (seedling, pre corn formation and corn formation) of maize and development and reproduction of Fall armyworm in three maize varieties at Dinajpur district during the period from January to June 2019.

Abundance of insect pest’s complex in maize fields

The survey was undertaken with pests’ problems faced by the farmers in maize field. More vulnerable stages of maize cultivation to insect pests were identified and number of insect pests were seen during survey period.

Sampling and collection of insects

The study was conducted in three different locations of the Dinajpur district such as Noshipur, Karnai, and Sadipur. in each location three different farmer’s maize fields were selected randomly. The insect pests of maize were sampled from each plot at different stages such as seedling, pre-corn formation and corn formation at every 10 days intervals (Plate .1).

Plate 1: Sampling and collection of insect pests

Field scouting

Field observation was done at every 10 days after and damage symptoms occured and number of insect pests from different maize fields locations were recorded. The eggs, larva, pupa and adults of maize insects were observed from randomly selected 10 maize plants per plots in a zigzag pattern. The collected specimens were brought in laboratory and identified and recorded with the help of stereo microscope (Amscope, China) and suitable keys with reference to books, journals, booklets, scientific articles etc.

Monitoring the fall armyworm by pheromone trap

Pheromone traps were used to monitor the fall armyworm moth in different locations. Plastic container (15 H × 5 D cm) having sex pheromone lure ((Z)-7-dodecen-1-ol acetate (Z7:12 Ac)) (Ispahani Agro limited) with soap water were placed to each plot and counted number of fall armyworm caught by using the trap. The samples were brought to laboratory for further identification and confirmation by stereo microscope (Amscope, China) Number of trapped fall armyworm moth was recorded at every 10 days interval.

Developmental biology of fall armyworm on maize cultivars

Mass rearing of fall armyworm

FAW Larvae was collected from maize field in Noshipur, Sadipur and Karnai near the HSTU campus in 2019. The collected larvae were reared in plastic cages for one generation provided three maize cultivars as food for larvae (10 × 5cm) net cage for (40 H × 38 D cm) (Plate. 2) at 31.62 ± 0.16°C, relative humidity 79.25% ± 1.60 and natural photoperiod in the laboratory. Larvae were supplied 15 days old fresh maize leaf for food in every day and moths were fed sugar solution for food. The pupa was kept on cage (10 H × 5 D cm). The cages were clean every day and supplied newly fresh maize leaves. A 10 days old maize plant and piece of wax paper were inserted for oviposition and collected the eggs every day.

Plate 2: Different stages of Fall armyworm inside the rearing box.

Reproduction of fall armyworm

The newly emerged adults (male and female) were transferred to cages (40 H × 38 D cm) for mating. This cage was a clear and transparent container. A 10 days old maize plant and piece of wax paper were placed inside the rearing cages for oviposition. After 12 h, the laid eggs were collected from the container. In order to calculate age-specific survival rate and daily fecundity of *S. frugiperda*, each egg was placed individually into plastic Petri dishes (5 H × 3 cm H) containing fresh leaves of maize. A hole (2 cm diameter) was cut at the center of top of Petri dishes and covered by fine nylon mesh for ventilation. 30 larvae of first instar were randomly selected and placed 30 container and fed with three varieties of maize (BISCO51, KOHINOOR1280 and M. GOLD) for each larva and recorded the development. Developmental stages were checked daily and developmental periods and mortality of eggs, larvae, pupae, and adults were recorded.

Fecundity and Longevity

Adults male and female (1:1) were selected randomly and transferred to cages (25 H × 20 cm D) 27 cages (25 H × 20 cm D) were used for mating in order to calculate the number of eggs laid in their next generation and their actual life span.

Statistical analyses

Seasonal number of different insects was analyzed by univariate mean separation using SPSS version 22. Development time, adult longevity, fecundity and life table parameters were statistically analyzed by the completely randomized design (CRD) using IBM SPSS Statistics 25 and Microsoft office Excel 2007 in a microcomputer. The treatment mean values were adjusted by Tukey alpha.

CHAPTER IV

RESULTS

Abundance of insect pests in maize fields

The experiment was conducted in three different locations near the HSTU campus like Noshipur, Sadipur and Karnai during March to May. Fluctuation of different insects was observed in the maize fields, which showed in figure 1. The maize aphids, *Rhopalosiphum maidis* (Aphididae: Hemiptera) was found higher than other insects (Fig.2) (1489) (F= 26.976; df = 6; P< 0.001). The highest number of aphids was found in Karnai than other two study sites (Fig.3) (573) (F= 1.344; df = 2; P< 0.291). The maize aphid's infestations were appeared in the month of March and peak in the month of May (Fig.1) (F= 66.44; df = 6; P< 0.001).

The fall armyworm, *S. frugiperda* was observed second highest insect than others (Fig.2) (265) (F= 26.976; df = 6; P< 0.001). The highest number of fall armyworm was recorded in Noshipur than other two study sites (Fig.3) (95) (F= 0.076; df =2; P<0.927) The fall armyworm infestations were appeared in the month of March and reached peak in the month of April and decreased in the month of May (Fig.1) (F= 66.44; df = 6; P< 0.001).

The maize stem borer, *Chilo partellus* (Crambidae: Lepidoptera) and maize earworm, *Helicoverpa zea* (Noctuidae: Lepidoptera) were noted third highest than other insects (Fig. 2) (167) (F= 26.976; df = 6; P<0.001), (156) (F= 26.976; df = 6; P<0.001). The highest number of maize stem borer and maize earworm were recorded in Karnai (Fig. 3) (72) (F= 2.772; df = 2; P<0.095) (62) (F= 2.772; df = 2; P<0.095). The maize earworm infestation was recorded in the month of March and peak in the month of May (Fig.1) (F= 66.44; df = 6; P< 0.001), (F= 1.444; df = 2; P<0.267). The maize stem borer infestation was recorded in the month of March and peak in the month of May (Fig. 1) (F= 66.44; df = 6; P< 0.001).

The black cutworm, *Agrotis ipsilon* (Noctuidae: Lepidoptera) were found the least pest than other insects (Fig. 2) (66) (F= 26.976; df = 6; P< 0.001). The highest number of black cutworm was recorded in Noshipur than other two sites of study (Fig. 3) (26) (F= 1.237; df = 2; P<0.138). The black cutworm infestation was recorded in the month of March and peak in the month of March (Fig. 1) (F= 66.44; df = 6; P< 0.001).

Insect fluctuation are shown in figures 4, 6,8 while number of insects showed in figures 5, 7 and 9. In Noshipur, the maize aphids, *R. maidis* were found higher than other insects (Fig. 5) (374) (F= 16.912; df = 6; P< 0.001). The maize aphid's infestations were appeared in the month of March and reached peak in the month of April (Fig. 4) (F= 16.912; df = 6; P< 0.001). The fall armyworm, *S. frugiperda* was found second than other insects (Fig. 5) (81) (F= 16.912; df = 6; P< 0.001). The fall armyworm infestation appeared in in the month of March and found peak in the month of April (Fig.4) (F= 16.912; df = 6; P< 0.001). The maize stem borer, *C. partellus* and maize earworm, *Helicoverpa zea* were noted third than other insects (Fig.5) (52) (F= 16.912; df = 6; P< 0.001) (51) (F= 16.912; df = 6; P< 0.001) (F= 16.912; df = 6; P< 0.001). The maize earworm infestation appeared in the month of March and observed peak in the month May (Fig.4) (F= 16.912; df = 6; P< 0.001). The maize stem borer, *C. partellus* infestation appeared in the month march and peak in the month May (Fig.4) (F= 16.912; df = 6; P< 0.001). The black cutworm, *A. ipsilon* were recorded fourth than other insects (Fig.5) (22) (F= 16.912; df = 6; P< 0.001). The black cutworm infestation appeared in the month of March until May in normal curve (Fig.4) (F= 16.912; df = 6; P< 0.001).

In Sadipur, the maize aphids, *R. maidis* were found higher than other insects (Fig.7) (542) (F= 16.912; df = 6; P< 0.001). The maize aphid's infestations were appeared in the month of March and appeared peak in the month of May (Fig.6) (F= 16.912; df = 6; P< 0.001). The fall armyworm, *S. frugiperda* were found second than other insects (Fig.7) (95) (F= 16.912;

df = 6; *P*< 0.001). The fall armyworm infestation appeared in in the month of March and peak in the month of April (Fig.6) (*F*= 16.912; *df* = 6; *P*< 0.001). The maize stem borer, *C. partellus* and maize earworm, *Helicoverpa zea* were noted third than other insects (Fig.7) (43) (*F*= 16.912; *df* = 6; *P*< 0.001) (43) (*F*= 16.912; *df* = 6; *P*< 0.001). The maize earworm infestation appeared in the month of March and appeared peak in the month May (Fig.6) (*F*= 16.912; *df* = 6; *P*< 0.001). The maize stem borer, *C. partellus* infestation appeared in the month march and peak in the month May (Fig.6) (*F*= 16.912; *df* = 6; *P*< 0.001). The black cutworm, *A. ipsilon* were recorded last than other insects (Fig.7) (26) (*F*= 16.912; *df* = 6; *P*< 0.001) The black cutworm infestation appeared in the month of March and peaked little in May (Fig.6) (*F*= 16.912; *df* = 6; *P*< 0.001).

In Karnai, the maize aphids, *R. maidis* were found higher than other insects (Fig.9) (573) (*F*= 26.976; *df* = 6; *P*< 0.001). The maize aphid infestations were appeared in the month of March and peak in May (Fig.8) (*F*= 26.976; *df* = 6; *P*< 0.001). The fall armyworm, *S. frugiperda* were found second than other insects (Fig. 9) (89) (*F*= 26.976; *df* = 6; *P*< 0.001). The fall armyworm infestation appeared in the month of March and reached peak in the month of April (Fig.8) (*F*= 26.976; *df* = 6; *P*< 0.001). The maize stem borer, *C. partellus* and maize earworm, *H. zea* were noted third than other insects (Fig.9) (72) (*F*= 26.976; *df* = 6; *P*< 0.001) (62) (*F*= 26.976; *df* = 6; *P*< 0.001). The maize stem borer infestations appeared in the month of March and found peak in the month of April (Fig.8) (*F*= 26.976; *df* = 6; *P*< 0.001). The maize earworm infestation appeared in the month of March and observed peak in the month May (Fig.8) (*F*= 26.976; *df* = 6; *P*< 0.001). The black cutworm, *A. ipsilon* were recorded last than other insects (Fig.9) (18) (*F*= 26.976; *df* = 6; *P*< 0.001). The black cutworm infestation appeared in the month of March until May in normal curve (Fig.8) (*F*= 26.976; *df* = 6; *P*< 0.001).

Abundance of natural enemies of maize insect pests in three different locations

Different natural enemies were found during the study period and the fluctuation was showed in fig. 1. Lady bird beetle, *Coccinella septempunctata* (Coccinellidae: Coleoptera) were found higher than lacewing (Fig.2) (373) (F= 26.976; df = 6; P< 0.001). The highest number of Lady beetle was found in Noshipur than other two study sites (Fig.3) (151) (F= 1.344; df = 2; P< 0.291). The lady beetle was appeared on March and peak in April (Fig.1) (F= 66.44; df = 6; P< 0.001).

Lacewing *Chrysoperla carnea* (Chrysopidae: Neuroptera) were found as second natural enemy (Fig.2) (296) (F= 26.976; df = 6; P< 0.001). The highest number of lacewings was found in Noshipur than other two study sites (Fig.3) (125) (F= 1.344; df = 2; P< 0.291). The lacewing was appeared on March and peak in April (Fig.1) (F= 66.44; df = 6; P< 0.001).

Natural enemies fluctuation in Noshipur was showed in (Fig.10). Lady bird beetle, *C. septempunctata* appeared on March and observed peak in May (Fig.10). Lacewing *C. carnae* appeared on March and reached peak in April (Fig. 10) (F= 3.485; df = 1; P< 0.091).

In Sadipur. lady beetle, *C. septempunctata* appeared on March and peak in May (Fig. 10). Lacewing *C. carnea* appeared on March and peak April and May (Fig. 10) (F= 528.328; df = 2; P< 0.001).

In Karnai, lady beetle, *C. septempunctata* appeared on March and reached peak in April and May (Fig 10). Lacewing *C. carnae* appeared on March and peak in April and May (Fig. 10) (F= 175.235; df = 2; P< 0.001). The distribution of natural enemies observed from March and found its peak on April.

Effect of host plants on the development of *S. frugiperda*

Developmental rates of *S. frugiperda* is shown in three different maize varieties in Table 1. Among the tested maize varieties, the developmental rate was found the highest in BISCO51cultivar while the lowest in M. GOLD. Oscillation was observed in the line of egg to adult developmental rates in three different maize varieties. Female *S. frugiperda* were fastest on BISCO51 followed by KOHINOOR1820 and then M. GOLD.

The duration of incubation period of *S. frugiperda* was 3, 2.6 and 2.59 days on BISCO51, KOHINOOR1820 and M. GOLD, respectively when fed the three maize varieties. But significant difference was found among the tested maize varieties (F = 7.250; df = 2; P< 0.001). Larval development not showed significant difference while reared with three maize cultivars (Table 2). Development time of first instar were 2.83, 2.90, 2.81 and 2.83, 2.86, 2.80 days for female and male while fed on BISCO51, KOHINOOR1820, and M. GOLD maize varieties respectively. Development time of first instar larva of female *S. frugiperda* was short on M. GOLD than BISCO51 and KOHINOOR1820 cultivars. Larvae of male *S. frugiperda* (1st instars) developed fastest on M. GOLD followed by BISCO51 and KOHINOOR1820. The first instar of male *S. frugiperda* and female were showed not significant differences (F = 0.076; df = 2, P<0.927) (F = 0.404; df = 2, P <0.669) among the variety. The female and male larvae of *S. frugiperda* (2nd instars) ranged from 2.83 to 2.83 2.83 to 2.93and 2.7 to 2.80 days, respectively. The development time of female and male *S. frugiperda* (2nd instars) larva on the three varieties of maize also showed not significant differences (F = 0.00; df = 2; P <1.00) (F = 0.270; df = 2; P <0.764). The development time of female and male larvae of *S. frugiperda* (3rd instars) ranged from 3.03 to 2.93, 3.03 to 3.1 and 2.91 to 2.9 days, respectively. The development time of female and male *S. frugiperda* (3rd instars) larvae showed no statistical difference and not significant (F = 0.169; df = 2; P <0.845) (F = 0.819; df = 2; P < 0.444). The development time of female and male larvae (4th instars ranged from 3.03 to 2.8, 3.0 to 2.86 and 2.86 to 2.78 days, respectively. The development time of male and female *S. frugiperda* (4th instars) larva showed not significant differences *(F* = 0.920*; df* = 2*; P*<0.403*) (F* = 0.097*; df* = 2*; P* <0.907*)*. The development time of female and male larva (5th instars) ranged from 3.1 to 2.9, 3.0 to 3.0, and 2.92 to 2.85 days respectively. The development time of male and female *S. frugiperda* showed no significant differences *(F* = 0.495*; df* = 2*; P*<0.611*) (F = 0.959; df = 2; P < 0.387)*. The development time of female and male larva (6th instars) ranged from 2.93 to 2.96, 2.96 to 2.9 and 2.87 to 2.86, days respectively. The development time of male and female *S. frugiperda* showed no significant differences *(F* = 0.044*; df* = 2*; P* <0.957*) (F* = 0.021*; df* = 2*; P* <0.979*)*. Development time of the pupa stage female and male *S. frugiperda* occurred in different maize varieties shown Table 1. The time ranged from 7.6 to 8.0, 8.3 to 8.6 and 8.0 to 8.23 days for male. The longest female development time occurred in KOHINOOR1820 (8.3 days) but the shortest in BISCO51 (7.6 days) while the longest male development time took place KOHINOOR1820 (8.6 days) but the shortest happened on BISCO51 (8.0 days) and statistically was not significant *(F* = 2.355*; df* = 2*; P* <0.101*) (F* = 1.357*; df* = 2*; P* <0.263*)*. Development time of the adult female and male *S. frugiperda* occurred in different maize varieties and shown Table 1. The time ranged from 10.9 to 10.9, 10.3 to 10.3 and 9.1to 9.20 days and The longest female development time occurred in BISCO51 (10.9 days) but the shortest in M. GOLD (9.1 days) where the longest male development time took place BISCO (10.9 days) but the shortest in M. GOLD (9.2 days). The development time of female and male *S. frugiperda* showed significant differences *(F* = 5.357*; df* = 2*; P* <0.006*) (F* =5.221*; df* = 2*; P* <0.007). The development time from the egg stage to adult of *S. frugiperda* occurred in different maize varieties shown in Table1. The time ranged elapsed from (female) and (male) egg stage to adult emergence was 39.0 to 39.1, 38.8 to 36.8 and 36.5 to 35.6 days days.

The development time of female and male S. *frugiperda* showed significant differences (F = 158.910; df = 2; P <0.001) and (F= 107.421; df = 2; P < 0.001).

Effect of host plants on sex ratio of female *S. frugiperda*

The proportion of male *S. frugiperda* ranged from 0.45 to 0.56 on the three maize varieties (Fig. 11). The proportion of males was the maximum in BISCO51 while minimum in M. GOLD.

Effect of treatments on the reproduction of *S. frugiperda*

Reproductive phases and fecundity of *S. frugiperda* is presented in Table 2. The longest re-oviposition and post oviposition period (1.77 and 7.0 days) were observed on KOHINOOR1820 and BISCO51. The both periods were found the shortest (1.72 and 4.7 days) on the varieties BISCO51 and M. GOLD. Upon adult emergence, the females were arranged to get mated with released males. Maize varieties showed no significant effect on the duration of the pre oviposition *(F* =0.029*; df* = 2*; P* <0.971*)*, oviposition *(F* =0.178*; df* = 2*; P* <0.837*)* and post oviposition period *(F* =3.050*; df* = 2*; P* <0.056*)*. The age specific fecundity rate (m_x) was found peak on BISCO51and the fecundity period was constricted on M. GOLD. The adult *S. frugiperda* observed for characters like oviposition period, daily fecundity and lifetime fecundity are presented in Table 2. The longest oviposition period (2.72 and 2.68 days) were observed M. GOLD and KOHINOOR1820 while the shortest period (2.61 days) were found BISCO51. The total oviposition period of female *(F* =0.178*; df* = 2*; P* <0.837*) S. frugiperda* on the three maize varieties of maize showed no significant differences. The daily fecundity of the *S. frugiperda* occurred in different maize varieties shown in Table 2. The maximum number of eggs (63.78 eggs) was laid on BISCO51, while minimum (32.9 eggs) oviposited on M. GOLD. The total daily fecundity of female *(F* =5.030*; df* = 2*; P* <0.010*) S. frugiperda* on the three maize varieties of maize showed significant differences. The lifetime fecundity of the *S. frugiperda* the maximum number of eggs (143.05 eggs) was laid on BISCO51, while minimum number (88.6 eggs) oviposited on M. GOLD. The total lifetime fecundity of female *(F* =11.801*; df* = 2*; P* <0.001*) S. frugiperda* on the three maize varieties of maize showed significant differences.

Effect of treatments on the life table parameters of *S. frugiperda*

Variations of life table parameters were estimated on three different maize varieties (Table 3). The net reproductive rate *(Ro)* was the highest (195.85) while fed on BISCO51 but the lowest (135.06) on M. GOLD. Intrinsic rate of natural increase (r_m) was observed maximum (0.185) on BISCO51 but minimum on (0.172) on M. GOLD. Mean generation time, *T* was the longest (29.42days) on KOHINOOR1820 while the shortest (28.35) on M. GOLD. Finite rate of increase (λ) was the longest (1.30) on BISCO51 while the shortest (1.18) on M. GOLD. Population doubling times, *DT* was the longest (4.01) on M. GOLD while the shortest (3.74) on BISCO. The gross reproductive rate (GRR) was the highest (195.85) hosted on BISCO51 while the shortest (158.28) on M. GOLD.

CHAPTER V

DISCUSSION

Maize is one of the most important food grains in the world as well as developing countries and one of the cash crops in Bangladesh which has the potential to pull-out farmers against poverty. The experiment was carried out the seasonal occurrence of the major insect pest in maize in the northern part of Bangladesh and observed the fall armyworm development in different maize variety. Maize aphids were the highest (1489) insect species than others in March to May and appeared peaked in May. The population of aphids increased gradually towards the crop maturity and attained maximum when the plant was soft and succulent (Singh and Gaurav, 2019).

Fall armyworm was the second highest (265) than other pests March to May which reached peak in April. (Sisay *et al.*, 2019). reported that percent FAW infestation ranging from 5.3% to 100% and relatively high FAW infestation (>73%) were recorded in Kenya and Tanzania.

Maize stem borer (167) and maize earworm (156) were the third insect pest and then other insects March to May and observed peak in the month May. Maize stem borer was the most predominant species in June to September (60.0%) and October to January (8.43%) and also found that the lower abundant in March (Rajin *et al.,* 2000). The infestation of stem borer was started in early seedling stages and increasing the growth of plants.

Black cutworm, *A. ipsilon* was the less dominant insect pest (66) than others in March to May and peaked in the seedling stage and reduced gradually as the maize plant growth(Shrivastava *et al.* ,1987) stated that cut worm infestations differed significantly among different stages maize with the mean ranged from 0.35 to 2.94 per 10m^2. The highest number of cut worm (2.94) was recorded at seedling stage followed by a pre-cob formation 0.95 and lowest (0.35) at corn formation stage. (Shrivastava *et al.,* 1987).

Lady bird beetle was the highest than lacewing in all study sites (373) which appeared from March to May and reached peak in April and May. The differences among the result may be due to the environmental conditions led the growth stages of crops. Jatoi and Ghulam *et al.,* (2016) revealed that the lowest population of lady bird beetles (0.096±0.010/plant) was monitored when maize was cultivated as trap crop, followed by sunflower and peas with population of 0.102±0.009/plant and 0.108±0.004/plant, respectively but the against highest population (0.125±0.0.003/plant) in the control. Lacewing was the second natural enemy (296) after lady bird beetle from March to May and appeared its peak in April and May.

The duration of incubation period ranged from 2.83, 2.3, and 2.4 days in BISCO51, KOHINOOR1820 and M. GOLD. Barcelos and Fernandes, (2019) found that the incubation period of *S. frugiperda* was 3.0 days in BRS 506, BRS 509 and BRS 511 cultivars of sorghum. The average incubation period was closely related to our study.

The development time of larvae (1^{st} instars, 2^{nd} instars, 3^{rd} instars, 4^{th} instars, 5^{th} instar, 6^{th} instars) were 2.83 to 2.82, 2.97 to 2.88, and 2.96, 2.91 days under BISCO51, KOHINOOR1820 and M. GOLD maize cultivars respectively. (Urúa *et al.,* 2004) assessed Population Parameters of *S. frugiperda* fed on corn and two predominant grasses found developmental time of larvae (1^{st} instars, 2^{nd} instars, 3^{rd} instars, 4^{th} instars, 5^{th} instar, 6^{th} instars) were 2.61, 2.68, 2.80, 3.73, 3.83, and 6.63 days. (Castro and Henry 1988) assessed the development of fall armyworm, *S. frugiperda* on sorghum or corn in the laboratory were found that 2.0, 1.7, 2.0 2.5, 3.0 days when fed corn and 2.0, 1.6, 2.2, 2.5, 3.1 days when fed sorghum. Our result is quite relevant to these two studies.

The development time of pupa was 7.8, 8.45 and 8.1 (days) in BISCO51, KOHINOOR1820 and M. GOLD maize cultivars. Mello &Bueno (2015) found that the developmental time of *S. frugiperda* pupa was 9.58, 9.44, 8.54, 8.86, 9.08, 9.70 days.

The development time of adult ranged from 10.9, 10.3, and 9.15 (days) under BISCO51, KOHINOOR1820 and M. GOLD maize cultivars. Lauren & Fernandes (2018) studied the development time of *S. frugiperda* on three maize varieties BRS 506, BRS 509 and BRS 511, found that development time of the adult was 12.6, 6.4, 15.1, whereas our result is 10.9, 10.9, 10.3, 10.3, 9.1, 9.2 days.

The mean development time from egg to adult was 37.6 (days) under BISCO51, KOHINOOR1820 and M. GOLD. Tendeng and Etienne (2019) studied the fall armyworm *S. frugiperda* a new pest of maize in Africa and the mean development time from egg to adult reported as 26.0 days. The difference may be caused by the environmental and climatic differences.

The pre-oviposition period ranged 1.72, 1.77 and 1.72 days and post-oviposition period ranged from 7.0, 6.2, and 4.7 days where the oviposition ranged 2.61, 2.68 and 2.72 days of BISCO51, KOHINOOR1820 and M. GOLD maize cultivars, respectively.

The daily fecundity was 63.78, 42.8 and 32.9 (eggs) and life time fecundity was 143.05, 110.8, 88.6 (eggs) on BISCO51, KOHINOOR1820 and M. GOLD varieties, respectively. Barfield & Ashley (2019) Effects of corn phenology and temperature on the life cycle of the fall armyworm, *S. frugiperda* found that 10, 11 and 13 adults of FAW laid on 1929, 2080 and 1337(eggs) late vegetative maize stage. Polanczyk, Antonio and Batista (2005) Biological parameters of *S. frugiperda* assayed with *Bacillus thuringiensis* reported that total number of eggs 111.4, 123.8, 115.1 and 115.6 in 7 days.

The net reproductive rate *Ro*, mean generation time *T*, intrinsic rate of natural increase *rm* per day, population doubling time *DT* in days and finite rate of increase λ was (195.85, 172.36, 135.06), (28.45, 29.42, 28.35), (0.185, 0.174, 0.172), (3.74, 3.97, 4.01), (1.30, 1.19, 1.18) in BISCO51, KOHINOOR1820 and M. GOLD varieties respectively.Valencia and Sandra2016) revealed that the effect of genetically-modified cotton cultivars on demographic parameters of *S. frugiperda* and found the net reproductive rate *Ro* was 335.7, 261.8, 121.1, 4.1, intrinsic rate of natural increase r_m per day was 0.172, 0.164, 0.158, 0.038, mean generation time *T* in days was 33.9, 34.0, 30.5, 37.1, finite rate of increase λ was 1.187, 1.178,1.171, 1.039, population doubling time *DT* was 4.0, 4.2, 4.4, 17.7days, respectively. Montezano & Specht 2019) studied biotic potential and reproductive parameters of *S. frugiperda* and showed the R_o net reproductive rate was 1079.730, *T* mean generation time in days was 31.99, r_m intrinsic rate of natural increase per day was 0.218, λ finite rate of increase was 1.2444 days, respectively.

This study indicates the importance of the reproductive biology, since many details can compromise the data of reproductive parameters and the full expression of the biotic potential of *S. frugiperda* and other Lepidoptera. Our results also indicate concerns for the need of a better understanding of the reproductive parameters of *S. frugiperda* in the field, such as studies which include the collection of adults of other species. Therefore, further studies should be carried out to investigate the potential of those cultivars for control of *S. frugiperda*.

CHAPTER VI

SUMMARY AND CONCLUSION

Maize is one of the most important food grains in the world as well as developing countries like Bangladesh and Somalia. It is one of the cash crops in Bangladesh which has the potential to pull-out farmers agents of poverty. The present experiment was conducted to study the abundance and development of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on three maize varieties. The present study revealed that maize aphid's *R. maidis* were highly dominant (1489) in three different locations. Fall armyworm *S. frugiperda* (265), maize stem borer *C. partellus* (167) maize earworm *H. zea* (156) and black cutworm *A. ipsilon* (66) were observed during the study period, March to May. Lady beetle *C. septempunctata* (373) and Lacewing *C. carnea* (296) were found in all three locations. *S. frugiperda* was found all the study area. On the other hand, biological performance of *S. frugiperda* was studied on three maize cultivars in the laboratory. Development of *S. frugiperda* showed no significant differences while fed on three maize cultivars. The highest longevity period of female was 39.0 days on the BISCO51 but the shortest 36.5 days on M. GOLD. The daily fecundity showed significant differences among the three maize cultivars. The maximum number (63.78) of eggs was laid on BISCO51, while minimum (32.9) oviposited on M. GOLD. The sex ratio (proportion of male) was maximum in BISCO51 (0.56) while minimum in M. GOLD (0.45). The net reproductive rate (Ro = 195.85), intrinsic rate of natural increase (r_m =0.185), finite rate of increase (λ= 1.3) were maximum in BISCO51 and population doubling time (T= 29.42) were maximum in KOHINOOR1820 and minimum in M. GOLD. Therefore, maize aphid (1489), fall armyworm (265), maize stem borer (167) maize earworm (156), and black cutworm (66), were the major maize pest. Fall armyworm can develop faster in M. GOLD cultivar than KOHINOOR1820 and BISCO51 while in terms of reproductive phase and fecundity.

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Table 1: Developmental time and adult longevity (days) of *Spodoptera frugiperda* reared on three maize cultivars under laboratory condition (Mean ± SE)

Variety	Sex	Egg	1st Instar	2nd Instar	3rd Instar	4th Instar	5th Instar	6th Instar	Pupa	Adult	Egg to adult
BISCO51	♀	2.66±0.08A	2.83±0.06	2.83±0.06	3.03±0.11	3.03±0.05	3.1±0.07	2.93±0.11	7.66±0.17	10.9±0.45A	39.0±0.5A
	♂	3.0±0.00a	2.83±0.10	2.83±0.10	2.93±0.13	2.8±0.13	2.9±0.14	2.96±0.13	8.0±0.31	10.9±0.45a	39.1±0.64c
KOHINOOR1820	♀	2.3±0.08B	2.9±0.05	2.83±0.06	3.03±0.08	3.0±0.08	3.0±0.06	2.96±0.05	8.3±0.26	10.3±0.55AB	38.8±0.61B
	♂	2.66±0.08b	2.86±0.17	2.93±0.10	3.1±0.13	2.86±0.11	3.0±0.14	2.9±0.12	8.6±0.29	10.3±0.55ab	36.8±0.62b
M.GOLD	♀	2.23±0.08B	2.81±0.05	2.7±0.06	2.91±0.07	2.86±0.07	2.92±0.07	2.87±0.08	8.0±0.24	9.1±0.52B	36.5±0.55C
	♂	2.59±0.08b	2.80±0.11	2.80±0.11	2.9±0.12	2.78±0.12	2.85±0.12	2.86±0.13	8.23±0.25	9.20±0.51b	35.6±0.72a

♀ means females and ♂ means males.

All values are means ± SE. Means for each stage of the same sex in the same column are not significantly different at $P < 0.05$

Table 2: Reproductive phases (days) and fecundity (number of eggs) of *S. frugiperda* under laboratory condition

Maize Varieties	Pre-oviposition Period	Oviposition Period	Post-oviposition Period	Daily fecundity/♀	Lifetime fecundity/♀
BISCO51	1.72 ± 0.19	2.61 ± 0.14	7.0 ± 0.43a	63.78 ± 11.74a	143.05 ± 11.28a
KOHINOOR1820	1.77 ± 0.20	2.68 ± 0.14	6.27 ± 0.69ab	42.8 ± 2.39ab	110.8 ± 5.19b
M.GOLD	1.72 ± 0.15	2.72 ± 0.10	4.7 ± 0.76b	32.9 ± 2.06b	88.6 ± 5.97c

Means in the same column followed by the different letters are significantly different at $P < 0.05$

Table 3: Life table parameters of *S.frugiperda* while fed on three maize varieties

Variety	Ro	GRR	T	r_m	DT	λ
BISCO51	195.85±5.28a	195.85±5.28	28.45±0.03a	0.185±0.001a	3.74±0.023a	1.30±1.30a
KOHINOOR1820	172.36±4.49b	172.36±4.49	29.42±0.04ab	0.174±0.001ab	3.97±0.02ab	1.19±0.001ab
M.GOLD	135.06±4.10c	158.28±22.58	28.35±0.02ab	0.172±0.001ab	4.01±0.035ab	1.18±0.001ab

R_o net reproductive rate, r_m intrinsic rate of natural increase per day, *T* mean generation time in days, *DT* population doubling time in days, λ finite rate of increase, *GRR* gross reproductive rate.

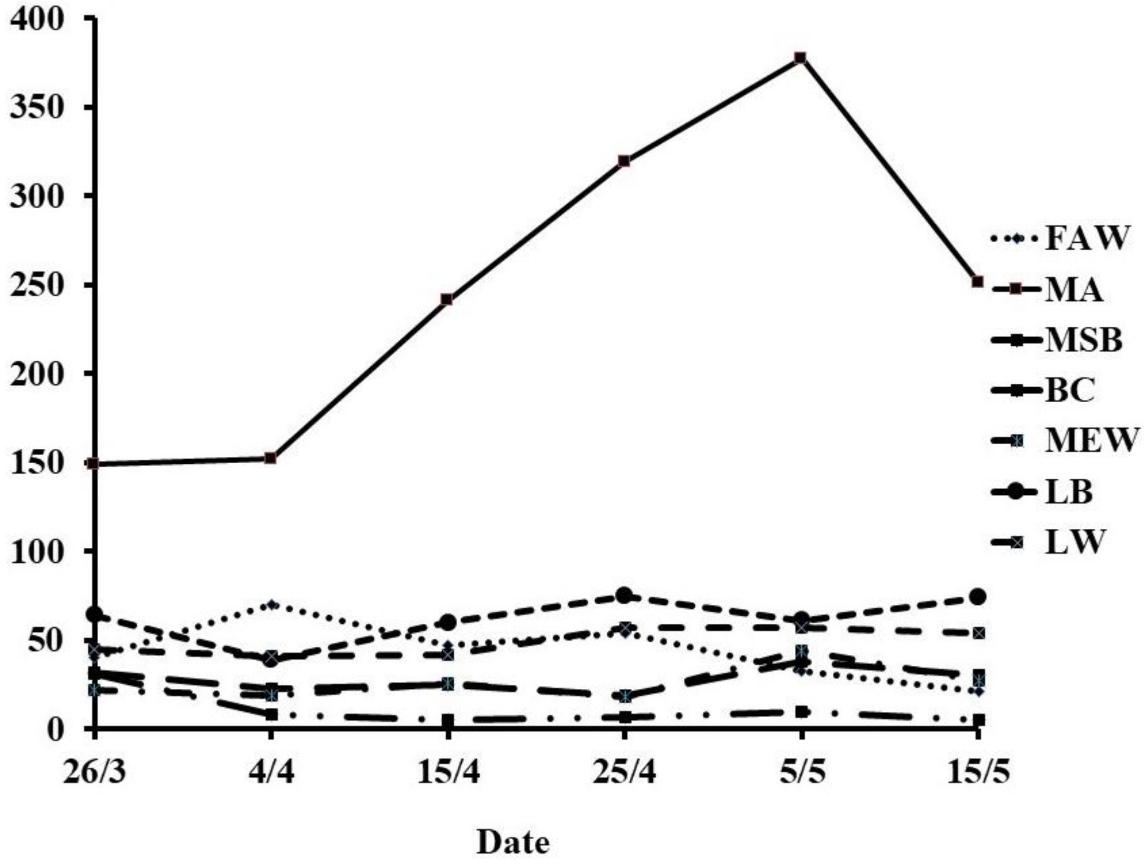

Figure 1: Seasonal fluctuation of insects in three study sites. Values are analyzed significantly different by one-way ANOVA (P < 0.05).

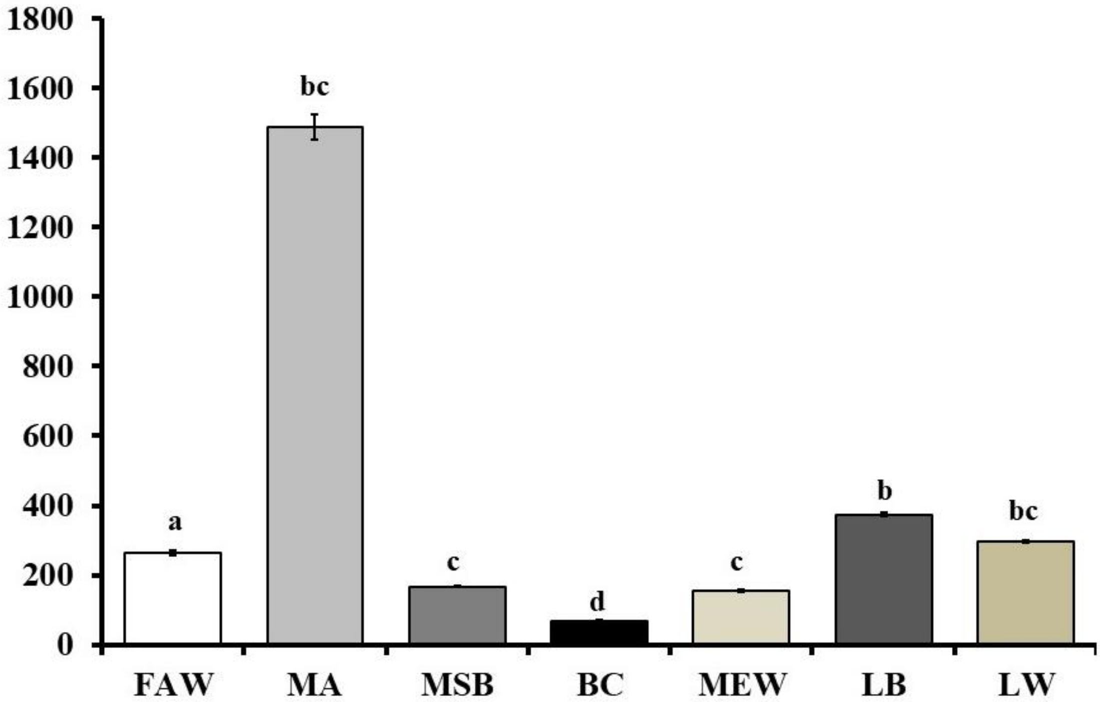

Figure 2: Number of insects of three study sites. Values followed by different letters are significantly different by one-way ANOVA ($P < 0.05$).

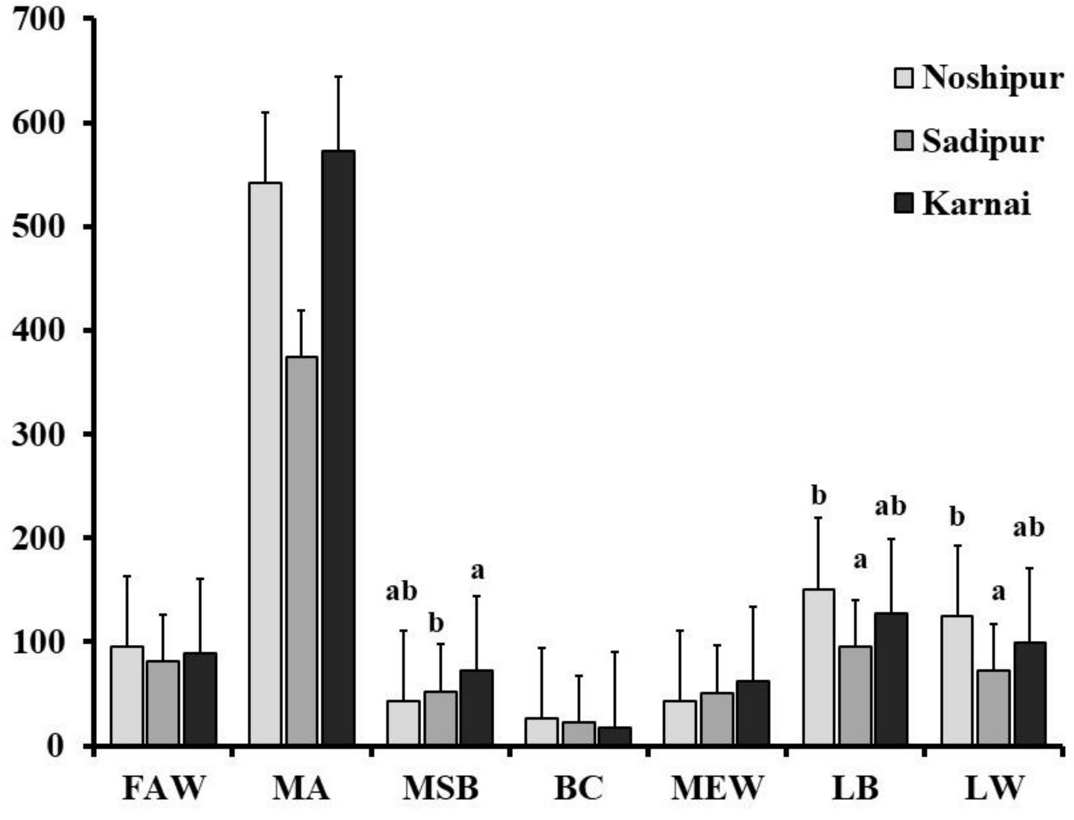

Figure 3: Total number of insects in three locations. Values followed by different letters are significantly different by one-way ANOVA ($P < 0.05$).

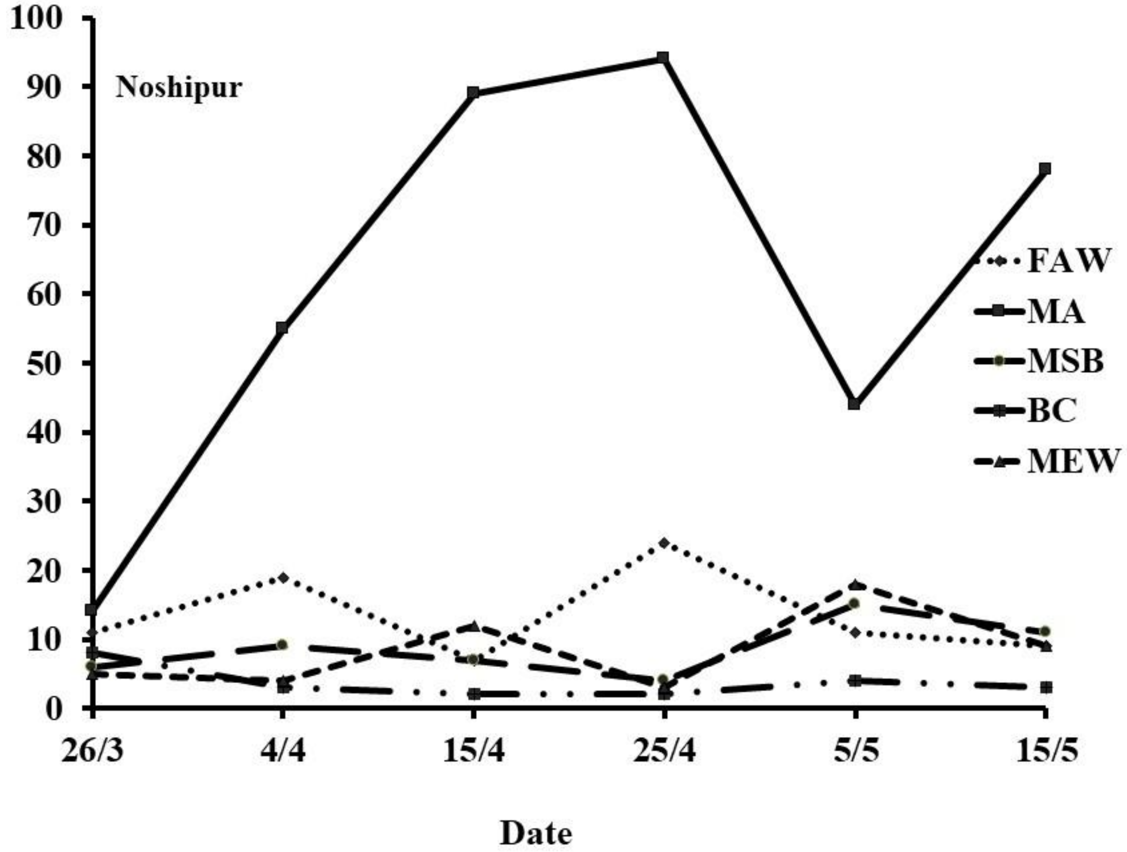

Figure 4: Seasonal fluctuation of insects in Noshipur. Values are analyzed significantly different by one- way ANOVA (P < 0.05).

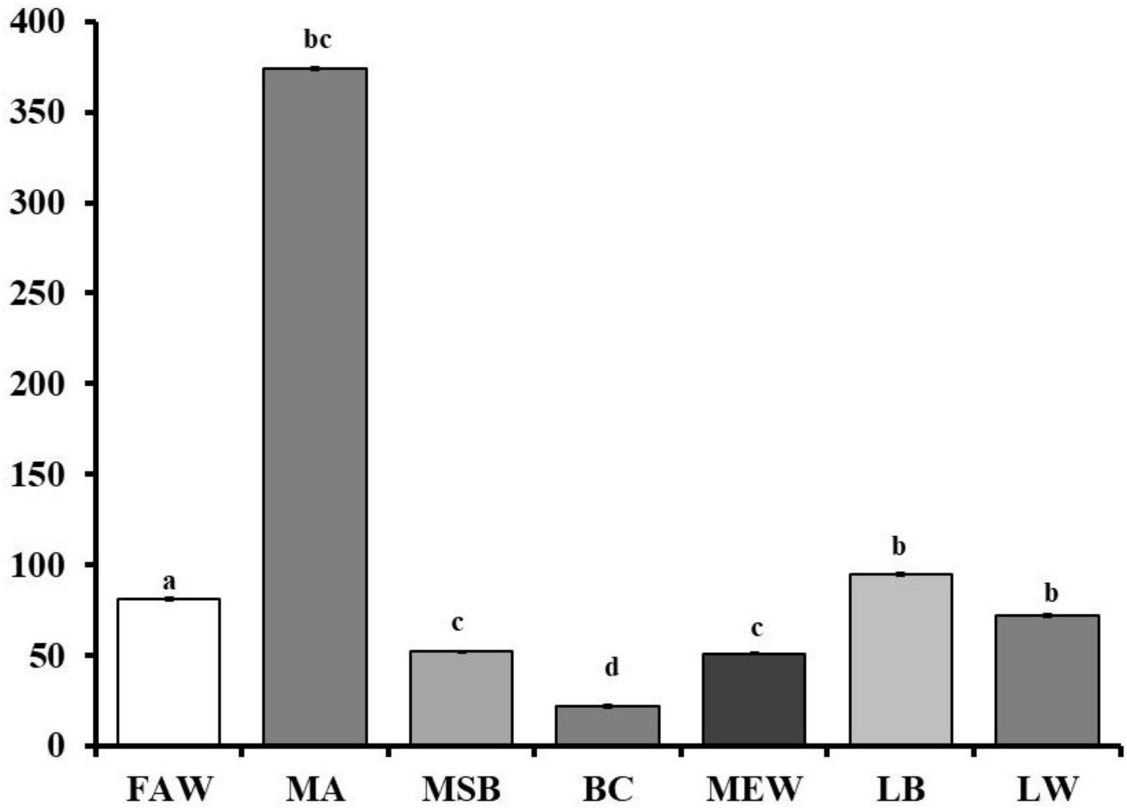

Figure 5: Number of insects in Noshipur. Values followed by different letters are significantly different by one-way ANOVA ($P < 0.05$).

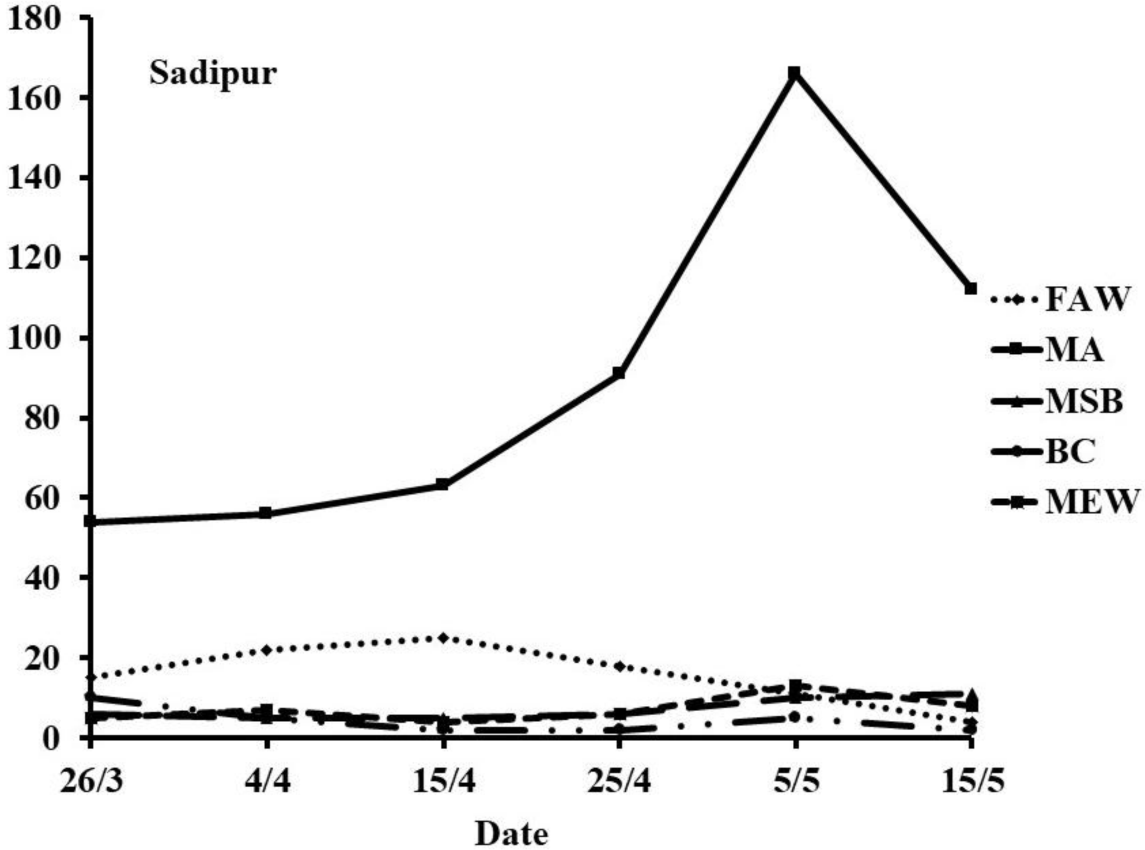

Figure 6: Seasonal fluctuation of insects in Sadipur. Values are analyzed significantly different by one-way ANOVA ($P < 0.05$).

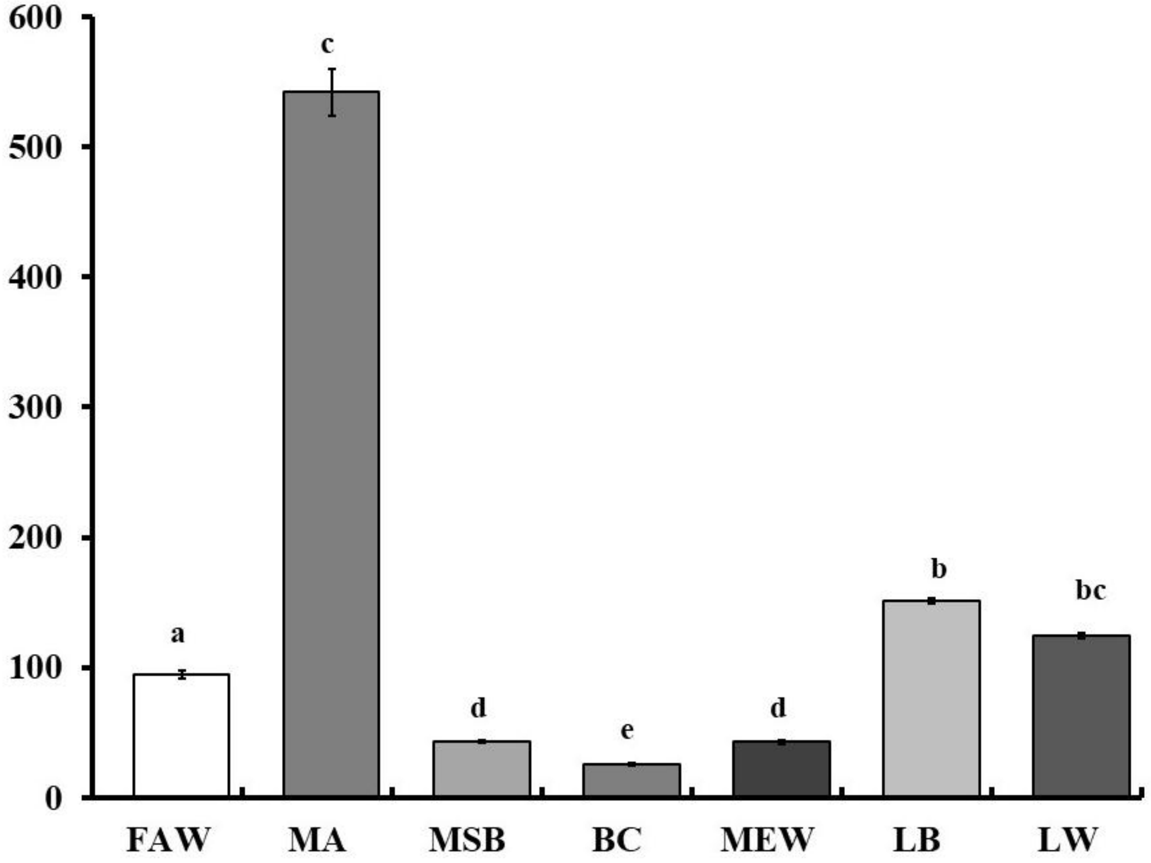

Figure 7: Number of insects in Sadipur. Values followed by different letters are significantly different by one-way ANOVA ($P < 0.05$).

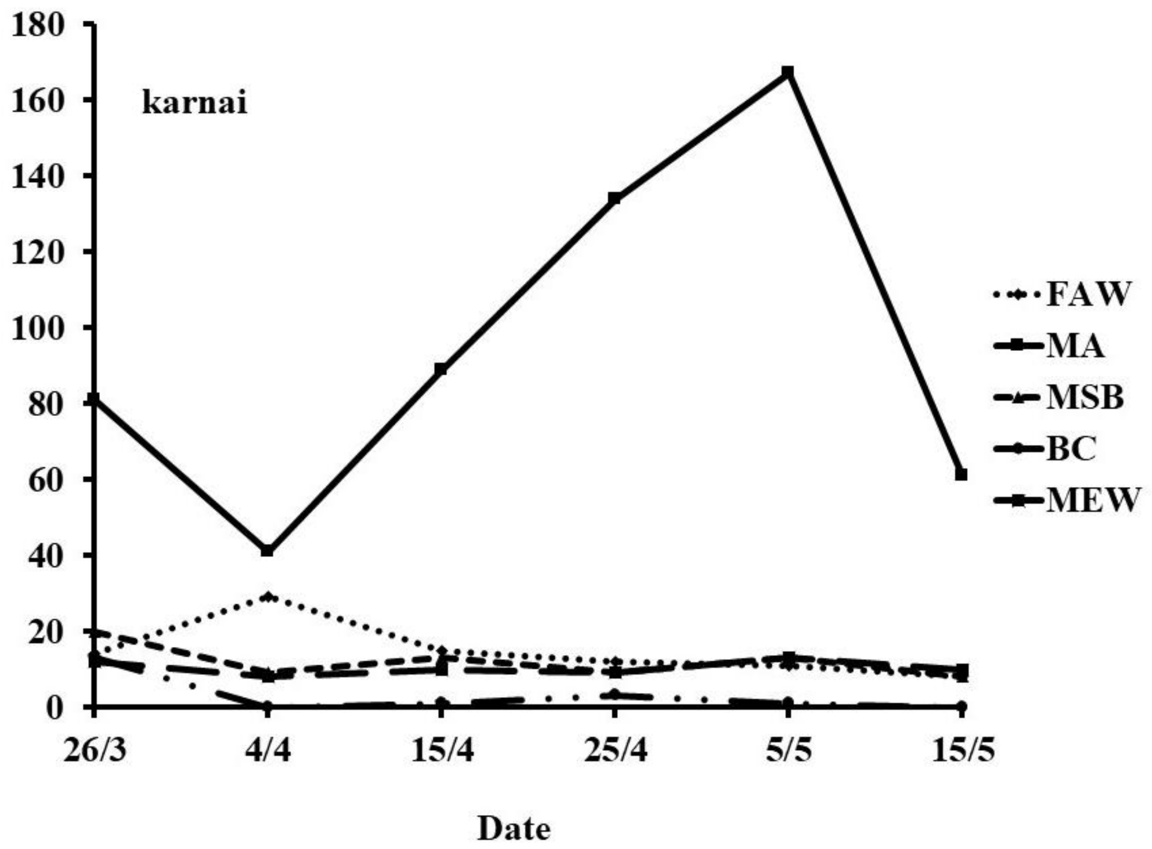

Figure 8: Seasonal fluctuations of insects in Karnai. Values are analyzed significantly different by one-way ANOVA ($P < 0.05$).

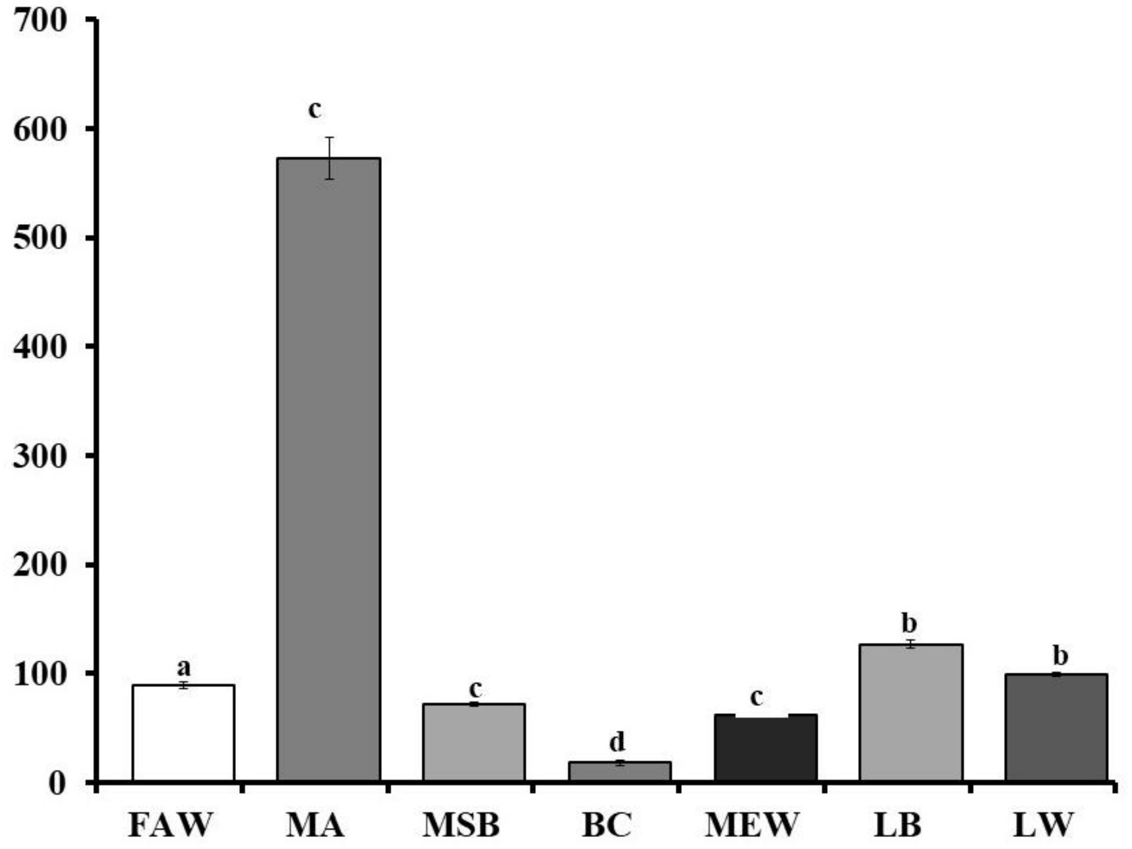

Figure 9: Number of insects in Karnai. Values followed by different letters are significantly different by one-way ANOVA (P < 0.05).

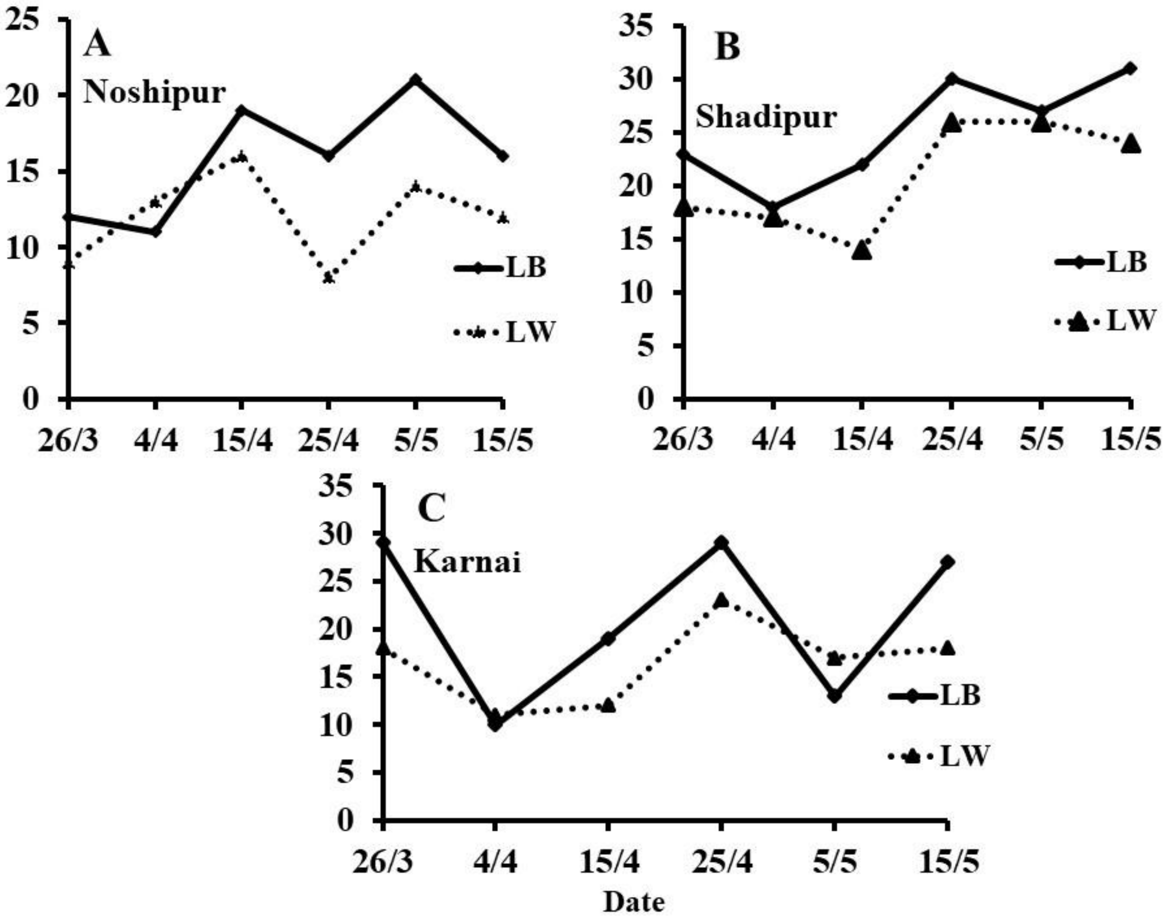

Figure 10: Seasonal fluctuations of natural enemies in three locations. Values are analyzed significantly different by one-way ANOVA (P < 0.05).

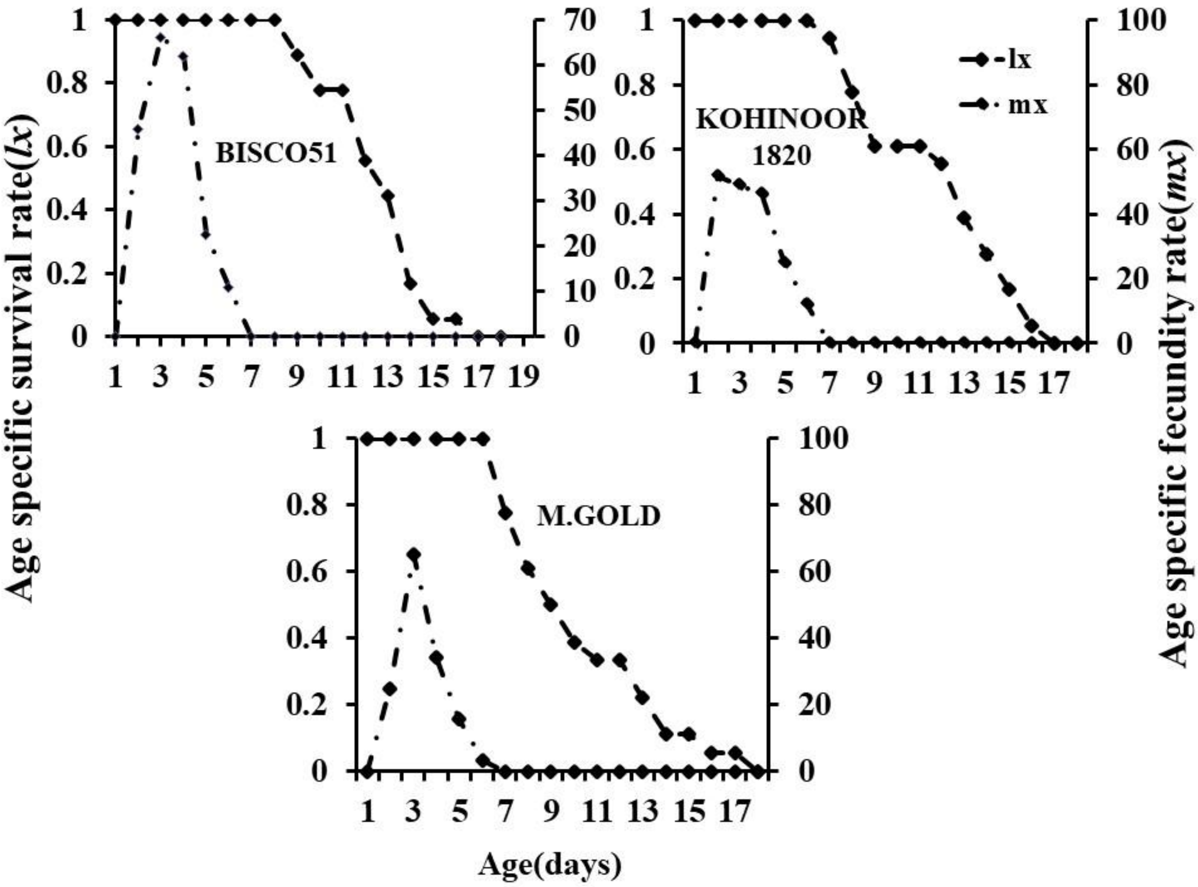

Figure 11: Age specific survivorship *(lx)* and age specific fecundity (*mx*) of *S. frugiperda* female on three maize varieties. *lx* = proportion of female alive at age x. *mx* = (proportion of male) x (age specific oviposition).