STUDY ON INSECT DIVERSITY AND POLLINATION EFFECT ON BUCKWHEAT (*FAGOPYRUM ESCULENTUM*) YIELD

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CERTIFICATE

This is to certify that the thesis entitled, "**STUDY ON INSECT DIVERSITY AND POLLINATION EFFECT ON BUCKWHEAT (*FAGOPYRUM ESCULENTUM*) YIELD**" 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 (MS) in Entomology, embodies the result of a piece of bonafide research work carried out by Most. Farjana Akter, Registration No. 14-06041, under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma.

I further certify that any help or sources of information, as has been availed of during the course of investigation have been duly acknowledged.

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STUDY ON INSECT DIVERSITY AND POLLINATION EFFECT ON BUCKWHEAT (*Fagopyrum esculentum*) YIELD

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ABSTRACT

The experiment was conducted at the research farm of Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from November 2019 to March 2020. The experiment was consisted of two different strategies of pollination treatment on buckwheat (*Fagopyrum esculentum*) flowers viz., T_1=Without netting and T_2= Netting. Randomized Complete Block Design (RCBD) was adopted to layout the present experiment with 12 replications. The most abundant species were identified as *Apis cerana* F. (9.28±2.62) from Hymenoptera and *Menocheilus sexmaculatus* (8.36±1.05) from Coleoptera foraging the field at 11 A. M., while *Syrphus* sp. (2.53±1.1) found as dominant species from Diptera order visited the field at early morning (7 A. M.). *Apis cerena* and *Apis mellifera* were found to stay more time spending insects in buckwheat flower. The growth, yield and yield contributing characters were significantly influenced by different treatments of the pollinators. The highest 1000-seed weight of buckwheat was recorded (18.39 g) from plot without netting (T_1), whereas the lowest 1000-seed weight was recorded (9.17 g) from the with netting (T_2). The highest seed yield per plant of buckwheat was recorded 22.68 gm when the buckwheat plot was without netting (T_1) and the lowest seed yield per plant of buckwheat was recorded 12.35 gm when the buckwheat plot was netted (T_2). The highest yield per plot was recorded (0.8258 kg) when the field was opened for pollinators (T_1) and the lowest yield per plot was recorded (0.399 kg) when the field was netted (T_2). From the study, it can be concluded that, without netting was the best for maximum pollination for obtaining better yield of buckwheat.

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LIST OF COMMONLY USED ABBREVIATION

ABBREVIATION	FULL WORD
et al.	And others
cv.	Cultivar
^0C	Degree Celcius
i.e.	That is
g	Gram
Kg	Kilogram
mg	Microgram
%	Percentage
e.g.	Example
cm	Centimeter
AEZ	Ago-Ecological Zone
TSP	Triple Super Phosphate
MoP	Muriate of Potash
t/ha	Ton per hectare
CV%	Percentage of coefficient of variance
LSD	Least Significant Difference
±	Standard Deviation of foraging time
Spp.	Species(plural number)
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database

CHAPTER I

INTRODUCTION

Buckwheat (*Fagropyrum esculentum* Moench; Polygonales: Polygonaceae) is an old World crop believed to have originated in China (Ohnishi, 1998) and was introduced into the New World by European settlers in the 17th century (Treadwell and Huang, 2008). Once a commonly planted crop in the United States, buckwheat production sharply declined in the 20th century due to the introduction of nitrogen fertilizer, which induce corn and wheat cultivation which become prevalent in the United States. In recent years, buckwheat has become more popular due to its newly discovered nutritional value (Cawoy *et al*., 2008). China, Russia, and Japan are currently the world's top producers of buckwheat (Treadwell and Huang, 2008). It remains important for food security in the temperate and hilly regions of countries in East Asia, East Europe and the Himalayan region (Arora, 1995). The crop is not a cereal, but the seeds (strictly achenes) are usually classified among the cereal grains because of their similar usage. The grain is generally used as human food and as animal or poultry feed and the flour used in the preparation of pancakes, biscuits, noodles, cereals, etc. One cup of cooked buckwheat contains 155 calories, 6 g of protein, 1 g of fat, 33 g of carbohydrates, 5 g fiber, only 1.5 g of sugar, 86 mg manganese, 86 mg magnesium, 118 mg phosphorus, 6 mg niacin, 1 mg zinc, 34 mg iron, 0.13 mg vitamin B_6, 24 mg folate, 0.6 mg pantothenic acid (Mahata, 2018). By supplying important vitamin and minerals buckwheat grains help to improve heart health like lowering down cholesterol, blood pressure level, prevent diabetes and ensure gluten free and non-allergenic. Presence of high content of fiber it helps to improve digestion and it works surprisingly against aging and hair growth (Mahata, 2018). Buckwheat produces flowers that are distylous and self-incompatible, and can be pollinated by wind or insects (Sasaki and Wagatsuma, 2007). There are 2 types of flower morphologies (pin or thrum), with pin flowers having long styles extending their stamens and thrum flowers having long stamens that extend beyond the styles (Taki *et al*., 2009). In many distylous plants, the 2 different flower structures allow pollen to be carried on different parts of an insect's body, resulting in transfer of pollen between the 2 types of flowers (Beach and Bawa, 1980). Buckwheat fields have approximately equal numbers of pin and thrum flowers (Quinet *et al*., 2004). In Florida, buckwheat blooms approximately 3–5 week after planting and mature seeds form 6–8 week after planting (Treadwell and Huang, 2008). Although pollination can occur by wind (Marshall, 1969), most pollination is considered to be accomplished by insects, which may be necessary for successful pollination (McGregor, 1976). Despite numerous insects being documented visiting buckwheat, the study of insect pollination and visitation on buckwheat is incomplete (Sasaki and Wagatsuma 2007), and findings appear to differ in various parts of the world. For example, western honeybees (*Apis mellifera* L.; Hymenoptera: Apidae) comprised 80% of all insect visitations in Australia (Goodman *et al*., 2001), 95% in central New York (Björkman, 1995) and Poland (Banaszak, 1983), 97% in Belarus (Kushnir, 1976), and 18 to 51% in Belgium (Jacquemart *et al*., 2007). Alternatively, Sasaki and Wagatsuma (2007) found that 2 *Bombus* species (Hymenoptera: Apidae) accounted for over 75% of insect visitation in Japan and were presumed to be the most important pollinators of buckwheat in that study. In a cage experiment, *Apis cerana* F. (Hymenoptera: Apidae) (the Asian honeybee) was found to be an important pollinator in India (Rahman & Rahman, 2000). Other authors have documented other insect groups (e.g., Syrphidae, Sphecidae, Crabronidae, Vespidae, and Scoliidae) as common visitors (Bugg and Dutcher, 1989; Carreck and Williams, 1997; Ambrosino *et al*., 2006). Although buckwheat is not a major crop planted in the southeastern United States, its potential as a cover crop to bring in entomophagous insects and as a weed suppressor has been explored in southern Georgia (Bugg and Dutcher, 1989) and Florida (Huang, 2009), respectively. Little is known about the attractiveness of buckwheat flower to pollinate and other beneficial insects in Bangladesh. Hence the proposed study will be done to fulfill the following objectives.

Objectives

- to find out the insect biodiversity in buckwheat field and
- to determine the impact of pollinator on buckwheat field

CHAPTER II

REVIEW OF LITERATURE

2.1 Buckwheat

Buckwheat has been called by many people during the history of its development. The ancient Yi people of Yunnan province called buckwheat er, common buckwheat er chi and Tartary buckwheat erka, Common wild buckwheat was called qi chi erluo and wild Tartary buckwheat chi ruoerluo (Li and Yang, 1992).

The Scottish coined the term “buckwheat” from two Anglo-Saxon terms, boc (beech) and whoet (wheat), because it is much similar to beech nut (Berglund and Duane, 2003; Edwardsen, 1995).

Buckwheat belongs to the family Polygonaceae and genus *Fagopyrum*. It is a broad leaved, annual, and dicotyledonous crop that obtains a maximum height of about 60–152 cm. (Skrabanja *et al*., 2004).

The genus *Fagopyrum* contains about 19 species besides four new species that have recently been included, namely, *Fagopyrum crispatifolium* (Liu *et al*., 2008); *Fagopyrum pugense* (Tang *et al*., 2010); *Fagopyrum wenchuanense* (Shao *et al*., 2011); and *Fagopyrum qiangcai* (Shao *et al*., 2011), and their taxonomic position as well as phylogenetic relationships have been clarified (Zhou *et al*., 2012; Shao *et al*., 2011).

All buckwheat species found to date possess eight chromosomes, 2n = 16, as their base complement except *Fagopyrum cymosum* and *Fagopyrum gracilipes*, which are tetraploids with 4n = 32. Buckwheat is distinguished by having a single, erect, and hollow stem that shows variation in color from green to red and becomes brown toward maturity. Leaves are triangular or heart shaped, 2–3 cm in length, and are arranged on the stalk in an alternate manner. Inflorescence is composed seven to nine blossoms. Flowers are showy, attractive, and are generally clustered in racemes at the ends of the branches or on short pedicles arising from the axils of the leaves. The flowers are habitually bisexual and consist of distinct variable parts, which include sepals (3–5) and petals (called tepals), stamens (6–9), and a single pistil. The superior ovary of fused carpels has one chamber (locule) with one ovule, which develops into an achene. The color of flowers varies from white or light green to pink or red (Janovska *et al*., 2009; Cawoy *et al*., 2009; Tahir and Farooq, 1989b).

Seeds are triangular in shape but sometimes prominently winged and the color of the seeds may be glossy brown, gray brown, silvery gray, or black (Krkoskova and Mrazova, 2005; Farooq and Tahir, 1987).

2.2 Origin and distribution of buckwheat

Buckwheat (*Fagopyrum esculentum* Moench), family Polygonaceae, classified as a pseudocereal, is one of the traditional crops cultivated in central and eastern Europe and in Asia and now it is one of the crop consumed as alternative crops for organic cultivation (Kreft *et al*., 2003).

Among the various underutilized crops, buckwheat is one of the ancient domesticated crops of Asia, Central, and Eastern Europe that has been mainly consumed as a staple food especially in arid regions of the world. Buckwheat is believed to have originated in central Asia; however, the origin of its domestication dates back about 4000–5000 years in South China (Gondola and Papp, 2010).

Buckwheat is chiefly cultivated in India, Nepal, Bhutan, China, Canada, Mongolia, North Korea, far eastern Russia, and Japan. However, buckwheat production turned down during the first half of the 20th century, especially in Russia and France. (Farooq *et al.*, 2016).

In India, buckwheat is cultivated in Jammu and Kashmir, Himachal Pradesh, Uttrarakh, West Bengal, Sikkim, Meghalaya, Arunachal Pradesh, and Manipur (Tahir and Farooq, 1988). The origin of buckwheat in Northern China or Siberia was contradictory to the distribution of wild *Fagopyrum* species enumerated by Steward (1930) (Ohnishi, 1995; Nakao, 1957). Therefore, the origin of common buckwheat should be at the location of this species which is the northwest corner of Yunnan province, as this is the distribution of *Fagopyrum esculentum* subsp. Ancestral is in nature as found to this point (Ohnishi, 1995).

The earliest Chinese records on buckwheat suggested that increased production took place in China in the 5th and 6th centuries AD (Krotov, 1963). The cultivation of common buckwheat in the Himalayas was bounded to approximately 500-2500 m in altitude. Above 2500 m, Tartary buckwheat replaces it in cropping patterns (Ohnishi, 1988).

Buckwheat is cultivated in hilly areas in Europe (also in lowlands), East Asia, and the Himalayan region. China is the biggest producer and exporter of buckwheat followed by USSR, and Japan is a principal importer of buckwheat up to 2000 (Sherch, 2000), but the scenario has modified, and USA became main exporter and Japan remains a major importer of American buckwheat although China, Russia, and Canada are leading sources of buckwheat flour (Faostat, 2012).The exact place of origin of common buckwheat is considered as Yunnan province and in between Yunnan and Sichuan provinces of China (Ohnishi, 1995).

In Nepal, it is one of an essential underexploited crops and majorly grown with conventional technologies in mid-hills (345 to 4,500 m above msl) occupying 10,339 ha of land area, with the production of 10,021 t/ha and productivity of 0.97 t/ha (MoAD, 2012). Russia is the largest producer of buckwheat. China is the second largest producer of buckwheat with 4.13 million ha under cultivation and contributing about 0.6–0.95 million tons (Li and Zhang, 2001).

Although buckwheat is known to have been cultivated in China as early as the 2^{nd} 1st centuries BC (Li and Yang, 1992), it is not believed to be very ancient (Hunt, 1910). The earliest Chinese records on buckwheat suggested that increased production occurred in China in the 5th and 6th centuries AD (Krotov, 1963). Presumably it was cultivated in China for nearly a millennium before it spread to Europe via Russia. It was pioneered into Europe in the middle ages, probably from Siberia reaching Germany early in the 15th century (Hughes and Hensen, 1934). In Russia apparently it was not developed to any great extent until the 15th century (Krotov, 1963). It is not believed that buckwheat was cultivated in Indian ancient times. It was found in India, China and most of Europe in the 17th century. From Europe, buckwheat spread to North America along with immigrants from several countries as it was often consumed on newly cleared land.

A considerable uniformity of allelic frequencies of isozyme loci suggests that the recent cultivation of buckwheat in this area is a possible interpretation. Migration could have taken place along several trade routes through this area from southern China and Tibet (Ohnishi, 1988). She also found that the places where differentiation occurred were those where a sufficient genetic source for migration had been lacking, that is the margin of the distribution. Buckwheat is believed to have been introduced into Japan about 3000 years ago as archeological evidence suggests (Nagatomo, 1984). Buckwheat had already been cultivated extensively as a catch crop when it first noticed in records at Japan in the 8th century.

Buckwheat was pioneered to Japan via the Korean peninsula from Northern China (Muraiand Ohnishi, 1995; Nagatomo, 1984). Buckwheat cultivation in Japan dates back to as early as 6600 BP in the Early Jomon period (7000-5000 BP) (Tsukada *et al.*, 1986). Buckwheat producing countries, production, cultivated area (ha) and percent of total cropped area are presented in Table 1.

Table 1. Buckwheat production and cultivation area

Country	Production (ton)	Cultivated area (ha)	% of total cropped area
China	1270000	1055000	1.18
Russian Federation	875007	1764770	3.06
Ukraine	424356	473333	3.78
Kazakhstan	148000	389667	1.79
Poland	47425	46249	0.55
Brazil	44800	42900	0.21
USA	35150	35550	0.06
Canada	23025	24661	0.12
France	21659	8501	0.09
Japan	19555	23690	0.94
Belarus	10000	26333	1.02
Korea Republic	7486	8111	0.58
Bhutan	6135	7319	7.09
Tajikistan	5733	10833	3.98
Moldova Republic	3604	6427	0.89
Slovenia	567	553	0.47
South Africa	498	1300	0.02
Lithuania	200	600	0.05
Estonia	167	100	0.03
Yugoslavia	152	112	0
Croatia	30	50	0.01
Total	2943549	3926059	

Source: FAOSTAT

2.3 Importance of buckwheat in Bangladesh

Dr Dilwar Ahmed Choudhury, Chief Scientific Officer & Head, Agronomy Division, Bangladesh Agricultural Research Institute, Gazipur distinguished Buckwheat (*Fagopyrum esculentum*) is one of the minor crops grown in Bangladesh belonging to the family Polygonaceae. It is called 'Poor man's food' in Danish. In Bangladesh, buckwheat is cultivated in the north-west region, especially in Thakurgaon, Panchagarh and parts of Dinajpur and Rangpur districts (Figure 1) during the rabi (October to March) season.

He also reveals that buckwheat is receiving increased attention as a nutraceutical food crop because of certain unique active principal components. However, progress in cultivar breeding and crop management is still required. Buckwheat has immense potential in crop improvement programs as reported by various research agencies like the International Plant Genetic Resources Institute and the Consultative Group on International Agriculture. Buckwheat farming has been gaining popularity among the farmers in Rajshahi district due to its lucrative market price and gradually growing demands. Farmers of the district cultivated buckwheat on five hectares of land, while it was cultivated on two and a half hectares of land last year, said the officials of Panchagarh Department of Agricultural Extension (DAE).

It is well suited to light and well-drained soils such as sandy loam or silt loams and it grows satisfactorily on soil, too acid for other grain crops. It produces a better crop on relatively infertile, poorly tilled land than other grain crops when the climate is favorable. For this reason, buckwheat can be called as 'poor land's crop'. Therefore, it is very essential to identify and select suitable genotypes for varietal improvement. It could be grown well in hilly areas for grain as well as cover crop to protect soil erosion. At the same time agronomic management studies have also prime importance to ensure higher yield of buckwheat. However, still now it is an underutilized crop in Bangladesh but due to its high nutritional, medicinal and industrial value and good export potential, the crop should get proper exposure to increase its production

Figure 1. Buckwheat growing areas in Bangladesh

2.4 Relative abundance of insect visitors

European honeybees (*Apis mellifera* L.) are frequently the main pollinators of buckwheat, and are often assumed to be the most effective pollinators, but that has not been demonstrated. Bees account for nearly all the insect visits to buckwheat flowers in many places: 90% in Germany (MUler 1883), 95% in western Poland (Jablonski *et al*., 1986; Banaszak, 1983), 97% in Belorus (Kushnir, 1976). However, there are places where other insects dominate and bees account for few visits: 5% in Japan (Namai, 1986), 37% in Orel, Russia (Naumkin, 1992).

Honey bees (*Apis mellifera* L.) were at least 95% of the insect visitors to buckwheat flowers in fields of central New York State (Bjorkman and Pearson, 1995). The main insect pollinators were honeybees from 72.1% in 1999 to 94.9% in 2000 (Racys & Montviliene, 2005). The bumblebees regarded as 3.1% to 10.0% of all pollinators. The other pollinators are varied from 2.0% to 21.5% of buckwheat visitors. Three to four insect visits are enough to pollinate one blossom of buckwheat (Bjorkman, 1995).

Buckwheat is visited by a diverse fauna, including Hymenoptera: honey bees (*Apis mellifera* L.), bumble bees, solitary bees and wasps; Diptera: Syrphidae and others; and Lepidoptera, and other orders (Carreck and Williams, 2002; Goodman *et al*., 2001; Wang and Li, 1998; Lee and Choi, 1997; Ogasahara *et al*., 1995; Hedtke and Pritsch, 1993). In some countries, such as Germany, Poland, Korea, the USA and Australia, honey bees are the main pollinators (Goodman *et al*., 2001; and Choi, 1997; Björkman, 1995a, c; Hedtke and Pritsch, 1993; McGregor, 1976).

Apis florea F., *Andrena* sp., *Synoeca* sp., *Chalcid* sp., *Formica* sp., *Syrphus* sp. and various Dipteran, Coleopteran, and Lepidopteran were also the flower visitors of buckwheat close to natural habitat (Aryal *et al*., 2016). Diptera and Hymenoptera were the principal visitors. Hymenoptera were mainly represented by honey bees (18.5 – 51.8% of total visitors), while Diptera were represented by syrphid flies and other families (Jacquemart *et al*., 2007). Numerous insect groups, including Hymenoptera, Diptera, Coleoptera, and Lepidoptera, visit common buckwheat flowers, however Hymenoptera especially honeybees are the major pollinators (Campbell, 1997).

The Rock bee, Little bee, European bee, Native bee, Syrphid fly, Tabanid fly, March fly, Rice skipper, Legume pod bug, Hymenopteran wasp, Lady bird beetle, Mud wasp and Muscid fly were the flower visitors on buckwheat (Dhakal, 2003).

Flower visitors found in buckwheat fields were Honeybees (80.1%), Ladybird beetle (10.10%), Hoverflies (2.70%), Blowflies (1.50%), Small flies (1.50%), Drone flies (1.40%), Cabbage butterflies (1.30%), Native bees (1%), Beetles (0.10%), Wasps (0.10%), Moths (0.10%) and Dragonflies (0.10%) (Goodman *et al*., 2001).

The major pollinators of common buckwheat in Honshu, the main island of Japan, are *Apis mellifera* and some hoverflies (Diptera: Syrphidae) (Namai, 1986). In his research, two species of bumblebees, *B. ardens sakagamii* and *B. hypocrite sapporoensis* were captured as the predominant species (75.4%) that visited the common buckwheat (Sasaki and Wagatsuma, 2007).

Apis cerana F. (Hymenoptera: Apidae) (the Asian honey bee) was found to be an important pollinator in India (Rahman & Rahman, 2000). Other authors have documented that other insect circles (e.g., Syrphidae, Sphecidae, Crabronidae, Vespidae, and Scoliidae) as common visitors of buckwheat (Ambrosino *et al*., 2006; Carreck & Williams, 1997; Bugg & Dutcher, 1989).

During the bloom and survey period, 3,422 insect flower visitors (excluding honey bees) were visited on buckwheat flowers and Honey bees accounted for an additional 5,300 flower visits (61% of overall flower visits) during the survey period (Campbell *et al*., 2016). Native wasps comprised the majority of non-Apis flower visitors (81.3%; n = 2,782), followed by Diptera (12.5%; n = 427), native bees (5.8%; n = 197), and beetles (0.47%; n = 16) and most of the non-Apis flower visitors were parasitoid wasps (Campbell *et al*., 2016).

Excluding Apidae, Scoliidae (n = 1,080) and Tiphiidae (n = 628) were the most commonly observed families (Hymenoptera: Scoliidae) (n = 948) being the most common species in the buckwheat fields and excluding the honey bee, only 7 native bee species (superfamily Apoidea) were visited to buckwheat flowers (Campbell *et al*., 2016).

The highest number of bushels per plant of buckwheat was observed in *Apis cerana* F. pollination plot (17.64), *Apis mellifera* L. pollinated (15.78), open pollinated (12.53), hand pollinated (11.53) and control plot (7.73) (Aryal *et al*., 2014).

Species from the orders Diptera and Hymenoptera were the principal visitors and Hymenoptera were mainly represented by honey bees (*Apis mellifera* L.; 18.5 – 51.8% of total visitors), while Diptera were represented by syrphid flies and several other families (Jacquemrt *et al*., 2004).

2.5 Foraging behavior of insect visitors

In their research, insect visited every hour on the half hour, from 8: 30 am. to 2 : 30 pm. So, the total number of bee visits to each flower during the period that pollen was available was roughly calculated. Pollen was normally available for 1/ 2 h, and bees visited every open flower in each inflorescence (Bjorkman & Pearson, 1995).

At the beginning of the blooming season, bee visits are at a low level but reach their peak during the full blooming stage and when blooming stops, the nectar content of flowers drop and the bee visitation declines. Flowers of buckwheat are more likely to be pollinated when the blooming period is longer than in the case of a shorter blooming season (Alekseyeva & Bureyko, 2000).

Apis cerana F. started foraging on buckwheat at 7.03±0.22 AM and ceased their foraging at 4.51±0.15 PM, while *Apis. mellifera* L. started foraging at 7.29±0.28 AM and ceased at 4.48±0.13 PM. Similarly, on rapeseed, *Apis cerana* F. started foraging at 6.52±0.12 AM and ceased at 5.07±0.01 PM, while *Apis mellifera* L started foraging at 6.59±0.38 AM and ceased their foraging at 4.48±0.12 PM (Dhakal, 2003).

Apis mellifera L. started their foraging late in the morning and ceased early in the evening as compared to *Apis cerana* F. Also, *Apis cerana indica* was found to be more active in the forenoon than afternoon (Panda *et al*., 1991). The maximum number of foragers per square meter per minute and the maximum time spent during 0900-1000 hours of the day indicating the best time of foraging on buckwheat flower (Rahman and Rahman, 2000).

Apis cerana F. started their foraging activities early in the morning (8.24 ± 0.5 AM) and ceased late in the evening (5.18 ± 0.2 PM) compared to *Apis mellifera* L. which started foraging at 8.29 ± 0.5 AM and ended at 4.56 ± 0.5 PM. The number of buckwheat flower visited by *Apis cerana* F. was the highest at 10 AM while by *Apis mellifera* L. it was the highest at 12 Noon and *Apis cerana* F. bee spent on an average of 1.95 seconds per flower while *Apis mellifera* L. bee spent on an average of 2.37 seconds per flower of buckwheat (Aryal *et al*., 2016).

The number of *Apis cerana* F. and *Apis mellifera* L. bees get into the hive in five minutes was the highest (51.69 ± 0.45 in *Apis cerana* F., and 62.81 ± 0.45 in *Apis mellifera* L.) at 12 Noon while lowest (11.24 ± 0.11 in *Apis cerana* F., and 5.89 ± 0.11 in *Apis mellifera* L.) at 5 PM and no activity was started at 8 AM. Likewise, the number of *Api scerana* F. and *Apis mellifera* L. bees get out of the hive in five minutes was the highest (42.67 ± 0.98 in *Apis cerana* F. and 48.71 ± 0.98 in *Apis mellifera* L.) at 12 Noon and the lowest (4.31 ± 0.07 in *Apis cerana* F. and 2.39 ± 0.07 in *Apis mellifera* L.) at 5 PM (Aryal *et al*., 2016).

Buckwheat flowers are highly attractive to bees in the first sunshine and most of the pollination activities happen in this time. It is said that a single visit of buckwheat flower by a bee rising plant productivity by 25-30%. As in other studies, honey bees visited flowers predominantly between 09.00 – 12.00 h of the day during the field trials (Goodman *et al*., 2001; Alekseyeva and Bureyko, 2000; Free, 1993; McGregor, 1976).

The nectar productivity of buckwheat dependent on, fertilization and growth conditions and varies from 6 to 362 kg/ha (Burmistrov and Nikitina, 1990; Gluchov, 1974; Elagin, 1967). Bumblebees and honeybees visit buckwheat predominantly between 09.00-12.00 h of the day, whereas syrphids are still active in the afternoon (Jacquemart *et al*., 2007; Goodman *et al*., 2001; Alekseyeva and Bureyko, 2000; Naumkin, 1998; Limonta and Antignati, 1994; Free, 1993; Hedtke and Pritsch, 1993; McGregor, 1976).

Honeybee foraging activity (time spent per inflorescence and plant) is not influenced by day period, although fewer flowers are visited per trip after mid-day, whereas syrphid foraging activity reduces in the course of the day (Jacquemart *et al*., 2007). Honeybees are more active during warm and sunny days as well as during the flowering peak (Alekseyeva and Bureyko, 2000). A single honeybee visits on an average of 14-20 flowers min-1, and works on buckwheat for 4-5 h d-1 (Jacquemart *et al*., 2007; Free, 1993; Hedtke and Pritsch, 1993).

A. cerana F. bee spent on an average of 1.95 seconds per flower while *A. mellifera* L. bee spent on an average of 2.37 seconds per flower of buckwheat. This finding corroborates with the findings of Verma and Dutta (1986) on apple bloom and Desh Raj and Rana (1994) on rapeseed bloom.

2.6 Amount of nectar sugar in Buckwheat flowers

The greatest amount of nectar – 0.312 mg or 0.11 mg biological sugar per plant was assembled in 2000 and the smallest amount of nectar 0.013 mg or 0.007 mg biological sugar was obtained in the droughty summer of 2001, but the nectar concentration was high – 50.6%. The largest amount of biological sugar – 56.9 kg per hectare was secreted in 2000 and the lowest content of biological sugar in nectar was secreted in 2001, it was only 6.1 kg/ha (Racys & Montviliene, 2005).

The cultivation of buckwheat along with beekeeping may produce 50 to 100 kg of honey per hectare, due to its extended flowering period for more than 30 days (Rajbhandari, 2010). The nectar productivity of different buckwheat cultivars during the period of full blossom was 9.6 to 13.7 mg of sugar/l00 flowers on the average of three years under a competitive quality test (Burmistrova and Yakovleva, 1984), but was 14.0-15.6 mg among some individual mutants (Kirilenko and Bochkaryeva,1983).

Nectar secretion begins after the opening of the perianth and nectar drops accumulate on the receptacle against the nectaries (Cawoy *et al*., 2008). The nectar is composed of sucrose, fructose and glucose (Cawoy *et al*., 2006a; Alekseyeva and Bureyko, 2000; Kirillenko and Bochkareva, 1983). The two hexoses (fructose and glucose) are the major components of buckwheat nectar (85%); nectar ‘hexoses-dominant’ (Cawoy *et al*., 2006a). Fructose becomes the main sugar with more than 50% at the flowering peak (Lee and Heimpel, 2003). In the field, an average nectar production is calculated to 0.08-0.10 mg sugar per flower during the period of full flowering (Alekseyeva and Bureyko, 2000). In controlled conditions, a flower producted about 0.16 µl of nectar after 10 hours of secretion (Cawoy *et al*., 2006a). Sugar concentration in the field varies along the day: from 34% in early morning to less than 10% at mid-day (Lee and Heimpel, 2003). However, other total sugar concentrations were reported in the literature, fluctuating from 36 to 51% under field conditions and up to 55% under controlled conditions (Cawoy *et al*., 2006a; Racys and Montviliene, 2005; Lee and Heimpel, 2003; Jablonski and Szklanowska, 1990).

Nectar production does not significantly differ within pollinated and unpollinated flowers and no nectar reabsorption was observed (Cawoy *et al*., 2008, 2006a). Nectar production of flowers is positively related to the number of open flowers per plant which fluctuates with the plant age (Cawoy *et al*., 2006a). The huge amount of nectar per flower and per plant is the highest during the flowering peak. Inflorescences of the terminal cluster have the maximum nectar production per flower (Cawoy *et al*., 2008). Biological characteristics of buckwheat cultivars influence nectar production (Alekseyeva and Bureyko, 2000; Naumkin, 1998). Tetraploid cultivars produce more nectar and pollen than diploids (30-40% more) and are thus more attractive for insects (Alekseyeva and Bureyko, 2000; Jablonski and Szklanowska, 1990; Kirillenko, 1984).

Low temperatures decrease sucrose production and modify consequently the relative concentration of sugars in buckwheat nectar (Alekseyeva and Bureyko, 2000). With a fridge and wet weather, sugar production per flower can be 15 times higher than during droughty periods (Racys and Montviliene, 2005). Optimal soil humidity for nectar production averages 60% and water stress lower sugar production (Alekseyeva and Bureyko, 2000). Therefore sowing dates could affect nectar production (Alekseyeva and Bureyko, 2000; Naumkin, 1998). High soil fertility could also have a positive influence (Munitsa, 1978).

2.7 Pollination requirements

Buckwheat is naturally cross-pollinated to produce seeds, so insect pollinators are necessary for effective fertilization and seed set. The efficiency of pollination basically depends on insect abundance, flower morphology, nectar production, and the ability of the insects to collect, transport, and deposit pollen on a compatible stigma. Nectar production can be influenced by heteromorphy, ploidy level, cultivar type, plant age, inflorescence position, and abiotic factors (Cawoy *et al*., 2008). Tetraploid cultivars produce more nectar and pollen than diploids (about 30–40% more) and are thus more attractive for insects (Alekseyeva and Bureyko, 2000).

Among abiotic factors, light is an important factor that influences nectar production. It has been reported that nectar production drops down when plants or inflorescences are transferred from light to dark conditions (Cawoy *et al.*, 2008). Also nectar volume is light dependent as nectar volume/flower is enhanced by about 41% when the light irradiance doubles (Cawoy *et al*., 2007a).

The available data reveal that nectar production appears to be linked to photosynthesis but when plants undergo defoliation, nectar production persists and the nectar is still highly sugary (defoliation; minimum 30%; control 50%). Photosynthesis may take place in other parts of the plant such as the inflorescence pedicles, the cyme bracts, and the main stem (Cawoy *et al*., 2008). In the case of buckwheat approximately 1% pollination is carried out by means of wind and depending on the speed of the wind, pollen can reach 600 m if wind speed is lower than 3 m/s and 1000 m when wind speed is higher than 6 m/s (Bjorkman, 1995).

The numerous pollinators involved in the pollination mechanism of buckwheat flower which include Hymenoptera: honey bees (*Apis mellifera* L.), bumble bees, solitary bees, and wasps; Diptera; Syrphidae, Calliphoridae; and others; and Lepidoptera and Hemiptera (Jacquemart *et al*., 2007; Tahir *et al*., 1985). Moreover, the major visitors of buckwheat belong to Apoidea (Hymenoptera, *Apis mellifera*, and *Bombus* species) and Syrphidae (Diptera and Eristalis species) (Racys and Montvilienne, 2005). The main pollinators are honey bees as they accumulate both types of pollen (pin and thrum) on the same trip. Thus buckwheat is considered as an excellent plant for bee pasture and insectary gardens (Lee-Mader *et al*., 2014; Mader *et al*., 2011). Besides its foraging and prospecting behavior, collecting nectar and pollen, the honey bee promotes frequent touch with stigmas (Jacquemart *et al*., 2007; Bjorkman, 1995). However, the honey bee spends more time on thrum flowers than on pin flowers because there is more nectar production in thrums. There are uncommon differences in nectar production between morphs in distylous species (Ornelas *et al*., 2004).

However, the total sugar concentration is similar in both morphs, but sucrose level is significantly higher in thrum flowers (16.8% against 12.9%), so the sucrose/hexose ratio is higher for thrum flowers (Cawoy *et al*., 2006a). It is advised that one honey bee colony per acre is sufficient for effective pollination. It has been reported that honey bees are more active during warm and sunny days. In addition, they are also active during the flowering peak and the optimum temperature (20˚C) for effective pollination (Alekseyeva and Bureyko, 2000; Sugawara, 1956). Bumble bees and honey bees visit buckwheat predominantly between 9 and 12 h of the day while syrphids are still active in the afternoon (Goodman *et al*., 2001). On average a single honey bee visits about 14–20 flowers/min and works on buckwheat for 4–5 h/day (Jacquemart *et al*., 2007).

It has also been reported that under experimental conditions the efficiency of honey bee pollination is good since this insect deposits compatible pollen on most flowers (>90%) without discrimination between floral morphs (Jacquemart *et al*., 2007).

The low temperature influences the rate of pollination because of the reduction in sucrose production in buckwheat plants, consequently reducing the relative concentration of sugars in the nectar. It has been reported that under cool and wet climatic conditions, sugar production per flower can be about 15 times higher than during dry and drought conditions (Racys and Montvilienne, 2005).

CHAPTER III

MATERIALS AND METHODS

3.1 Experimental Site

The research farm of Sher-e-Bangla Agricultural University, Dhaka-1207 (Appendix I) was used to conduct the present study during the period from November 2019 to March 2020. The experimental field was located at 90º 33 E longitude and 23º71 N latitude at a height of 8m above the sea level. The land of research area was medium high topography.

Plate 1. Preparation of experimental site

3.2 Experimental design and layout

The experiment was laid out in a Pairplot technique with 12 replications, where the experimental area was divided into two equal blocks representing the replications. The unit plot size was 4 m ×1.25 m having 1 m space between the replications and 0.4 m between the plots. Each plot contains 3 rows and row to row distance 25 cm and 20 cm between plants. The design and layout of the experimental plot was presented in Appendix II.

3.3 Climate

Sub-tropical climate is characterized by the research areas with three distinct seasons, Kharif-1 (April-June), Kharif-2 (July-September) and Robi/Winter (October-March). Due to lower rainfall, this weather is the favorable for crop production. The average maximum temperature during the period of experiment was 29.18°C and the average minimum temperature was 9.17°C. Details of the meteorological data related to the temperature, relative humidity and rainfalls during the period of the experiment was collected from the Bangladesh Meteorological Department, Dhaka and presented in Appendix III.

3.4 Collection of seeds

Buckwheat seeds were collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

3.5 Preparation of land and rate of fertilization

A power tiller was used to open the plots selected for the research in the last week of October 2019 and exposed to the sun for a week, after which the land was harrowed, ploughed and cross-ploughed two times followed by laddering to obtain a good tilt conditions of soil with removal of weeds and stubbles (Plate 1). During land preparation 40kg decomposed cow dung were mixed. TSP, MOP and Boric acid were used 0.4kg, 0.8kg, 0.2kg, respectively as the source of Phosphorus (P_2O_5), Potassium (K_2O) and Boron (B).

3.6 Seeds sowing

At November 13, 2019 seeds were sown continuously in 4-4.5 cm deep furrows made by hand iron tine maintaining desired row spacing. Before seed placement in rows light water was applied in furrows for easy emergence of seeds (Plate 2).

Plate 2. Seed sowing of buckwheat in the experiment field

After placement, the seeds were covered with soil by hand. Within 14 days of sowing the germination was started and full germination was completed within 20 days after sowing the seeds.

3.7 Intercultural operations

Operations like thinning, weeding were done as and when necessary for proper growth and development of the crop. Two watering were done throughout the growing season. The mulching was also done by breaking the soil crust after irrigation properly. Irrigation was provided to maintain moist condition in the early stages to establish the seedlings and then irrigated whenever necessary throughout the entire growing period. No water stress was encountered in reproductive phase.

3.8 Treatments of the experiment

The experiment was consisted of the following two treatments are as follows:

T1 = Without Netting (open)

T2= Netting

3.9 Insect visited per plant

Five plants were randomly selected from each plot, then the number of insects visited was recorded at different time of the days at flowering of each plant, and then means were calculated.

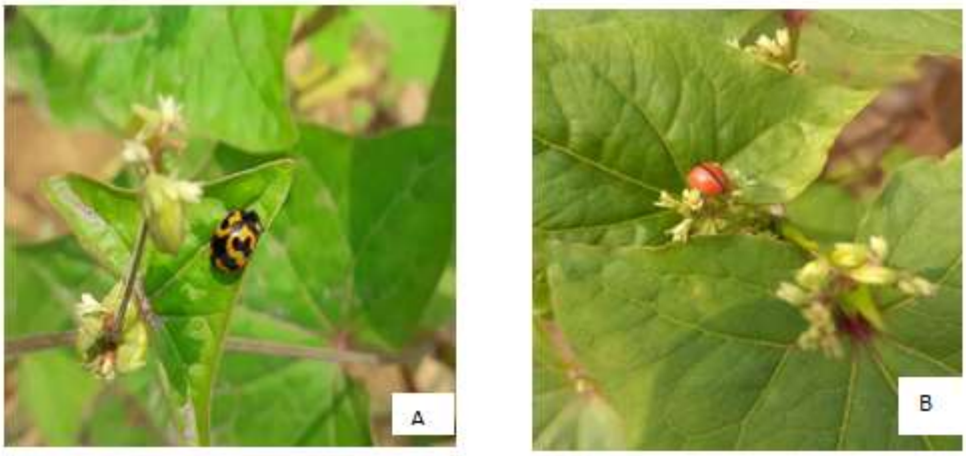


Plate 3. Ladybird beetle (A) and Spotless ladybird beetle (B) available foraging flower of buckwheat open plot

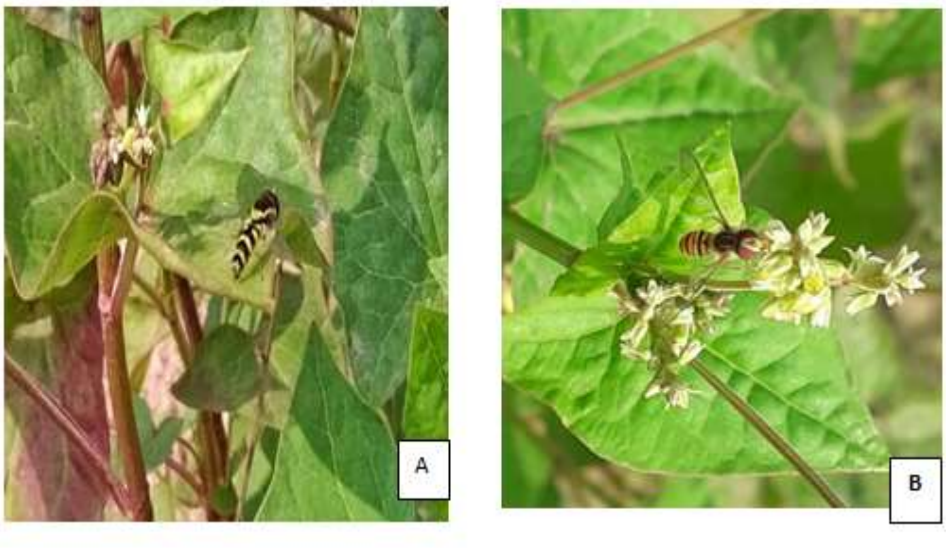


Plate 4. Indian Honey bee (A) and Syrphid fly (B) visiting on the flower of buckwheat open plot

3.10 Relative abundance of insect visitors

For relative abundance of insect visitors, five different plants were selected randomly from each plots and observations were started 2-3 days after the flowering. These observations were taken between 7 AM, 9 AM, 11 AM, 1 PM, 3PM and 5 PM of the days and were continued for 20 sunny days (Plate 3, 4).

3.11 Foraging behavior of bees

Major pollinator associated with pollination of buckwheat with different foraging behavior were recorded in every plot as follows: the number of pollinator foraging was recorded in randomly selected five plants during 7 AM, 9 AM, 11 AM, 1 PM, 3 PM and 5 PM of the day.

3.12 Determination of Diversity Index

Many of the collected specimens were identified up to species level and the rest specimens were identified up to genus level using morphological technique. Biodiversity of the community was calculated using the Shannon-Weiner diversity index $H \ or \ H' = -\sum_{i=1}^{i=N} \text{pi} \log 2 \ \text{pi}$ where, pi is the proportion of each super family within the community, N expresses the total number of super families within the community. The community dominance was also evaluated from the Shannon-Weiner diversity index by this formula: $\frac{Y1+Y2}{Y}$x100. In this equation, Y expresses the total number of genus within a community; Y_1 expresses the super family having the highest genus, and Y_2 expresses the super family having the second highest genus.

3.13 Harvesting

Because of the indeterminate growth habit of the buckwheat plant, it is difficult to harvest grains at a particular time period. At the harvesting period, seeds of all stages, namely, mature seeds, immature seeds, and a few flowers, are present at the same time. The seed was harvested by hand. Full harvest should begin when 70–75% of the seeds have reached physiological maturity. Buckwheat is easy to thresh because most of the seeds fall out if a dry bundle of grain is shaken. The seed yield per hectare was calculated from the yield of seed per plot with each respective treatment.

3.14 Sample collection and data recording

To take and calculate the data on different traits, five plants were selected randomly from each plot. A brief description of procedures of data collection from different parameters presented bellow:- The percent proportion of different insects were counted by considering the major insect orders. Then, all the counted insect found in crop sorted as per as their respective orders.

3.14.1 Plant height

Five plants were randomly selected from each plot and then the height (cm) of plant was measured by using a measuring tape in centimeter unit and then means were calculated.

3.14.2 Number of primary branches per plant

The branching main stem is called primary branch. Five plants were randomly selected from each plot and then total number of primary branches per plant was counted from the main stems and then means were measured.

3.14.3 Number of blossom per plant

Five plants were randomly selected and total number of blossom on the sample plants of each unit plot was counted and the means was considered as number of blossom per plant (Plate 5).

Plate 5. Blossoms of buckwheat in open plot

3.14.4 Number of seed per plant

Seeds were taken from randomly selected five plants and counted seed of each plant and then the mean was calculated.

3.14.5 Seed weight per plant

Seeds were taken from randomly selected five plants and weighed with the help of electronic balance and then the mean was calculated in gram unit.

3.15.6 1000-seed weight

Thousand seeds were taken from randomly selected five plants and weighed with the help of electronic balance and then the mean was calculated in g.

3.14.7 Seed weight per plot

Seeds were taken from randomly selected five plants and weighed with the help of electronic balance was calculated in g (Plate 6).

Plate 6. Buckwheat seeds

3.14.8 Seed yield

Weighed the total amount of seed produced per plot with the help of electric balance and then the yield of seed per plot was converted per hectare in tons.

3.14.9 Determination of unfilled grain

Five plants from each unit plot were randomly selected at the time of harvest and counted the total number of unfilled grain then the percentage of unfilled grains were calculated by the following formula:

Percent unfilled grains = (No. of unfilled grains/Total no. of grains) X 100

3.15 Statistical Analysis

After collection of all the data, those were analyzed following the ANOVA techniques and using the STATISTIS 10 computer package program. The means were separated by using Least Significant Difference (LSD) at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER III
RESULTS AND DISCUSSION

The results obtained during the investigations carried to "Study on insect diversity and pollination effect on buckwheat (*Fagopyrum esculentum*) yield " are presented in this chapter. In this chapter; figures, tables and appendices have been used to present, discuss and compare the findings obtained from the present study. The pollinators had the significant roles on pollination of buckwheat and its yield contributing characters. The ANOVA (analysis of variance) of data of all the visual and measurable characteristics have been presented in Appendix (III-VI). The all results obtained and interpretations were given under the following sub-headings:

4.1 Insects visit and their relative abundance on buckwheat flower

4.1.1 Insect visitors on Buckwheat flowers in open plot

There were different types of insect species which visited the buckwheat flowers during blooming, which listed in Table 2. In total visiting insect species belonging to 6 genera under 5 families were recorded on the buckwheat flowers during study. Out of these, 2 belonged to Diptera, 2 to Coleoptera and 5 species belonged to Hymenoptera. Among these, most frequent visitor was Hymenoptera, whereas Coleoptera and Dipera were less frequent visitors.

Table 2. List of insect visitors recorded on buckwheat flowers in open plot

Common Name	Scientific Name	Family	Order
Ant	*Formica* sp.	Formicidae	Hymenoptera
Indian Honey Bee	*Apis cerana F*	Apidae	Hymenoptera
Giant honey bee	*Apis dorsata F*	Apidae	Hymenoptera
Little bee	*Apis florea F*	Apidae	Hymenoptera
European honey bee	*Apis mellifera L*	Apidae	Hymenoptera
Syrphid Fly	*Syrphus* sp.	Syrphidae	Diptera
House fly	*Musca* sp.	Muscidae	Diptera
Ladybird Beetle	*Menocheilus sexmaculatus*	Coccinellidae	Coleoptera
Spotless lady beetle	*Coccinella* sp.	Coccinellidae	Coleoptera

4.1.2 Foraging frequency of Hymenopteran insects on buckwheat flower in open plot

Monitoring was done six times in a day, i.e. at 7 AM, 9 AM, 11AM, 1 PM, 3 PM and 5 PM at peak blooming stage. The number of *Apis cerana* F. was the highest (9.28±2.62) and (6.57±2.72) at 11 AM and 1 PM, respectively, while the lowest number of *Apis cerana* F. was found (0.92±0.83) and (0.85±0.94) at 5 PM and 7 AM respectively. The number of *Apis dorsata* F. was the higest (4.83±1.60) and 3±0.90) at 1 PM and 11 AM, respectively, while the lowest number of *Apis dorsata* F. was found (0.67±0.81) and (0.58±0.69) at 3 PM and 9 AM, respectively and no foraging activity was recorded at 7 AM. The number of *Apis florea* F. was the highest (2.45±0.64) and (1.25±0.72) at 11 AM and 1 PM, respectively, while the lowest number of *Apis florea* F. was found (0.99±0.74) and (0.64±0.64) at 9 AM and 3 PM respectively and no activity was initiated at 7 AM and 5 PM. The number of *Apis mellifera* L. was the highest (3.8±1.4) and (1.47±1.31) at 1 PM and 11 PM respectively while the lowest number of *Apis mellifera* L. was found (0.82±0.57and (0.8±0.7)) at 3 PM and 9 PM respectively and no activity was seen at 7 AM and 5 PM.

There was no significance difference on the number of flowers visited by four species of honeybees, *Apis cerana* F., *Apis dorsata* F., *Apis florea* F. and *Apis dorsata* L. The number of buckwheat flower visited by *Apis cerana* F. and *Apis florea* F. was highest at 11 AM, while by *Apis dorsata* F. and *Apis mellifera* L. was highest at 1 PM. But, for both species of honeybees it was the lowest at 7 AM and 5 PM (Table 3). This might be due to the effect of high solar radiation. At 10 AM influenced the more flower visit by *Apis cerana* F. was observed at 12 noon due to high solar radiation and high light intensity influenced more flower visit by *Apis mellifera* L (Abroal, 1998).

Table 3. Foraging frequency of Hymenopteran insects on buckwheat flower in open plot per plant

Species	7AM	9AM	11AM	1PM	3PM	5PM	LSD (0.05)	CV (%)
Apis cerana **F**	0.85±0.94	2.08±2.14	9.28±2.62	6.57±2.72	2.17±1.81	0.92±0.83	1.08	35.80
Apis dorsata **F**	0±0	0.58±0.69	3±0.90	4.83±1.60	0.67±0.81	0.25±0.48	0.60	47.52
Apis florea **F**	0±0	0.99±0.74	2.45±0.64	1.25±0.72	0.64±0.64	0±0	0.41	56.74
Apis mellifera **L**	0±0	0.8±0.7	1.47±1.31	3.8±1.4	0.82±0.57	0±0	0.59	62.57

4.1.3 Foraging frequency of Coleopteran insects visit on buckwheat flower in open plot

Monitoring was done six times in a day, i.e. at 7 AM, 9 AM, 11AM, 1 PM, 3 PM and 5 PM at peak blooming stage. The data on the foraging frequency of insect visitors of the day hours showed that *Menocheilus sexmaculatus* and *Coccinella* sp. were most frequent visitors in all days. The number of buckwheat flower visited by *Menocheilus sexmaculatus* was the highest, whereas in case of *Coccinella* sp., it was the lowest in number (Table 4).

4.1.4 Foraging frequency of Dipteran insects visit on buckwheat flower in open plot

Monitoring was done six times in a day, i.e., at 7 AM, 9 AM, 11AM, 1 PM, 3 PM and 5 PM at peak blooming stage. The number of *Syrphus* sp. was the highest (2.53±1.1) and (2.50±1.08) at 7 AM and 5 PM, respectively which followed by 9AM (1.33±0.65), while the lowest number of *Syrphus* sp. was found (0.25±0.62) and (0.33±0.49) at 1 PM and 11 AM, respectively (Table 5).

Table 4. Foraging frequency of Coleopteran insects on buckwheat flower in open plot per plant

Species	**7AM**	**9AM**	**11AM**	**1PM**	**3PM**	**5PM**	**LSD (0.05)**	**CV (%)**
Menocheilus sexmaculatus	6.93±0.82	7.72±1.1	8.36±1.05	8.13±1.1	8.3±0.98	7.74±1.1	0.57	8.79
Coccinella sp.	1.42±0.79	1.5±0.7	2.24±0.7	1.96±0.6	1.94±0.5	0.02±0.5	0.49	32.15

Table 5. Foraging frequency of Dipteran insects on buckwheat flower in open plot per plant

Species	**7AM**	**9AM**	**11AM**	**1PM**	**3PM**	**5PM**	**LSD (0.05)**	**CV (%)**
Syrphus sp.	2.53±1.1	1.33±0.65	0.33±0.49	0.25±0.6	0.75±1.06	2.50±1.08	0.77	73.77

4.1.5 Time spent by honey bees per cluster

For time spent of honey bee visitors, five different plants were selected randomly in every plots and observations were started 2-3 days after the flowering. These observations were taken between 7 AM, 9 AM, 11 AM, 1 PM and 3PM of the days. In every sampling days, only one individual insect (*Apis cerena* /*Apis dorsata*/ *Apis florea*/ *Apis mellifera)* was observed per cluster and after 20 days observation data was calculated per insect per cluster. The data (Table 6) showed that at 7 AM, there was significant difference among the four species of honey bee. *Apis dorsata*, *Apis florea* and *Apis mellifera* did not spent time at 7 A.M and *Apis cerena* spent 2.85 sec per cluster.

At 9 AM, there was no significant difference among the spending time of four honey bee species. *Apis dorsata* and *Apis mellifera* spent same time (2.60 sec), whereas *Apis florea* spent slightly more time (2.80 sec) than *Apis cerana* (2.75 sec).

At 11 AM, among four species of honey bee *Apis melllifera* and *Apis cerena* spent more time than *Apis dorsata* and *Apis florea*.

At 1 PM, *Apis mellifera* spent longest time (4.80 sec) cluster than the other three species of honey bee. In this case, *Apis cerena*, *Apis dorsata* and *Apis florea* spent 3.72 sec, 2.23 sec and 2 sec, respectively. There are statistically no significant differences between two species of honeybees on time spent per cluster on buckwheat flower. But, slightly more time was taken by *Apis mellifera* L. than *Apis cerana* F. per cluster visit.

Apis cerana F. bee spent on an average of 1.95 seconds per cluster, while *A. mellifera* L. bee spent on an average of 2.37 seconds per cluster of buckwheat. This finding corroborates with the findings of Aryal *et al*., (2016) on foraging behavior of native honeybee (*Apis cerana* F.) and European honeybee (*Apis mellifera* L.) on flowers of common buckwheat (*Fagopyrum esculentum* M.) in Chitwan, nepal.

At 3 P.M, there was no significant difference among the four species of honey bee. But *Apis cerena* spent slightly more time (2.12 sec) than the other three species.

Table 6. Time spent by honey bee species per cluster of buckwheat flower

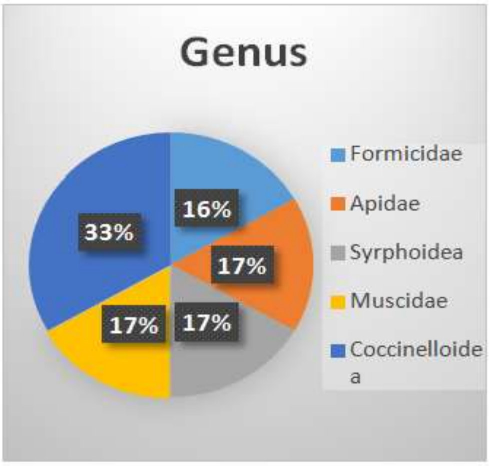
Time	Time spent (sec)				CV (%)
	Apis cerena	*Apis dorsata*	*Apis florea*	*Apis mellifera*	
7AM	2.85±0.41	0±0	0±0	0±0	28.93
9AM	2.75±0.93	2.60±0.76	2.80±0.45	2.60±0.55	22.97
11AM	3.77±0.66	2.65±0.49	2.40±0.89	3.80±0.84	23.86
1PM	3.72±0.90	2.23±0.54	2.0±0.71	4.80±0.83	26.14
3PM	2.12±0.93	1.66±1.12	1.40±0.89	2.40±0.89	36.27

4.1.6 Diversity and abundance of pollinators on buckwheat flower in open field

A total number of six genera of pollinators was identified under 5 super families. There were nine species identified under six genera. The diversity of genus and species respectively in Formicoidea was 1 and 1, in Apoidea 1 and 4, in Syrphoidea 1 and 1, respectively; Muscoidea 1 and 1, in Coccinelloidea 2 and 2(Table 7).

Table 7. Total number of identified genera and species on pollinators in buckwheat flower in field

Super Family	Genus(No.)	Species(No.)
Formicoidea	1	1
Apoidea	1	4
Syrphoidea	1	1
Muscoidea	1	1
Coccinelloidea	2	2
Total	**6**	**9**



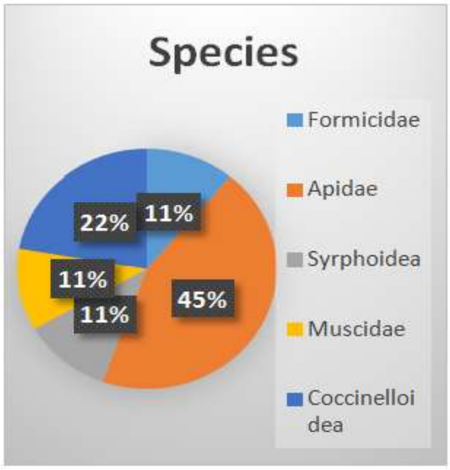


Figure 2. Diversity observed in super families: a. genus; and b. species

The most dominant super family of pollinator species individuals (45%) was observed in Apoidea followed by Coccinelloidea (22%) while in other super families (11%) and (11%). Highest diversity in genera was obtained from super family Coccinelloidea (33%) these was followed by other Super families with similar diversity (17%) (Figure 2. a & b).

Diversity Index: The Shannon-Wiener diversity index in buckwheat under open field condition for genus and species was 1.57 and 1.43, respectively with 9 species richness, where the evenness was 0.71 and 0.65, respectively. There were 50% and 67% community dominance for genus and species, respectively in buckwheat under open field condition (Table 8 & 9).

Table 8. Biodiversity index assessment (genus)

Super Family	Genus	Pi	log_2pi	$pilog_2pi$
Formicoidea	1	0.17	-1.77	-0.30
Apoidea	1	0.17	-1.77	-0.30
Syrphoidea	1	0.17	-1.77	-0.30
Muscoidea	1	0.17	-1.77	-0.30
Coccinelloidea	2	0.33	-1.11	-0.37
Total	5		8.20	-1.57
Speices Richness (SR)				9
H or H'				1.57
H_{max}				2.20
Evenness				0.71
Community dominance				50%

Table 9. Biodiversity index assessment (species).

Super Family	Species	pi	log_2pi	$pilog_2pi$
Formicoidea	1	0.11	-2.20	-0.24
Apoidea	4	0.44	-0.81	-0.36
Syrphoidea	1	0.11	-2.20	-0.24
Muscoidea	1	0.11	-2.20	-0.24
Coccinelloidea	2	0.22	-1.50	-0.33
Total	9		8.91	-1.43
Speices Richness (SR)				9
H or $H^{'}$				1.43
H_{max}				2.20
Evenness				0.65
Community dominance				67%

4.2 Yield attributes

4.2.1 Plant height

The plant height of buckwheat was significantly differed due to different condition (Table). Numerically the tallest plant (95.14 cm) was recorded from netting plot (T_2) and the shortest plant (85.48 cm) was recorded from without netting plot (T_1). The pollinators had effects of plant height due to the varietal trait (Table 10). The findings is collaborated with the results found by Rijal *et al*. (2018) and found that the plant height of buckwheat was not significant among locations, however it was significant among treatments. The significant difference on the plant height due to the effect of insect pollination on buckwheat was evident. The plant height was shorter in open, hand pollinated, bee pollinated treatments compared to control (Rijal *et al*. 2018).

4.2.2 Number of primary branches per plant

The number of primary branches per plant of buckwheat were not significantly affected by different due to the open and netted conditions. The results of the experiment revealed that, the maximum number of primary branches per plant (5.63) was recorded in without netting (T_1) condition and the minimum number of primary branches per plant (5.58) was recorded from when the plot was netted (T_2). There was no significant effects on branches number plant^{-1}(Table 10). So, under present study no significant differences among pollination modes were found(Table 10).

Table 10. Effect of different pollinating conditions on the plant height, Branches plant^{-1} and flower plant^{-1} of buckwheat crop

Sl. No	Treatments	Plant Height	Branches/Plant	Blossoms /Plant
1.	**Without netting (T_1)**	85.483 b	5.6358 a	1651.0 a
2.	**Netting (T_2)**	95.142 a	5.5800 a	1614.5 a
	LSD(0.05)	7.6811	0.7095	61.579
	CV (%)	9.47	14.08	4.20

4.2.3 Number of blossoms per plant

The number of blossoms per plant of buckwheat significantly was not affected by different condition. The results of the experiment revealed that, the maximum number of blossoms per plant (1651.0) was recorded in without netting (T_1) condition and the minimum number of blossoms per plant (1614.5) was recorded from when the plot was netted (T_2) (Table 10).

4.2.4 1000-seed weight

Different pollination condition significantly affected the 1000-seed weight of buckwheat crop (table). The highest 1000-seed weight was recorded (18.39 g) from without netting (T_1) and the lowest 1000-seed weight was recorded (9.17 g) from netting (T_2) condition (Figure 3).

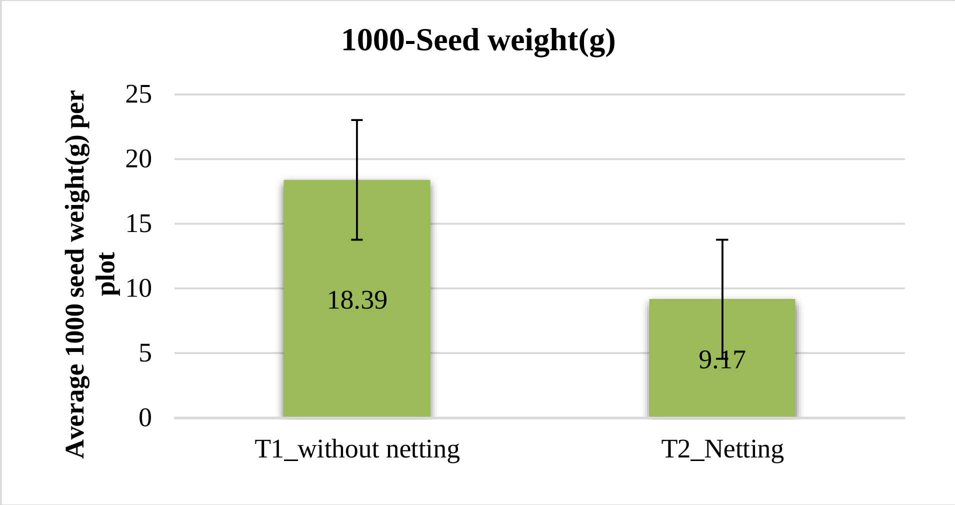


Figure 3. 1000 seed weight per plot in two different treatments ($LSD_{(0.05)}$= 0.27)

From the above Figure 3 it was revealed that, 1000 seed weight of buckwheat per plot was the highest in plots without netting.

4.2.5 Seed yield per plant

Highest seed yield per plant of buckwheat was recorded 22.68 gm when buckwheat field was left without netting (T_1). On the other hand, the lowest seed yield per plant of buckwheat was recorded 12.35 gm when buckwheat field was netted (T_2). They were statistically difference observed from each other (Figure 4).

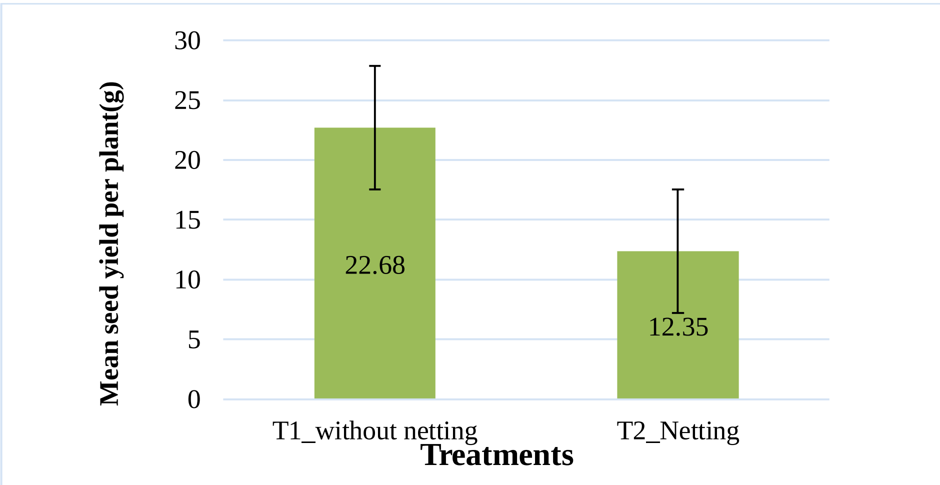


Figure 4. Mean seed yield per plant in two different treatments ($LSD_{(0.05)}$= 0.75)

The Figure 4 it was revealed that, pollinators helped pollination of buckwheat that increased the mean seed yield per plant of buckwheat than netting field.

4.2.6 Seed weight per plot

Highest yield per plot of buckwheat was recorded 0.8258 Kg when buckwheat field left open for pollinators (T_1). On the other hand, the lowest yield per plot of buckwheat was recorded 0.399 Kg when the field was netted (T_2). They were statistically different from each other (Figure 5).

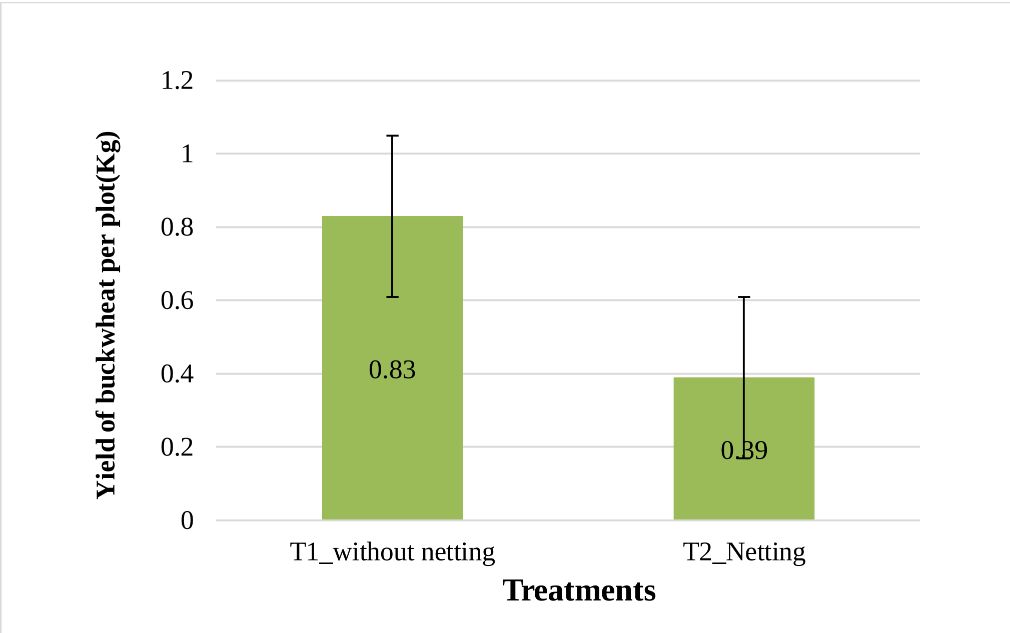


Figure 5. Yield of buckwheat per plot in two different treatments ($LSD_{(0.05)}$= 0.031)

From the above Figure 5 it was revealed that, pollinators helped pollination of buckwheat and increased the yield of buckwheat per plot than netted plots.

4.2.7 Seed yield

Yield per plot of buckwheat showed statistically significant variation in two different treatments. The highest yield per hectare was recorded from T_1 (1.67 ton), whereas the lowest yield per hectare was recorded from T_2 (0.73ton) treatment.

The seed yield of buckwheat can be more than 2t/ha under optimal soil and especially climate condition. However, under unfavorable condition, it will remain below 1t/ha (Varga, 1966). According to FAO data the seed yield of buckwheat ranged 0.35t/ha (1992) to 1.5 t/ha (1997) in Hungary during the period of 1992 to 2008 (FAOSTAT 2010).

4.2.7 Unfilled grain percentage

Experiment result showed that, the highest number of total seed per plant (1558.7) was recorded in T_1 treatment whereas the lowest total number of seed per plant (1313.1) was recorded in T_2 treatment which was statistically not similar with each other (Table 11).

In term of number of unfilled grain per plant, experiment result showed that T_2 treatment recorded the maximum unfilled grain per plant (362.50) whereas T_1 treatment recorded the minimum number of unfilled grain per plant (35.42)

Table 11. Unfilled grain percentage in case netting and without netting

Treatment	Number of grain /plant	Number of unfilled grain/plant	Percentage of unfilled grain
Without netting (T_1)	1558.7	35.42	2.3200
Netting (T_2)	1313.1	362.50	28.00
LSD(0.05)	67.152	18.070	2.6563
CV (%)	5.20	10.11	19.49

Again considering the unfilled grain percentage, the minimum unfilled grain (2.32 %) found in plot without netting (T_1) treatment whereas the maximum unfilled grain (28.00 %) was recorded in netted (T_2) treatment.

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY

The experiment was conducted at the research farm of Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from November, 2019 to March, 2020 in rabi season. The experimental field was located at 90º 33 E longitude and 23º71 N latitude at a height of 8m above the sea level. The experimental site belongs to the agro-ecological zone of "Madhupur Tract", AEZ-28. A sub-tropical climatic zone was prevailed around experimental site, the site is characterized by winter during the months from November 01, 2019 to March, 2020 (rabi season). The soil is silty clay in texture was the main traits of top soil. The experiment was consisted of two (2) different strategies of pollination of buckwheat flowers viz., T_1= without netting, T_2= Netting. Randomized Complete Block Design (RCBD) was selected to lay out the present experiment with 12 replications. The allocated plots were fertilized by recommended doses of fertilizers. All the intercultural operations and plant protection measures were taken as and when needed. Data on different growth yield and yield contributing characters were collected and analyzed by using STATISTIX 10 computer package and means were compared by Least Significant Difference (LSD) at 5% level of probability.

Results demonstrated that, the important role on the pollination of buckwheat flowers for better yield. Results revealed that, the most abundant species were identified as *Apis cerana* F. (9.28±2.62) from Hymenoptera order and *Menocheilus sexmaculatus* (8.36±1.05) from Coleoptera order foraging the field at 11 A. M. while *Syrphus sp.* (2.53±1.1) was found as dominant species from Diptera order visited the field at early morning (7 A.M.). *Apis cerena* spent 2.85 sec per cluster at 7 AM whereas *Apis dorsata*, *Apis florea* and *Apis mellifera* did not spent time. At 9 AM, *Apis dorsata* and *Apis mellifera* spent same time (2.60 sec) whereas *Apis florea* spent slightly more time (2.80 sec) than *Apis cerana* (2.75 sec). At 11 AM, among four species of honey bee *Apis melllifera* and *Apis cerena* spent more time than *Apis dorsata* and *Apis florea*. At 1 PM, *Apis mellifera* spent longest time (4.80 sec) than the other three

species of honey bee. At 3 P.M, there is no significant difference spending time cluster^{-1} among the four species of honey bee. But *Apis cerena* spent slightly more time (2.12 sec) than the other three species.

The growth, yield and yield contributing characters were significantly influenced by treatments of pollination. The highest 1000-seed weight of buckwheat was recorded (18.39 g) from the plot without netting (T_1) whereas the lowest 1000-seed weight was recorded (9.17 g) from plots with netting (T_2) condition of the field. The highest seed yield per plant of buckwheat was recorded as 22.68 gm when the buckwheat field was left open (T_1) and the lowest seed yield per plant of buckwheat was recorded as 12.35 gm when the field was netted (T_2). The highest yield per plot of buckwheat was recorded as 0.8258 kg when the field was opened for pollinators (T_1) and the lowest yield per plot of buckwheat was recorded as 0.399 kg when the field was netted (T_2). The highest seed yield (1.67 t ha^{-1}) was recorded from treatment T_1 and the lowest seed yield (0.73 t ha^{-1}) was recorded from T_2. It can be concluded that, without netting was the best option for maximum pollination for obtaining better yield of buckwheat.

CONCLUSIONS

Based on the results of the present study the following conclusion could be drawn:

1. *Apis cerana, Menocheilus sexmaculatus* and *Syrphus* sp. were identified as the most abundant species in the buckwheat field as a pollinator.

2. The growth, yield and yield contributing characters were significantly influenced by different strategies of pollination with insect pollinators.

3. Without netting (open) was found as the best strategy for better yield of buckwheat. The highest seed yield per plant of buckwheat was recorded as 22.68 gm when the buckwheat field was left open without netting (T_1) and the lowest seed yield per plant of buckwheat was recorded as 16.00 gm when the buckwheat field was netted (T_2). The highest yield per plot of buckwheat was recorded as 0.8258 kg when the field was left open for pollinators (T_1) and the lowest yield per plot of buckwheat was recorded as 0.6108 kg when the field was netted (T_2).

Recommendations

1. For seed production of buckwheat, netting along with pollinators after flowering may be best suited for obtaining maximum seed yield.

2. The results obtained from the present study should be re-confirmed by conducting similar type of studies in different Agro-ecological Zones (AEZs) of Bangladesh with the combination of other cultivars at different conditions.

CHAPTER VI

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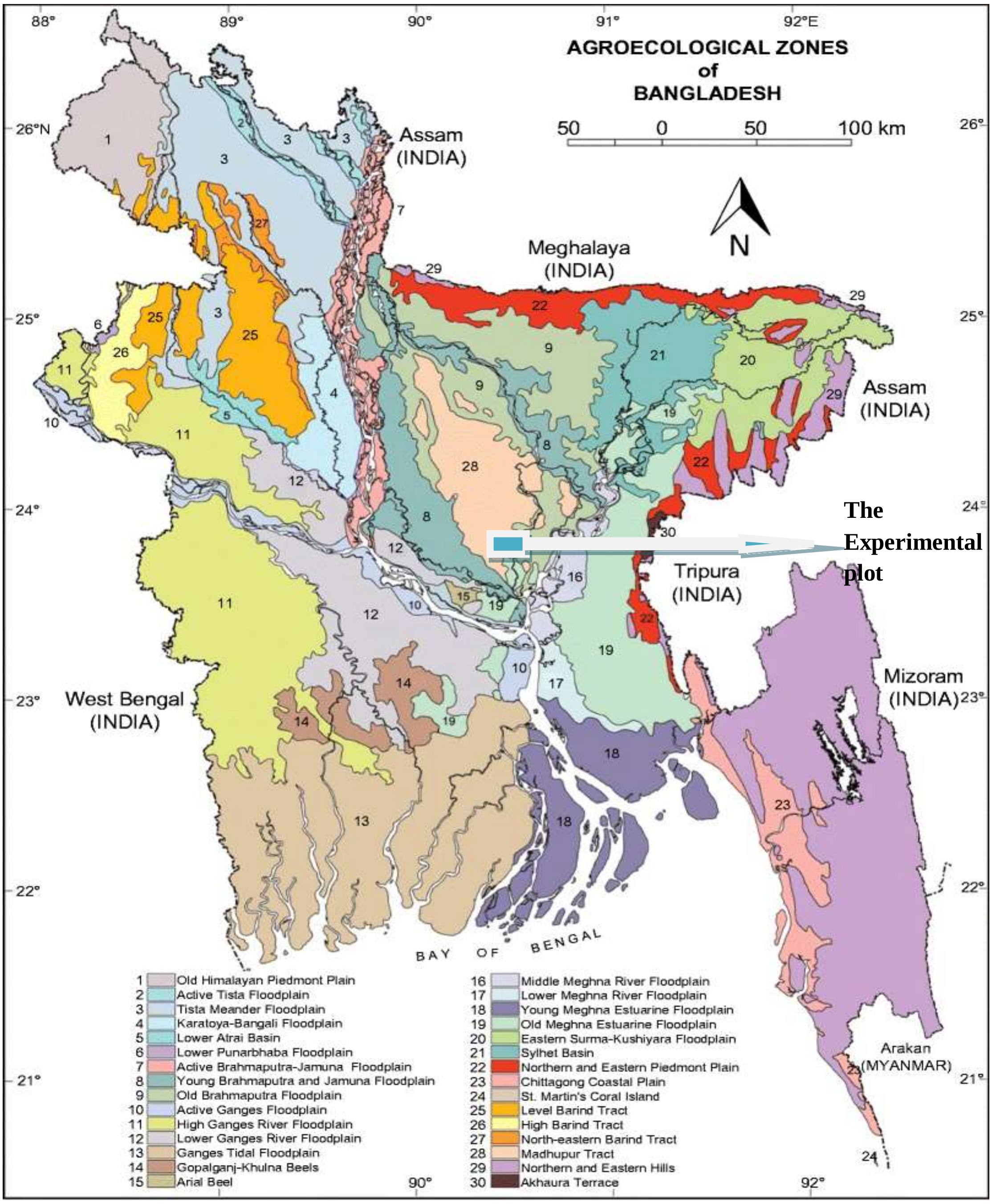
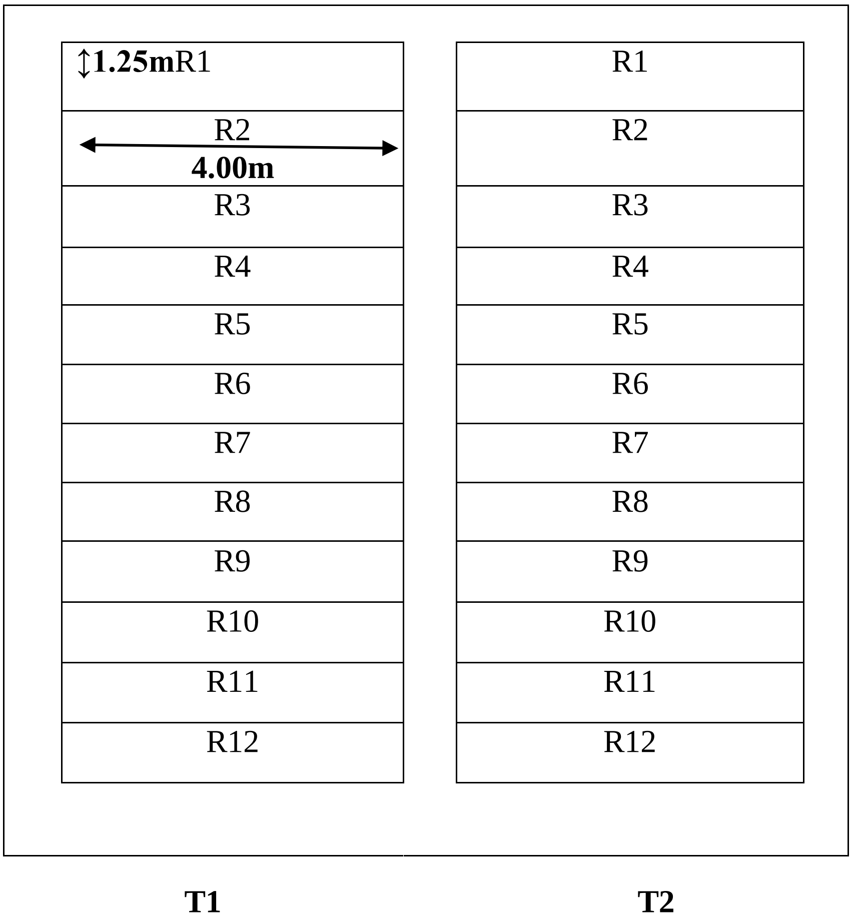
CHAPTER VII

APPENDICES

Appendix I. The map of the experimental site



Appendix II. Lay out of experimental site



Legends:

Line to line distance: 25 cm

Plant to plant distance: 20 cm

Unit plot size: 4.0 m × 1.25 m

Appendix III. Monthly average air temperature, relative humidity and rainfall during the period from October 2019 to April 2020 at Sher-e-Bangla Agricultural University campus

Year	Month	Air temperature (°C)			Relative humidity (%)	Rainfall (mm)
		Max	*Min*	*Mean*		
2019	**October**	30.42	16.24	23.33	68.48	52.60
2019	**November**	28.60	8.52	18.56	56.75	14.40
2019	**December**	25.50	6.70	16.10	54.80	0.0
2020	**January**	23.80	11.70	17.75	46.20	0.0
2020	**February**	22.75	14.26	18.51	37.90	0.0
2020	**March**	35.20	21.00	28.10	52.44	20.4
2020	**April**	34.70	24.60	29.65	65.40	165.0

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1212.

Appendix IV. Mean square values of the data for plant height, number of primary branches/plant, number of blossoms/plant of buckwheat

Source of variation	Degrees of freedom	Plant height	Number of primary branches /plant	Number of blossoms/plant
Replication	11	31.541	2.05654	22458.9
Treatments	1	559.700	0.01870	7998.2
Error	11	73.074	0.62356	4696.6

Appendix V. Mean square values of the data for 1000-seed weight, yield/plant and seed yield of buckwheat

Source of variation	Degrees of freedom	1000-seed weight(g)	Yield/plant(g)	Yield/plot(kg)
Replication	11	0.128	3.084	0.00500
Treatments	1	510.327	640.357	1.09227
Error	11	0.091	0.700	0.00118

Appendix VI. Mean square values of the data for number of seed/plant, number of unfilled grain/plant, percentage of unfilled grain of buckwheat

Source of variation	Degrees of freedom	Seed/plant	Unfilled grain/plant	Percentage of unfilled grain/plant (%)
Replication	11	29213	923	15.04
Treatments	1	362113	641901	3953.69
Error	11	5585	404	8.74