BHEARD Program Country Summary
Reporting Period: 01/2022-09/2022

Project Overview

The BHEARD Bangladesh Program activities formally closed in 2021 but with additional funds available, the Bangladesh Program team requested the funds go toward the start of the Integrated Pest Management Innovation Lab (IPM) activities supported by Virginia Tech. The project and focus of the work align with BHEARD's mission and with the USAID Bangladesh Mission's approval, BHEARD Bangladesh began to report directly to Virginia Tech. This summary provides excerpts from the most recent IPM report demonstrating how final BHEARD funds have been spent.

Country Overview

Crop losses due to pest attack are a major constraint to alleviating poverty and improving nutrition in Bangladesh. Pests such as insects, mites, bacteria, fungi, viruses, nematodes and weeds cause up to a 40% reduction in crop yields[1]. In recent years, alongside native and naturalized pests which cause chronic crop damage, globalization and other non-agricultural economic activities have enhanced the movement of invasive alien species, which contribute to substantial economic harm and require innovative, rapid and thorough approaches to tackle them. One of the best examples of this is the Fall Armyworm (FAW), an invasive pest native to the Americas. Its migration from North America has been unprecedented, destroying more than 13.5 million tons of maize worth USD3 billion in Sub-Saharan Africa over a period of just two years before reaching South Asia. FAW feeds on more than 80 species of plant, with maize (*Zea mays*) its preferred host. It was identified in Bangladesh for the first time in late 2018 following its migration from southern India and has already spread throughout the country, creating significant crop loss especially in summer maize. Experience in Africa indicates that the two to three years following FAW establishment results in the most crop losses. Use of chemical pesticides to manage pests and reduce these losses has grown over time in Bangladesh, despite evidence of the negative impacts of pesticides on soil and water. Integrated pest management (IPM) is a better approach, using combinations of practices and technologies to reduce losses due to pests while minimizing reliance on synthetic pesticides. Achieving broad-based and inclusive IPM adoption for major crops in Bangladesh is essential for supporting the country's agriculture sector to become more resilient and productive. Urgent action is needed to address the threat of FAW, using IPM strategies that can be sustainably implemented by resource-constrained farmers.

The United States Agency for International Development (USAID) Feed the Future Integrated Pest Management Activity began in 2021. Its main goal is to strengthen the capacity of Bangladesh's agricultural sector stakeholders to control and prevent the spread of current and emerging threats in order to ensure more efficient, profitable and environmentally safe agricultural production and productivity. This will be achieved by implementing the following objectives:

[1] SP-IPM, 2010. Integrated pest management and crop health – bringing together sustainable agroecosystems and people's health. White Paper. SP-IPM Secretariat, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, 17 pp.

***Objective 1*:** Increase the availability and affordability of IPM measures for the prevention and spread of current and emerging threats.

***Objective* 2:** Increase the capacity of Bangladesh agricultural stakeholders such as academia, local lawyers, financial institutions, government, media, civil society, the private sector and value chain actors to implement IPM measures.

***Objective* 3:** Increase the adoption of IPM measures by smallholder farming households to increase agricultural production and productivity, while reducing environmental hazards caused by indiscriminate use of pesticides.

Project Activities

- **Fall Armyworm monitoring:** The FAW National Task Force decided that as in the previous two years, in 2021–22 monitoring of FAW populations would be continued by International Maize and Wheat Improvement Center (CIMMYT) and the Department of Agricultural Extension (DAE). Activities included:
    - Hosting a virtual kickoff meeting to start the monitoring
    - Field data was collected weekly through a) weekly moth counts of adult male FAW moths attracted to and killed in sex pheromone traps, and b) weekly scouting for signs of crop damage caused by FAW larvae feeding on the plant, infestation of whorls, and damage to maize cobs
- **Digital monitoring of FAW populations with the solar-powered, cost-effective, self-cleaning and auto-counting 'Trapview' system**
    - One disadvantage of the methods used by DAE for the manual observation of FAW populations – namely, pheromone traps and field scouting – is that they are time-consuming and difficult, meaning that in the long-term, more time- and cost-effective methods will be needed. To this end, the Activity facilitated the setting of three solar-powered, self-cleaning and auto-count traps, part of the Trapview monitoring system manufactured by European Union private company EFOS, in three maize fields in Chuadanga, Bogura and Dinajpur, which were tested during the 2021–22 *rabi* and 2022 *kharif* seasons


Above: hands-on training program on the use, maintenance and data analysis capacity of Trapview for FAW monitoring (23–30 March 2022) in Dinajpur, Bangladesh

- **Develop and validate FAW management technologies at farm level; integrate these with an IPM package for maize; conduct multi-locational studies on intercropping and agro-ecological management of FAW**
    - Until 2020 no research had been conducted in Bangladesh to identify FAW's local natural enemy population or the efficacy of this population in managing the pest, its agro-ecological management, or integrated management strategies against it. However, during the winter cropping season (*rabi*) 2020–21 and *kharif* 2021, BARI and BWMRI, with financial and technical assistance from the USAID–CIMMYT "Fighting Back Against FAW" Activity, conducted noteworthy research into some of these issues. During the *rabi* 2021–22 and *kharif* 2022 seasons, some of the research findings, along with some new studies, have been produced with financial and technical assistance from the Feed the Future–IPMA Activity. As part of these efforts, CIMMYT, in collaboration with BWMRI, has been undertaking the agro-ecological management of FAW under a sub-grant proposal.
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Project One Accomplishments/Progress + Challenges and Setbacks

For further details on the most recent efforts to reduce FAW and pest management, please see the attached, "Feed the Future Integrated Pest Management Activity Annual Report" attached.

Next Steps

This is the final report for BHEARD Bangladesh but work will continue under their funding through the Innovation Pest Management Lab at Virginia Tech.

Annual Report

Feed the Future Integrated Pest Management Activity

October 2021 – September 2022

CIMMYT

List of acronyms

BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BINA	Bangladesh Institute of Nuclear Agriculture
BRRI	Bangladesh Rice Research Institute
BSCRI	Bangladesh Sugar Crop Research Institute
BWMRI	Bangladesh Wheat and Maize Research Institute
CIMMYT	International Maize and Wheat Improvement Center
CV	Coefficient of variation
DAE	Department of Agricultural Extension
DG	Director General
ETL	Economic Threshold Level
FAO	Food and Agriculture Organization of the United Nations
FAW	Fall Armyworm
FtF	Feed the Future
IPM	integrated pest management
IPMA	Integrated Pest Management Activity
NARS	National Agricultural Research System
PERSUAP	Pesticide Evaluation Report and Safer Use Action Plan
RH	Relative humidity
SAAO	Sub-Assistant Agriculture Officer
SE	Standard error
US	United States
USD	United States Dollar
USAID	United States Agency for International Development

Introduction

Crop losses due to pest attack are a major constraint to alleviating poverty and improving nutrition in Bangladesh. Pests such as insects, mites, bacteria, fungi, viruses, nematodes and weeds cause up to a 40% reduction in crop yields[1]. In recent years, alongside native and naturalized pests which cause chronic crop damage, globalization and other non-agricultural economic activities have enhanced the movement of invasive alien species, which contribute to substantial economic harm and require innovative, rapid and thorough approaches to tackle them. One of the best examples of this is the Fall Armyworm (FAW), an invasive pest native to the Americas. Its migration from North America has been unprecedented, destroying more than 13.5 million tons of maize worth USD3 billion in Sub-Saharan Africa over a period of just two years before reaching South Asia. FAW feeds on more than 80 species of plant, with maize (*Zea mays*) its preferred host. It was identified in Bangladesh for the first time in late 2018 following its migration from southern India and has already spread throughout the country, creating significant crop loss especially in summer maize. Experience in Africa indicates that the two to three years following FAW establishment results in the most crop losses. Use of chemical pesticides to manage pests and reduce these losses has grown over time in Bangladesh, despite evidence of the negative impacts of pesticides on soil and water. Integrated pest management (IPM) is a better approach, using combinations of practices and technologies to reduce losses due to pests while minimizing reliance on synthetic pesticides. Achieving broad-based and inclusive IPM adoption for major crops in Bangladesh is essential for supporting the country's agriculture sector to

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become more resilient and productive. Urgent action is needed to address the threat of FAW, using IPM strategies that can be sustainably implemented by resource-constrained farmers.

The United States Agency for International Development (USAID) Feed the Future Integrated Pest Management Activity began in 2021. Its main goal is to strengthen the capacity of Bangladesh's agricultural sector stakeholders to control and prevent the spread of current and emerging threats in order to ensure more efficient, profitable and environmentally safe agricultural production and productivity. This will be achieved by implementing the following objectives:

***Objective 1*:** Increase the availability and affordability of IPM measures for the prevention and spread of current and emerging threats.

***Objective* 2:** Increase the capacity of Bangladesh agricultural stakeholders such as academia, local lawyers, financial institutions, government, media, civil society, the private sector and value chain actors to implement IPM measures.

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Detailed project progress

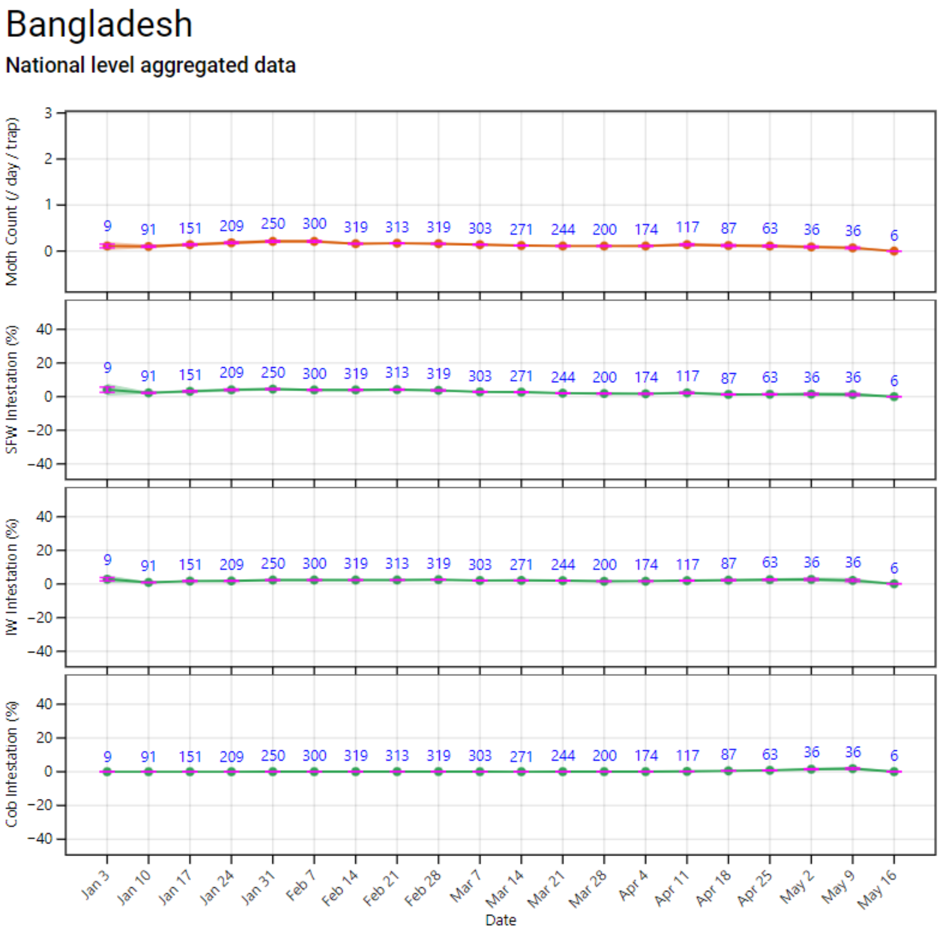
Objective 1: Increase the availability and affordability of IPM measures for the prevention and spread of current and emerging threats

Activity 1.B: Continue development of management actions for Fall Armyworm and integrate them in the IPM package for maize

Task 1B1: Fall Armyworm monitoring

In collaboration with DAE, manual observation of FAW populations in Bangladesh has been ongoing since the 2019–20 *rabi* maize season, using the Bangladesh "Fall Armyworm Monitor" mobile app (https://faw-monitor.firebaseapp.com/#/) developed originally by CSISA and the Fighting FAW activity. The FAW National Task Force decided that as in the previous two years, in 2021–22 monitoring of FAW populations would be continued by International Maize and Wheat Improvement Center (CIMMYT) and DAE. First, a virtual meeting was held between the relevant CIMMYT personnel to make the arrangements necessary to start the monitoring.

Field-level data collection was carried out through (1) weekly moth counts of the adult male FAW moths, attracted to and killed in sex pheromone traps, and (2) weekly scouting for signs of crop damage caused by FAW larvae feeding on the plant, infestation of whorls, and damage to maize cobs. Since 2019, CIMMYT and DAE have been working together to monitor and record this data, allocating them a FAW catch number, as well as scouting in the field by Activity-trained SAAOs. In response to CIMMYT's request to the DAE DG, data recording started for *rabi* maize crops 2021–22 in last week of December 2021, covering 104 sub-districts of 24 major maize districts. The national level average aggregated graph (below) shows there to be little difference in the weekly moth trapping and scouting data, which indicated (1) small fresh windowpane: sign of small larvae feeding (1–3 instar), (2) infested whorl: sign of matured larvae feeding (4–6 instar), and (3) infested plant: sign of cob damage. However, at the regional and local levels there was significant differences in infestation. In some of the major maize-growing areas (Cumilla, Bogura, Manikgonj and Dinajpur), FAW infestation, SFW and infested whorl were high, especially from the last week of January when the temperature started to increase (http://faw-monitor.firebaseapp.com). In those areas in the northern part of the country where maize cultivation is late (January onwards), infestation was especially high.



Above: national-level average FAW aggregated data, January–May, 2022

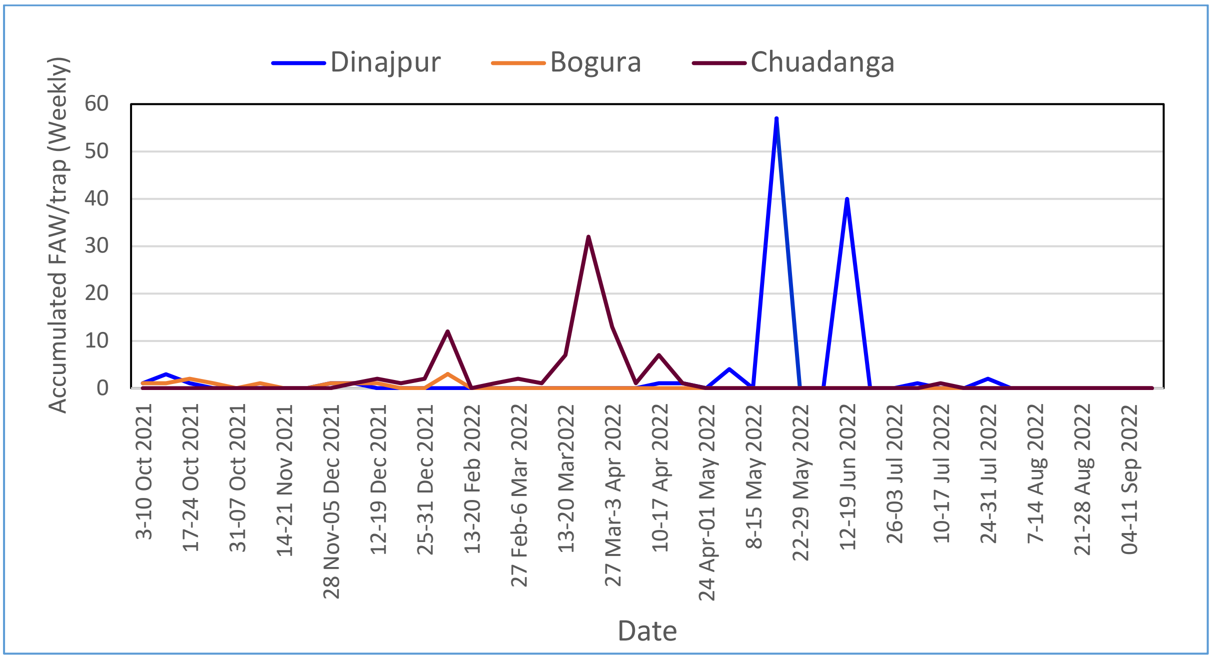
Task 1B2: Digital monitoring of FAW populations with the solar-powered, cost-effective, self-cleaning and auto-counting 'Trapview' system

One disadvantage of the methods used by DAE for the manual observation of FAW populations – namely, pheromone traps and field scouting – is that they are time-consuming and difficult, meaning that in the long-term, more time- and cost-effective methods will be needed. To this end, the Activity facilitated the setting of three solar-powered, self-cleaning and auto-count traps, part of the Trapview monitoring system manufactured by European Union private company EFOS, in three maize fields in Chuadanga, Bogura and Dinajpur, which were tested during the 2021–22 *rabi* and 2022 *kharif* seasons. Although the initial cost involvement was high, data collection using these traps is easy, and as a result they are growing in popularity with DAE field-level extension officers and NARS institution scientists involved in pest surveillance. From 23–30 March, 2022, the Activity arranged a hands-on training program for DAE field-level extension officials (specifically, the Additional Deputy Director of the Plant Protection Wing, *upazila* Agricultural Officers, Agricultural Extension Officers, Sub-Assistant Agricultural Officers), as well as entomologists from Bangladesh Agricultural Research Institute (BARI) and Bangladesh Wheat and Maize Research Institute (BWMRI) on the overall use, maintenance, data analysis and use of the data for FAW and other invasive pest forecasting.

Above: hands-on training program on the use, maintenance and data analysis capacity of Trapview for FAW monitoring (23–30 March 2022) in Dinajpur, Bangladesh

The graph below shows the weekly accumulated FAW population per trap from 3 October 2021–11 September 2022 at Dinajpur, Bogura and Chuadanga. The FAW population was high mainly during March 2022 at Chuadanga and May–June 2022 at Dinajpur. At Bogura the FAW population was not as high as the other two locations. In Chuadanga, maize cultivation started from mid-October (*rabi*) and continued till June (*kharif* 1); however, in Dinajpur the maize cultivation is late, with the main cultivation starting from December and continuing till July–August.

In Bogura, maize is mainly cultivated during winter (October–March). It was observed and reported (BWMRI Annual Report, 2021) that during winter cultivation the population of FAW is less; in fact, when the temperature falls below 10^{0}C the population becomes almost nil. Conversely, with the increase in temperature, FAW population also increased, observed in the year-round FAW population fluctuation data recorded through Trapview.



Above: weekly accumulated FAW/trap from 3 October 2021–11 September 2022 at Dinajpur, Bogura and Chuadanga, recorded by solar-powered, self-cleaning and auto-counting 'Trapview'

Task 1B3: Develop and validate FAW management technologies at farm level; integrate these with an IPM package for maize; conduct multi-locational studies on intercropping and agro-ecological management of FAW

As FAW is comparatively new to Bangladesh, until 2020 no research had been conducted in the country to identify its local natural enemy population or the efficacy of this population in managing the pest, its agro-ecological management, or integrated management strategies against it. However, during the winter cropping season (*rabi*) 2020–21 and *kharif* 2021, BARI and BWMRI, with financial and technical assistance from the USAID–CIMMYT "Fighting Back Against FAW" Activity, conducted noteworthy research into some of these issues. During the *rabi* 2021–22 and *kharif* 2022 seasons, some of the research findings, along with some new studies, have been produced with financial and technical assistance from the Feed the Future–IPMA Activity. As part of these efforts, CIMMYT, in collaboration with BWMRI, has been undertaking the agro-ecological management of FAW under a sub-grant proposal.

Agro-ecological management of Fall Armyworm

The study was implemented in two locations (Dinajpur and Rajshahi), providing a gradient of agro-ecological conditions: probable rainfall, temperature, humidity and soil type. Four replicates were maintained at each experimental location, arranged in blocks 2.5 m apart, with a distance of 1.5–2 m between experimental plots, depending on land area capacity. This agro-ecological approach to FAW management focuses mainly on intercropping with cowpea (*Vigna unguiculata*), as outlined below.

Basic module
The following module was implemented under an agreement between BWMRI and CIMMYT Bangladesh representatives: *Monoculture maize and intercrop with cowpea, Vigna unguiculata in conventional tillage*

Treatment
(a) Monoculture maize, with 60 cm row-to-row
(b) Monoculture maize, with 90 cm row-to-row
(c) Maize + cowpea intercrop, with 60 cm row-to-row
(d) Maize + cowpea intercrop, with 90 cm row-to-row

Randomized block design with four replicates

Variety
(a) Maize: Pioneer (hybrid)
(b) Cowpea: BARI Felon 1

Plot size
12 x 10 m (each plot)

Table 1: Planting dates and present status of the study in two locations

Sl No.	Location	Experiment set-up date	Present status
1	BWMRI, Dinajpur	14 December 2021	Crops harvested, mid-June 2022
2	Regional Office, BWMRI, Rajshahi	14 December 2021	Crops harvested, early June 2022

Pheromone trap

Two pheromone traps were placed in each location of two sites at the corner of experimental plots. Adult moths caught in the traps were counted on a weekly basis, from the planting to the tasseling stage of the maize crop. After counting the adults, the soap water was changed, maintaining the optimum level in the trap bucket. Pheromone lures were changed after six weeks to ensure they worked properly.

Pitfall trap

To assess the abundance and diversity of insect predators, a pitfall trap was used to catch and observe the insects/insect predators moved inside plot. 6.5 cm diameter with 4 cm depth plastic cup was used in this study. The cups were sunk into the soil keeping the lip flush with the soil surface and soap water poured in at the bottom of cup, keeping a depth of about 2 cm as a trapping medium. Three cups were placed diagonally in a plot between 10:00 a.m. and 11:00 a.m. and after 24 hours data were collected and lumped into a single sample for each plot.

FAW parasitism percentages and identity of parasitoids

FAW larvae were collected from the border row of an experimental plot and placed individually in small beakers. Observations were recorded on whether the larvae lived or died, and if died carefully checked the beaker for the release of parasitoid (if any). The percentage of larvae parasitized was calculated and the parasitoid collected for identification.

Leaf damage

Foliar damage was assessed on a scale of 1–9 using the CIMMYT pictorial guide. Data were collected from five spots in each plot (from the four corners and the middle of the core plot area) on a fortnightly basis from V3 to the tasseling stage.

Cob damage

Cob samples were collected diagonally from three spots of each experimental plot; 20 cobs were collected from each spot, and after harvest, cobs damaged by FAW were assessed according to the CIMMYT 1–9 scale.

Plant number

Plants were counted in the middle eight rows of each experimental plot and the mean number of plants per row calculated.

Plant height

Plant height was measured from each of the fifth plant in a line in core area and 40 plants measured from each plot. A wooden scale was used to measure from the plant base (soil level) to the bottom of the tassel, which was considered the plant height.

Number of cob in a plant

The number of cobs was counted from each of the fifth plant in a line in the core plant area, where 50 plants were considered for counting the cob number per experimental plot.

Cob length

Three spots were selected diagonally from each plot and all 20 cobs were collected from each spot. After dehusking the cob, its length was measured in centimeters, using a steel scale.

Maize yield

Three spots of each experimental plot were selected diagonally and three rows of plants within two meter in each spot were marked. The cobs were harvested from the marked plants, and after drying for two to three days, the grains were deshelled. The grains were dried in direct sun again, until 14%

moisture remained, and then weighed. Yield data were calculated for (1) 60 cm row-to-row spacing: 3 rows (= 180cm) x 2 m = 3.6 m^2 and (2) 90cm spacing as 3 rows (270 cm) x 2 m = 5.4 m^2 and finally converted into kilograms per hectare.

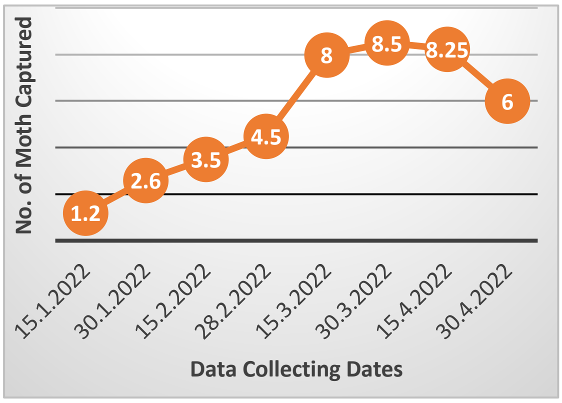
Cowpea yield

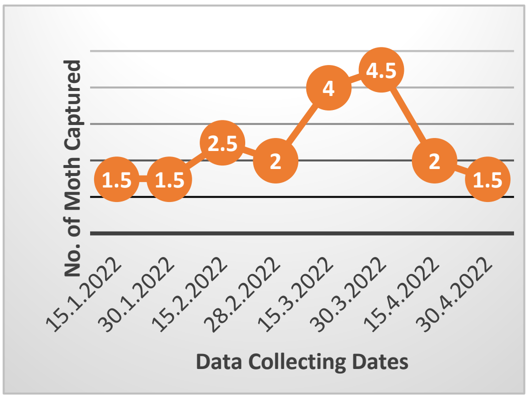
Cowpea pods were collected from whole plot three to four times when the pods matured. The pods were dried in direct sun and crushed to extract the peas. The pea grains were weighed and calculated into kilograms per hectare.

Results

Pheromone trap

Figures 1 and 2 show the FAW moths captured in pheromone traps at Dinajpur and Rajshahi sites on a fortnightly basis. The most moths were captured in March 2022 at both Dinajpur (8.5) and Rajshahi (4.5) sites.





Above: fortnightly FAW moths captured in pheromone traps at Dinajpur (left) and Rajshahi (right)

Pitfall trap

Table 2 presents the abundance and diversity of insect predators trapped in the pitfall traps in this study: spider, ground beetle, earwig, ant, ladybird beetle and grasshopper. A greater number of spiders, ants and ladybird beetles were found in the intercrop than in the monocrop.

Table 2. Number of predators trapped in pitfall trap in experimental plot in four treatments

Treatments	Mean number of predators					
	Spider	G. Beetle	Earwig	Ant	LBB	Grass-hopper
T_1 (MM 60)	1.7	1.6	0.5	3.0	1.2	2.2
T_2 (MM 90)	1.5	1.5	0.6	2.7	2.2	2.1
T_3 (MIC 60)	4.2	2.2	1.5	2.0	2.7	1.2
T_4 (MIC 90)	3.4	1.5	1.2	3.2	2.5	1.5

Foliage damage

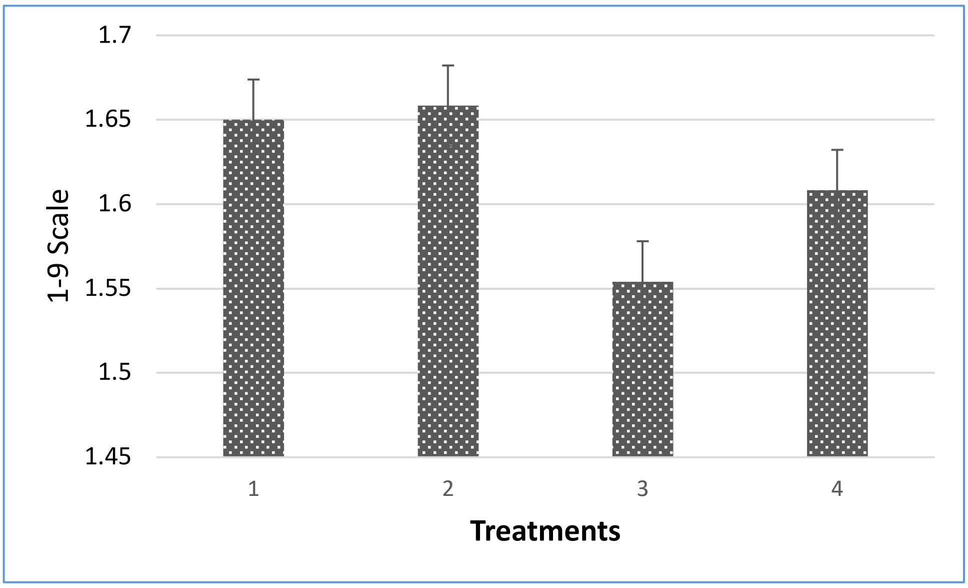
Foliage damage in different stages of crop growth differed among the treatments (Table 3). Although leaf damage is low in this season and usually in the winter season, comparatively higher leaf damage was observed in the mono-crop maize plots, in both the 60 cm and 90 cm row-to-row distance treatments.

Table 3. Foliar damage in different crop growth stages of maize under four treatments

Treatments	Foliar damage (on a 1–9 scale) at different crop stages					
	V2	V4	V6	V8	V12	Tasseling
T_1 (MM 60)	2.0	1.7	2.37	2.8	2.6	1.6
T_2 (MM 90)	2.2	1.6	2.58	2.8	3.2	2.5
T_3 (MIC 60)	1.2	1.3	2.38	1.1	1.0	1.1
T_4 (MIC 90)	1.2	1.2	1.78	1.8	1.1	1.1
$F_{3,9}$	26.35	2.73	5.56	96.7	227.9	33.65
P	**	ns	**	**	**	**

Cob damage

Cob infestation was very low in both the two locations. Cob damage among the treatments did not differ ($F_{3,25}$ = 0.06; P = 0.97) between the two sites; Figure 3 presents the mean cob damage in the two locations among the four treatments.



Above: cob damage among the four treatments

Yield and yield-contributing traits

The number of plants per unit area was similar among the treatments. Plant height was observed to be higher in 60 cm row spacing than in 90 cm row spacing. Cob length was higher in 90 cm row spacing than in 60 cm row spacing. Maize was observed to be higher in the intercropped plot with 60 cm row spacing, followed by maize mono crop (60 cm), maize intercropped (90 cm) and maize mono crop (60 cm row-to-row spacing). Cowpea grains yield in the intercropped plot were also not very high.

Table 4. Yield and yield-contributing traits of maize in the four treatments

Treatments	No. of plants/ 2m*3rows	Plant height (cm)	Cob length (cm)	Maize yield (kg/ha)	Cowpea yield (kg/ha)
T_1 (MM 60)	28.7	268.1	16.3	12930.0	-
T_2 (MM 90)	28.6	266.2	18.0	9911.3	-
T_3 (MIC 60)	29.0	275.1	15.9	13067.7	150.6
T_4 (MIC 90)	29.6	258.3	17.6	10494.2	230.5
$F_{3,25}$	1.07	7.40	7.83	12.93	-
P	ns	**	**	**	-

Benefit cost analysis

Table 5. Benefit cost analysis of monoculture maize and intercrop with cowpea in 60 cm and 90 cm row-to-row spacing

Treatments	Maize yield (gg/ha)	Cowpea yield (kg/ha)	Gross return (BDT/ha)	Variable cost (cowpea seed)	Net return (BDT/ha)
T_1 (MM 60)	12930.0	-	387899	-	387899/-
T_2 (MM 90)	9911.3	-	297338	-	297338/-
T_3 (MIC 60)	13067.7	150.6	405585	2250	403335/-
T_4 (MIC 90)	10494.2	230.5	335571	1485	334086/-

~Maize@30 BDT/Kg; cowpea@ 90 BDT/Kg; seed rate of cowpea 25kg/ha for 60cm and 16.5kg/ha for 90cm row-to-row spacing.

Benefit cost analysis suggests that 60 cm row-to-row spacing with cowpea intercrop provided the highest return.

Summary

This study concludes that intercropping maize with cowpea reduced FAW infestation of maize. Furthermore, more return from the intercrop is an extra benefit for the farmers. Very interestingly, a greater number of predators and parasitoids were observed in the cowpea intercropped plots than in mono culture maize plots. A greater number of hymenopteran insects was observed by means of a yellow sticky trap in cowpea intercropped plots, with very few found in mono culture maize plots, that is, many natural beneficial insects are conserved in an intercropped plot. From an agronomy point of view, it also observed that a greater moisture content was retained in intercropped plot soil than in mono culture maize plot soil. During field days, farmers expressed interest in intercropping maize with other legumes or vegetable crops.

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Field days

Two Farmers Field Days were conducted: in Rajshahi and at the Dinajpur site. Fifty farmers (half female, half male) participated in each of locations. They observed the management of Fall Armyworm through intercropping maize with cowpea. Farmers were acquainted with agro-ecological management of FAW in maize crops. They expressed surprised that FAW in maize crops could be managed without the use of any insecticides.

Above: Farmers Field Day, Rajshahi

Above: Farmers Field Day, Nashipur, Dinajpur district

Task 1B4: Survey the natural enemies of FAW in maize fields and study the efficacy of already-recorded parasitoids (*Telenomus remus*, *Trichogramma pretiosum* and *Habrobracon hebetor*) in the laboratory, screen houses and maize fields at BARI

As FAW is comparatively new to Bangladesh, until 2020 no research work had been conducted in the country to identify its local natural enemy population or the efficacy of this population in managing the pest. However, during the winter cropping season (*rabi*) 2020–21 and *kharif* 2021, BARI conducted noteworthy research into some of these issues, with financial and technical assistance from the USAID–CIMMYT "Fighting Back Against FAW" Activity. Further research was undertaken during the *rabi* 2021–22 and *kharif* 2022 seasons, with financial and technical assistance from the Feed the Future–IPM Activity. In collaboration with CIMMYT, BARI has conducted several studies on FAW's natural enemies in farmer's and its own research station's maize fields by collecting, identifying and recording the egg, larval and larval–pupal parasitoids and predators of FAW. Studies of the efficacy of the parasitoids *Telenomus remus*, *Trichogramma pretiosum* have also been conducted in BARI's laboratory, screen house and maize fields, along with the mass rearing protocol development of these two parasitoids. Details of some of these studies along with the results are provided below.

Survey of the abundance of natural enemies of Fall Armyworm (*Spodoptera frugiperda*) attacking maize crops in Bangladesh

Field surveys were conducted in Saturia *upazila*, Manikganj district, Burirhat, Rangpur, and the research field at BARI, Gazipur, between December 2021 and June 2022, to identify and assess the abundance of FAW's natural enemies attacking the maize crop. FAW was collected fortnightly at various points in its life stage (egg mass, larvae and pupae) from 10 randomly selected farmers' maize fields in Manikganj and three fields each in Rangpur and in Gazipur. In each field, the FAW samples were collected from a randomly selected 25 m^2 area at two spots during the afternoon. Egg masses found on plant parts were detached carefully, placed inside test tubes, and brought to the laboratory where they were held separately in rearing containers until the emergence of parasitoids or FAW larvae. Feeding injury in the leaf whorl and the presence of fresh frass were used to locate FAW larvae, which were collected from the whorl or unopened maize leaves and placed individually into sterilized plastic containers for further development. The larvae were provisioned daily with fresh maize leaves collected from BARI's research field. FAW pupae were collected from the soil surface adjacent to FAW-infested maize plants (without larvae) and isolated in rearing containers for the completion of development or emergence of parasitoids. The parasitoids that emerged from the eggs or larvae were recorded every 24 hours until pupation, and preserved individually in 70% alcohol.

Two species of egg parasitoid (identified as *Telelomus remus* and *Trichogramma pretiosum*), two species of larval parasitoid (*Cotesia* sp. and *Campolities* sp.), and one species of pupal parasitoid (*Brachymeria euploeae*) were found parasitizing the FAW egg mass, larvae and pupae in the farmers' fields in Manikganj. They were identified using available taxonomic keys, and their identity confirmed by molecular analysis. In Manikganj the egg mass parasitism rate by the two egg parasitoids (*T. remus* and *T. pretiosum*) was 20% and 1.74%, respectively, and 7.96% by *Trichogramma pretiosum* along with *Telenomus remus*. Larval parasitism by *Cotesia sp*. and *Campolities sp.* was 0.28% and 0.14%, respectively; pupal parasitism by *Brachymeria* sp. was 5.88% (Table 2). At Gazipur, egg parasitism by *T. remus* was 31.25%; larval parasitism was not found. Similarly, at Rangpur, egg parasitism by *T. remus* was 16.67%, and there was no larval parasitism.

Table 2: Location-wise parasitism of FAW egg mass/larvae by different parasitoids

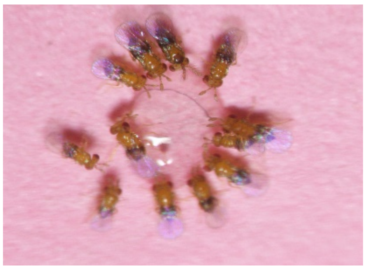
	No. of samples collected			Percentage of parasitism					
	egg mass	larvae	pupae	egg mass			larvae		pupae
				T. remus	*T. pretiosum*	*T. remus* + *T. pretiosum*	*Cotesia* sp.	*Campolities* sp.	*Brachymeria euploeae*
Manikganj	515	5705	Location	20.00	1.74	7.96	0.28	0.14	5.88
Gazipur	16	179	-	31.25	-	-	-	-	-
Rangpur	18	272	-	16.67	-	-	-	-	-

Rove beetle was found to predate FAW larvae in three different locations. Table 3 presents, location-wise, the mean rove beetle population per plant and the percentage of plants with a rove beetle presence. It shows that in Manikganj the beetle population per plant was 2.07, and 76.66% of plants had a rove beetle presence; in Rangpur, there were 1.83 rove beetles per plant, with 63.33% of plants having a rove beetle presence. No rove beetle was observed in Gazipur.

Table 3: Incidence of predatory rove beetle in maize fields in three different locations

Location	Mean rove beetle population per plant	Percentage of plants with rove beetle presence
Manikganj	2.07	76.66
Gazipur	-	-
Rangpur	1.83	63.33

Above: *T. remus* recovered from FAW eggs



Above: *T. pretiosum* recovered from FAW eggs

Above: *Brachymeria euploeae* recovered from FAW pupae

Above: *Cotesia* sp. recovered from FAW larvae

Above: *Campoletis sp.* recovered from FAW larvae

Above: rove beetle found to predate FAW larvae

Parasitism efficiency of *Telenomus remus* and *Trichogramma pretiosum* on Fall Armyworm eggs (*Spodoptera frugiperda*), in a no-choice test, under laboratory conditions

This study was conducted on the parasitization efficiency of *T. remus* and *T. pretiosum* on *S. frugiperda* (FAW) eggs in the IPM laboratory of the Entomology Division, BARI, Gazipur, in March 2022. The no-choice test used test tubes as the study area, with fresh eggs from the FAW host, collected from a mass culture at the IPM laboratory. The eggs used were up to 24 hours old (that is, up to 24 hours after female oviposition) and the egg masses glued to white paper (10 cm x 1.5 cm) with gum acacia diluted in distilled water. Female wasps used in the experiments were up to 24 hours old and were allowed to parasitize the FAW eggs for 48 hours. There were six replicates. Following the 48-hour exposure, the parasitism, emergence rates and duration of the egg-to-adult period of *T. remus* and *T. pretiosum* were investigated, as well as sex ratio and adult longevity. For the latter, a 10% honey solution was provided to the adults in droplets every alternate day until death.

Results of the no-choice test showed the parasitism efficiency of tested *T. remus* wasps to be 93.50%; the adult emergence rate from the parasitized eggs was 87.14% (88.61% female), and the egg-to-adult period of *T. remus* in FAW eggs was 14.65 days, with the adult female surviving up to 9.00 days (Table 4). With *T. pretiosum*, the parasitism efficiency of the *T. pretiosum* wasps was 83.67%; the adult emergence rate from the parasitized eggs was 81.66% (87.81% female), and the egg-to-adult period of *T. pretiosum* in FAW eggs was 10.0 days, with the adult female surviving up to 8.67 days (Table 4).

Table 4: Percentage of egg parasitization, adult emergence and female percentage of Fall Armyworm (*Spodoptera frugiperda*) host eggs parasitized by *Telenomus remus* and *Trichogramma pretiosum*, in a no-choice test, under laboratory conditions

Parasitoid spp.	Egg parasitization (%) ± SE	Adult emergence (%) ± SE	Egg-to-adult period (days) ± SE	Female adult longevity (days) ± SE	Female emergence (%) ± SE
T. remus	93.50 ± 0.61	87.14 ± 2.55	14.65 ± 0.33	9.00 ± 0.46	88.61 ± 1.33
T. pretiosum	83.67 ± 1.94	81.66 ± 2.73	10.0 ± 0.55	8.67 ± 0.33	87.81 ± 1.83

Above: *T. pretiosum* parasitizing FAW eggs

Above: FAW egg mass parasitized by *T. pretiosum*

Above: *T. remus* parasitizing FAW eggs

Above: FAW egg mass parasitized by *T. remus*

Efficacy of *Habrobracon hebetor* Say on *Spodoptera frugiperda* (J.E. Smith), evaluated with *Galleria mellonella* and *Corcyra Cephalonica* (Stainton) as alternate hosts

This study was conducted to document *Habrobracon hebetor* Say (*H. hebetor*) parasitization effects on *Spodoptera frugiperda* (*S. frugiperda*) (fifth instar onwards) in comparison with its effects on *Galleria mellonella* and *C. cephalonica*. This was achieved by providing all three as alternate hosts under laboratory conditions (25°C ± 2°C and 65% ± 5% RH) at the Entomology Division, BARI, Gazipur, in March 2022.

The results showed that when all the host larvae were offered to *H. hebetor*, it parasitized them all. *H. hebetor* laid eggs on *S. frugiperda* larvae but no Bracon larvae or pupae were produced. This efficacy study of *H. hebetor* was conducted with three replications. Ten larvae of each of the three host species were exposed to 20 *H. hebetor* adults, and parasitization allowed for 24 hours. Individual host larvae were then transferred to Petri dishes containing filter paper to observe the number of *H. hebetor* larvae, pupae and adults developing per host larva. The number of *H. hebetor* larvae formed on each host larva was quantified under the microscope, one day after transfer to Petri dishes; *H. hebetor* pupae were counted daily and the total calculated. *H. hebetor* adults emerging from each host larva 8–10 days after parasitization were counted daily and the total number of adults which emerged calculated.

The highest number of larvae, pupae and adults produced (7.33, 6.33 and 6.00 respectively) were formed on *G. mellonella*, followed by 4.00, 3.33 and 3.00 respectively on *C. Cephalonica*. Adult *H. hebetor* females first sting the FAW larvae and then inject them with venom, inserting the ovipositor, which paralyzes the larvae and leads to death. After 24 hours of exposure, all the *S. frugiperda* host larvae were transferred to Petri dishes, and 100% recorded as killed/paratisized by *H. hebtor*: black, dead and dried up within 24 hours of being injected with *Bracon* venom. However, no *H. hebetor* emerged from the dead FAW larvae, which dried up so quickly and entirely they left insufficient food for the *H. hebetor* larvae to thrive on. It can be concluded that *H. hebetor* can kill FAW larvae efficiently but that no new *H. hebetor* will emerge from the larvae. Effective control of FAW therefore needs innundative release of *B. hebetor*.

Table 5: Parasitization of *Habrobracon hebetor* on multiple hosts (*Spodoptera frugiperda, Galleria mellonella* and *Corcyra cephalonica*), under laboratory conditions

Host insect	Parasitization/killed (%)	No. of *H. hebetor* larvae formed/host larva (mean ± SE)	No. of *H. hebetor* pupae formed/host larva (mean ± SE)	No. of *H. hebetor* adults emerged/host larva (mean ± SE)
C. cephalonica	100	4.00 ±0.58	3.33 ± 0.67	3.00 ± 0.58
S. frugiperda	100	0.0	0.0	0.0
G. mellonella	100	7.33 ± 0.67	6.33 ± 0.67	6.00 ± 0.58

Task 1B5: Conduct mass rearing of egg and larval parasitoids of FAW (*Telenomus remus* and *Trichogramma pretiosum*) at BARI.

Host and oviposition preference of *Trichogramma pretiosum* and *Telenomus remus* for the eggs of four different Lepidopteran insect pests, under laboratory conditions

Laboratory studies were conducted on the host preference of egg parasitoids *T. pretiosum* and *T. remus* on the eggs of one natural Lepidopteran host (*Spodoptera frugiperda*) (FAW) and three factitious hosts (*Sitotroga cerealella*, *Corcyra cephalonica* and *Plodia interpunctata*). The parasitization behaviour of the female wasps was examined in a choice test. Developmental parameters including percentage of parasitism, adult emergence and female progeny were compared when reared on the four different hosts, under ambient conditions of 27°C ± 1°C and 65% ± 10% RH, and with a natural photoperiod.

Collection of laboratory host eggs

The eggs of Lepidopteran pests are the general media for the parasitization of *Trichogramma* spp.; this study used the eggs of *Sitotroga cerealella* (Oliver) (or *S. cerealella*), *Corcyra cephalonica* (Stainton) (or *C.*

cephalonica) and *Plodia interpunctella*. Fresh egg masses of these three hosts were collected from the IPM laboratory of the Entomology Division, BARI, and reared on wheat grain as a diet in a special mass-rearing chamber.

With *C. cephalonica* and *Plodia interpunctella*, 100 adults were placed in a two-liter plastic container (maintaining a 1:1 sex ratio) and the top covered with 32-mesh net to provide aeration and prevent the moths escaping. Wire netting was also placed inside the plastic container for the insects to rest on and lay their eggs. The adult moths were kept in the container for one day to mate and for subsequent egg-laying; the next day, the adults and their body parts were removed from the container. The fresh eggs were then collected on a fresh piece of paper by shaking.

To collect the *S. cerealella* eggs, thousands of adults were caught from the *S. cerealella* mass-rearing chamber and kept in a two-liter glass cylinder, again covered with 32-mesh net. Adults were kept in the cylinder for one day to mate and for subsequent egg-laying. The next day, any eggs laid on the wall of the cylinder were brushed and sieved to collect them, along with the moth body parts. The body parts were then cleaned by holding the sieve near an exhaust fan to obtain any additional eggs. The collected host eggs were placed in test tubes (3 cm x 15 cm) and labeled.

Collection of *Trichogramma pretiosum* and *Telenomus remus* to be used as egg parasitoids
This study used one species of *Trichogramma* (*Trichogramma pretiosum*, or *T. pretiosum*) and one species of *Telenomus* (*Telenomus remus*, or *T. remus*). They were initially obtained as pupae on an egg card from the IPM laboratory of the Entomology Division, BARI, Gazipur.

Preparation of egg strips
Paper strips with three different factitious host eggs and one natural host (FAW) were made up, using (1) paper strips (10 cm x 1 cm), labeled, (2) acacia powder (*Acacia arabica*), (3) distilled water, (4) a small Petri dish, and (5) a dropper. First, 10% gum acacia was prepared in a small Petri dish by mixing acacia powder with distilled water. This was achieved using a dropper to maintain the gum's proper viscosity and thus ensuring it would hold the host eggs firmly on the paper strip. Five hundred eggs from each host were then counted out separately, with 100 for each of five hosts placed separately on a sheet of paper (10 cm x 10 cm). In this way, a total of 500 eggs were used. To make the host egg strip, a small amount of gum acacia was applied by finger to the front of the labeled paper strip. The 100 eggs from each host counted out earlier were spread carefully on the glued part of the paper strip, ensuring just one layer of eggs. Each strip was then labeled with the date, host name, parasitoid name and number of eggs per strip.

Parasitoid (*Trichogramma* and *Telenomus*) stock cultures
Emerged *T. pretiosum* were maintained in *C. cephalonica* eggs and *T. remus* were maintained in *S. frugiperda* (FAW) eggs. These parasitoids had been reared in the IPM laboratory of the Entomology Division, BARI.

C. cephalonica eggs were glued with gum acacia (made from acacia power diluted in water at 30%) on to white cardboard (10 cm x 1 cm) and then inserted into a glass tube (15 cm x 2.5 cm). They were exposed to *T. pretiosum*, and the tubes sealed with cotton wool and placed in a wooden holder until the adults emerged. Parasitoid cultures were maintained at 26°C ± 2°C, 70% ± 5% relative humidity, and with a natural photoperiod.

The parasitism efficiency of *T. pretiosum* was evaluated through a choice test on *S. cerealella*, *C. cephalonica*, *Plodia interpunctella* and FAW eggs. One strip containing 100 eggs per host and 20 pairs of *T. pretiosum* were placed together in a test tube (15 cm x 3 cm). Pupae on the point of emergence were taken from the colony stock of *T. pretiosum* reared in the IPM laboratory, in the form of a strip containing 100 pupae/strip in *C. cephalonica* eggs. In this way, 20 strips of eggs (five each of the eggs of *S. cerealella, C. cephalonica*, *Plodia interpunctella* and FAW) were parasitized by *T. pretiosum*. The 20 test tubes, each containing a strip of host eggs and one pair of *T. pretiosum* adults, were labeled with the date, number of eggs, host name and parasitoid name, and placed in the paratization chamber. Similar procedures were then followed for parasitization by *T. remus* of eggs from each of the four hosts.

Each test tube was considered as one replication. The experiment followed a completely randomized design and was replicated five times. The least significant difference was used for mean separation after analysis of variance.

Parasitism efficiency of *Trichogramma pretiosum* on host eggs

A comparative study was undertaken on the rearing of the parasitoid *T. pretiosum* on the eggs of three Lepidopteran factitious hosts (*S. cerealella, C. cephalonica, Plodia interpunctella*) and FAW (*S. frugiperda,* a natural host), according to different biological parameters: parasitism (%), adult emergence (%) and female emergence (%) (Table 6). Table 6 indicates a significant difference in percentage egg parasitization of the four host eggs of *C. cephalonica*, *S. cerealella, Plodia interpunctella* and FAW, which was 81.8%, 31.0%, 33.2% and 85.2%, respectively. The percentage of adult emergence rates were 83.42, 56.5, 50.33 and 79.90, respectively, with female-biased progeny (Table 6). Adult parasitoid emergence from parasitized eggs differed significantly, with the highest number of adults (83.42%) emerging from the *T. pretiosum* parasitization of *C. cephalonica* host eggs, statistically similar to the *T. pretiosum* parasitization of FAW eggs (79.9%).

Table 6. Parasitism efficiency of *Trichogramma pretiosum* on the host eggs of *Sitotroga cerealella, Corcyra cephalonica*, *Plodia interpunctella* and Fall Armyworm (*Spodoptera frugiperda*), under laboratory conditions

Host	Egg parasitization (mean ± SE) %	Adult emergence (mean ± SE) %	Female emergence (%)
C. cephalonica	81.8a	83.42a	80.28
S. cerealella	31.0b	56.5b	75.59
Plodia interpunctella	33.2b	50.33b	74.64
FAW (*Spodoptera frugiperda*)	85.2a.	79.90a	79.97
CV (%)	10.00	7.45	NS

Parasitism efficiency of *Telenomus remus* on hosts' eggs

T. remus did not parasitize the *C. cephalonica*, *S. cerealella* and *Plodia interpunctella* eggs. It did however parasitize the FAW eggs (86.00%); adult emergence rate was 86.92% with 83.05% female progeny (Table 7).

Table 7. Parasitism efficiency of *Telenomus remus* on *Sitotroga cerealella, Corcyra cephalonica*, *Plodia interpunctella* and Fall Armyworm (*Spodoptera frugiperda*) host eggs, under laboratory conditions

Host	Egg parasitization (mean ± SE) %	Adult emergence (mean ± SE) %	Female emergence (%)
C. cephalonica	Eggs were not parasitized by *T. remus*		
S. cerealella			
Plodia interpunctella			
FAW	86.00	86.92	83.05

The Association of Natural Biocontrol Producers and the International Organization of Biological Control Subcommittee on Quality Control has developed quality control standards for *Trichogramma* and other natural enemies (Bigler, 1991). These include those for established culture on *Sitotroga*, which are 80% ± 5% egg parasitization, 90% ± 5% adult emergence, and a sex ratio of 1.2:1.5 females per male (Greenberg *et al.,* 1996). In this study, the *C. cephalonica* host followed this standard for an established culture of *T. pretiosum*. Based on the results of this experiment, the most appropriate host species for the laboratory rearing of *T. pretiosum* is *C. cephalonica,* and it can be mass reared most economically. It can be concluded that the rearing techniques used for *T. pretiosum* and the host (*C. cephalonica*) are acceptably productive and adequate for ensuring the required amount of parasitoids. To obtain the highest parasitoid production, it is important to use younger host eggs and *Trichogramma* for parasitization at a standard level.

Mass rearing of *Trichogramma pretiosum* on *Corcyra cephalonica* eggs in a no-choice test, under laboratory conditions

The mass rearing of *T. pretiosum* on *C. cephalonica* eggs was conducted in the IPM laboratory of the Entomology Division, BARI, Gazipur, in March, 2022. A no-choice test used test tubes as study areas with fresh *C. cephalonica* (Stainton) eggs, up to 24 hours old (that is, up to 24 hours after female oviposition), which were collected from a mass culture of *C. cephalonica* at the IPM laboratory. *C. cephalonica* eggs were glued to a white paper strip (10 cm x 1.5 cm) using gum acacia (made by mixing acacia powder with distilled water), with one strip holding 100 eggs of *C. cephalonica* and 10 pairs of *T. pretiosum* placed together in an individual test tube (15 cm x 3 cm). Female *T. pretiosum* wasps up to 24 hours old were used and allowed to parasitize *C. cephalonica* eggs for 48 hours. Parasitoid cultures were maintained at 26°C ± 2°C, 70 ± 5% relative humidity, and with a natural photoperiod. The study was designed as completely randomized with 15 replicates. Results showed that *T. pretiosum* parasitized 83% of *C. cephalonica* eggs, with 77.23% adult emergence (81.97% female). From this finding it can be concluded that *C. cephalonica* is a suitable host for mass rearing *T. pretiosum.*

Table 8. Percentage of egg parasitization, adult emergence and female emergence from *Corcyra cephalonica* host eggs parasitized by *Trichogramma pretiosum* in a no-choice test, under laboratory conditions

Parasitoid	Egg parasitization (%) (mean ± SE)	Adult emergence (%) (mean ± SE)	Egg-adult period (days) (mean ± SE)	Female adult longevity (days) (mean ± SE)	Female emergence (%) (mean ± SE)
T. pretiosum	83.00 ± 1.26	77.23 ± 1.42	9.90 ± 0.11	9.2 ± 0.22	81.97 ± 1.03

Evaluation of the potentiality of using *Spodoptera litura* eggs for mass-rearing *Telenomus remus*, a promising egg parasitoid of FAW (*Spodoptera frugiperda*)

This study was conducted to observe the parasitization efficiency of *T. remus* on eggs of the common cutworm *Spodoptera litura* (*S. litura*), in the IPM laboratory of the Entomology Division, BARI, Gazipur, May–June 2022. A no-choice test used test tubes as study areas and fresh eggs of the *S. litura* host. The eggs were collected from a stock culture of common cutworm at the IPM laboratory and were up to 24 hours old (that is, up to 24 hours after female oviposition). The egg mass was either glued to white paper (10 x 1.5 cm) with gum acacia (made by mixing acacia powder with distilled water) or stapled to card. Female wasps used in the experiments were up to 24 hours old, and allowed to parasitize the common cutworm eggs for 48 hours, with four replications. Following the 48-hour exposure, parasitism and emergence rates and the duration of the egg-to-adult period of *T. remus* were investigated.

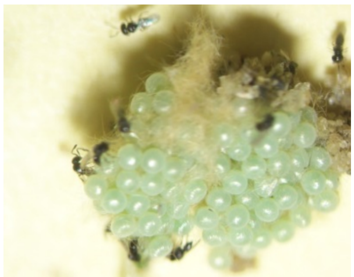
Results showed that *T. remus* developed successfully on *S. litura* eggs, with the rates of parasitization and adult emergence greater in second generation eggs: the percentage of parasitized eggs was 34.14 in Generation 1 and 53.36 in Generation 2; the emergence rate was 51.84 in Generation 1 and 63.55 in Generation 2. Thirteen to fourteen days were required for the emergence of the *T. remus* adult from the eggs; female-biased progeny were found in both generations. The results indicate that *S. litura* eggs are suitable as an alternative host for mass-rearing *T. remus*, although further studies are needed using fresh eggs and younger parasitoids.

Table 9. Generation-wise parasitism, adult emergence and female emergence of *Telenomus remus* on *Spodoptera litura* eggs, under laboratory conditions

Generation	Parasitization (%) (mean ± SE)	Adult emergence (%) (mean ± SE)	Female emergence (%) (mean ± SE)
G-1	34.14 ± 11.43	51.84 ± 6.64	74.97 ± 2.44
G-2	53.36 ± 11.34	63.55 ± 9.30	70.59 ± 1.46

Above: *S. litura* egg mass to be used for rearing *T. remus*

Above: rearing *T. remus* on *S. litura* egg mass

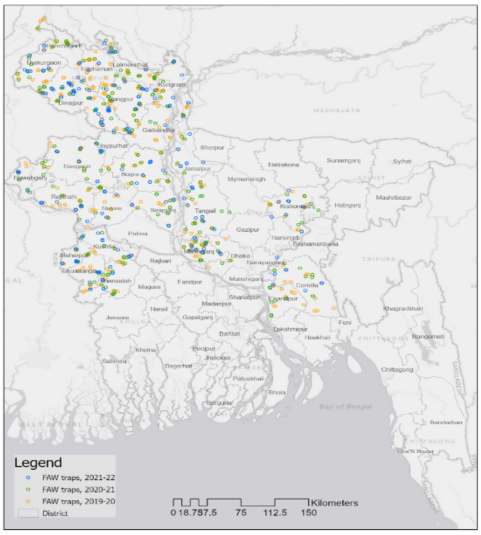


Above: *T. remus* parasitizing *S. litura* egg mass

Task 1B5: Survey and record current farmers' practice of management of FAW to identify misuse of pesticides as well as need for registration of safe pesticides.

FAW severity, incidence and management surveys to inform mitigation efforts

In 2019-20 Rabi season, 545 farmers out of 777 farmers with FAW pheromone traps located in their fields participated in the severity, incidence and management survey. Survey covered aspects such as awareness of farmers on FAW (ability to identify the worm) and management techniques (pesticides, handpicking etc.) used by farmers and how they reacted to the presence of FAW on their fields (what crop stage and what kinds of pesticides are sprayed, time of insecticide spray, rounds) in addition to their general agronomic practices (Maize varieties, tillage, fertilizer, herbicide application intercrops, planting dates etc.) that may affect FAW severity, Additionally, a matching sample of 498 non-monitored farmers for further assessment, which provides an aggregate sample of 1,043 maize farmers. In the control sample also, socio-economic information, data on agronomic practices and farmers' decision making in relation to Fall Armyworm infestation were collected.



Above: FAW pheromone trap locations in 2019-20, 2020-21 & 21-22 Rabi (Winter season)

For 2020-21 Rabi season, 678 farmers had pheromone traps located in their fields and the severity, incidence and management survey was conducted 1177 farmers including 600 non-monitored control farmers during August-September 2021. Because of COVID-19 restrictions, field level data collection through face-face interviews was avoided and data was collected through telephonic surveys similar to first round of survey. For the collection of phone numbers and contact information of farmers (monitored and control), an additional survey module among SAAOs in charge of the FAW pheromone traps wase deployed. The following figure X1 shows the location of FAW traps in 2019-20 and 2020-21 Rabi season.

For 2021-22 Rabi season, 397 farmers had pheromone traps located in their fields, The third round of survey collected data from 297 farmers of the farmers with traps located in the fields in September 2022. Similar to other two rounds, data was collected by telephonic surveys. The data generated in 2019-20, 2020-21 and 2021-22 is used to assess the damage levels caused by fall armyworm using structural equation models. The completed model results shows moth counts in pheromone traps significantly predicted the combined damage score reported in the field showing the efficacy of the monitoring program. In case of 1st and 2nd round of survey, around 50% of farmers expressed that they are only partially confident on controlling FAW in their field while it dropped to 35% in third round of survey. The spaying behavior i.e. scouting and proper spraying of pesticide offset the yield damage by 0.3 tons per ha, which is more important than the number of pesticide sprays. Around 35-40% of the surveyed farmers are now using effective pesticides again fall armyworm, which shows the effectiveness of the extension efforts, but continued support is required.

Objective 2: Increase the capacity of Bangladesh agricultural stakeholders including academia, local lawyers, financial institutions, government, media, civil society, the private sector and value chain actors, to implement IPM measures

Activity 2B: Involve stakeholders in the management of FAW and implementation of IPM for selected crops

Task 2B1: Identify and provide training for NARS scientists and DAE officials as master trainers in FAW management

FAW invaded Bangladesh for the first time in November 2018. In response, and particularly in light of its destructiveness experienced by other countries, the Government of Bangladesh along with a number of national and international institutions initiated massive awareness, monitoring and management activities to combat this new, invasive pest. As part of this drive, CIMMYT, in collaboration with DAE and other NARS institutes, has arranged several training programs for field-level officials, to develop master trainers with the capacity to tackle FAW during both rabi and kharif season of 2021–22. During the *rabi* season 2021–22, CIMMYT organized three Training of Trainers programs for DAE cadre officers and SAAOs. One was for district and *upazila*-level cadre officers from 25 maize-growing districts, and HQ, Khamarbari, Dhaka (18–19 December 2021). The other two were for SAAOs from 25 selected major maize districts, and scientists from BWMRI and BARI, held at BRAC Learning Center, Noshipur, Dinajpur (20–23 December 2021), where 90 trainers were trained. During *kharif* 2022, CIMMYT organized three more trainers training programs for DAE cadre officers, NARS scientists and SAAOs. One program was also for district- and *upazila*-level cadre officers from 10 *kharif* maize-growing districts and scientists from BARI and BWMRI (29–30 March 2022). The other two programs were for SAAOs from the same 10 selected major *kharif* maize districts, held at BRAC Learning Center, Nashipur, Dinajpur (23–24 and 27–28 March 2022). The total number of participants for both the *rabi* and *kharif* 2021–22 training was 180. The main objective was to involve stakeholders in the management of FAW and the implementation of IPM for selected crops, through the USAID-funded consortium Virginia Tech–CIMMYT–Michigan State University for IPMA. These six training programs have successfully developed ideal master trainers, each with the individual capacity to teach extension personnel and farmers about the introduction, identification, monitoring, scouting and integrated management of this devastating pest.

The format of the two-day residential training program was unique. The first day began with a half-day briefing on the introduction and identification of FAW and the primary monitoring and scouting system, followed by a visit to a nearby pre-selected maize field considerably infested with FAW to obtain practical experience of the theory learned in the morning. On the second day participants learned details of monitoring and scouting, and integrated management of the pest, through practical PowerPoint presentations and videos, and discussed lessons learned. They then returned to the BWMRI maize fields to visit several ongoing management-related studies, which again provided them with the opportunity to verify their thoughts about the scouting and management of FAW.

Another important part of the training was a practical session on the use of smartphone applications to monitor FAW, which the Activity has developed for the National FAW Task Force and DAE. Trainees learned how to enter data, monitor SAAOs (this was for DAE cadre officers), and use the app for data entry (for SAAOs, who will be directly involved in the data entry system). Hands-on training was also provided to participants on the solar-operated, self-cleaning and auto-count Trapview monitoring system, including its overall use and maintenance, and how to analyze and use the data it obtains for FAW and other invasive pest forecasting. Importantly, the training developed participants' confidence in fighting FAW.

The program trained a total of 89 Government of Bangladesh officials (18% of whom were women), 26 DAE cadre officers and four scientists from BARI and BWMRI, as well as 55 SAAOs and four BWMRI Scientific Assistants, in three batches. It assessed trainee with pre- and post-training questionnaires. Later on, through a telephone survey the participants were asked the same post-test questions to assess what they have retained. However, immediate significant improvement in knowledge (from around 45% to 96%) of aspects of FAW identification, monitoring, scouting and integrated management was observed in all participants. The greatest improvements were seen in by the front-level extension officials (the SAAOs).

Above: FAW *kharif* ToT was inaugurated by the Director General of BWMRI. The Program Director of CIMMYT was present as Special Guest

Above: the Director of the Plant Protection Wing, DAE was present as Chief Guest during the ToT of the Cadre Officers

Above: the training program in the classroom, facilitated via PowerPoint presentation, videos etc.

Above: hands-on training in the maize fields, covering FAW monitoring, scouting and management

Above: hands-on training in the field, scouting for FAW infestation

Above: trap registration as part of FAW monitoring

Task 2B2: Development of Bangla language FAW IPM educational materials

In light of its destructiveness in other countries, when FAW invaded Bangladesh in November 2018 a factsheet on its identification and management was rapidly developed by the government-led National Task Force, which had been developed by CIMMYT in January 2020. However, since then, numerous studies have been conducted by National Agricultural Research System (NARS) institutes with the technical support of CIMMYT and financial support of the USAID Fighting Back Against Fall Armyworm Activity and FAO, and the National Task Force decided that the factsheet needed updating. The updated version, developed by CIMMYT, incorporates information on monitoring and scouting (using CIMMYT/DAE apps), major infestation period, lifecycle (under Bangladesh conditions), management options (especially by incorporating recently registered products), agro-ecological management and IPM packages. The two-pager was validated by the relevant BARI, BRRI and BWMRI scientists, and then circulated to all Task Force members and academicians for comments and suggestions. After approval by the Task Force, 55,000 copies of the final version were printed. Its distribution to the related extension, research and academic institutes is on-going.

Task 2B2: Develop Bangla language educational videos on FAW management and FAW IPM educational materials

In light of the destructiveness of FAW experienced by other countries, the Government of Bangladesh and other national and international institutions have initiated massive awareness, monitoring and management activities to combat this new, invasive pest. These include a series of videos, developed by CIMMYT, on FAW identification, monitoring and management. With financial assistance from USAID-funded consortium Virginia Tech-CIMMYT–Michigan State University for IPMA, a video on FAW monitoring and integrated management technologies was developed in collaboration with BARI and BWMRI. This will be telecasted during next maize season on the agricultural program of different TV channels, and shown to the farming community as part of training programs and farmers gatherings.

Above: filming a FAW information video for farmers. Entomology Division, BARI maize field

Link to the video: https://www.youtube.com/watch?v=x23izk1Bfm4

Task 2B4: Conduct workshops for private sector, local lawyers, officials from financial institutions, media and civil society on FAW management, in collaboration with FAW National Taskforce.

Workshops: It was decided at the ninth FAW National Task Force meeting to arrange several workshops to present and discuss the latest developed technologies on FAW's monitoring and integrated management. Two national knowledge-sharing workshops, "Fighting Back Against Fall Armyworm: Integrated Pest Management Solutions" were thus held at BARC, Dhaka (22 June, 2022) co-sponsored by the CIMMYT–Virginia Tech IPMA project and BARC, and at BWMRI, Dinajpur (13 August, 2022), sponsored by USAID-funded consortium Virginia Tech–CIMMYT-Michigan State University for IPMA.

National workshops at BARC, Dhaka: The workshop had 168 participants[2] and three sessions. The inaugural session was chaired by Dr. Shaikh Mohammad Bokhtiar, Executive Chairman, BARC, and Ms. Wahida Akter, Additional Secretary (Admin), with the Ministry of Agriculture as Chief Guest and DGs of DAE, BARI and BWMRI as Special Guests. Mr. Jacob Morrin, Acting Deputy Director, Economic Growth Office, USAID Bangladesh was Guest of Honor and Dr. Timothy J. Krupnik, Country Representative, CIMMYT, Bangladesh presented the keynote paper. In Technical Session 1, chaired by Dr. Md. Aziz Zilani Chowdhury, Member Director (Crops), BARC, papers were presented by BAU, BARI, BWMRI and FAO on the most recent developments in monitoring and management of FAW in Bangladesh. In the afternoon Planning Session, moderated by Dr. Syed Nurul Alam, Former Director, BARI and Senior Consultant, CIMMYT, participants were divided into two groups to develop and discuss IPM strategies for tackling FAW, for *rabi* maize (Group 1) and *kharif* maize (Group 2).

National workshops at BWMRI, Nashipur, Dinajpur: There were 83 participants[3] in the workshop, which had two sessions. The inaugural session was chaired by Dr. Golam Faruq, DG, BWMRI; Mr. Md. Sayedul Islam, Secretary Ministry of Agriculture was the chief guest, while Dr. Shaikh Mohammad Bokhtiar, Executive Chairman, Bangladesh Agricultural Research Council (BARC), Mr. Md. Abdul Wadud, Executive Director (Add. Secretary), Bangladesh Institute of Research and Training on Applied Nutrition (BIRTAN), Mr. Md. Benojir Alam, Director General (DG), Department of Agricultural Extension (DAE), Dr. Debasish Sarker, DG, BARI, Dr. Mirza Mofazzal Islam, DG, Bangladesh Institute of Nuclear Agriculture (BINA), and Dr. Timothy J. Krupnik, Country Representative, CIMMYT Bangladesh were presented as Special Guests. Dr. Krupnik also presented the key note speech, where he showed the collaborative works of Ministry of Agriculture, different NARS institutes (BARI, BWMRI, BRRI, DAE), different international institutes (CIMMYT, CABI, FAO) and other NGOs and private organization regarding the overall management of FAW in Bangladesh. The technical session was chaired by Dr. Shaikh Mohammad Bokhtiar, Chairman, National Task Force Committee for Fall Armyworm Management in Bangladesh and Executive Chairman, BARC. Three technical papers were presented in the session by BWMRI, DAE and FAO, and the following recommendations undertaken in the technical session:

- Awareness program on FAW monitoring and integrated management should be strengthened in the upcoming seasons.
- Promotional activities (leaflet distribution, video show, training arrangement) on the latest technologies of the FAW management should be continued and strengthened.
- Efforts should be made by private and public institutes to make bio-pesticides which combat FAW available to farmers.
- Care should be taken in recommending and using chemical insecticides for the management of FAW: only registered chemical insecticide(s) must be recommended.

[2] Participants were from the Ministry of Agriculture, GOB (3); DAE (58, all Deputy Directors/Additional Deputy Directors Plant Protection of major maize-growing districts along with officials from Field Service, Plant Quarantine and Plant Protection wings); National Agricultural Research System (NARS) institutes: Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Bangladesh Institute of Nuclear Agriculture (BINA), Bangladesh Sugar Crop Research Institute (BSCRI) and Bangladesh Wheat and Maize Research Institute (BWMRI) (56); 13 participants from various agricultural universities: Bangladesh Agricultural University (Mymensingh), Sher-E-Bangla Agricultural University (Dhaka), Bangabandhu Sheikh Mujubur Rahman Agricultural University (Salna, Gazipur), Sylhet Agricultural University (Sylhet), Patuakhali Science and Technology University (Patuakhali), Hazi Danesh Science and Technology University (Dinajpur), and Khulna University (Khulna); 28 participants from private sector maize seed and pesticide companies, two each from USAID (2) and FAO (2), IPMA project, Virginia Polytechnic Institute and State University, (Virginia, USA) (3), and CIMMYT (3).

[3] Ministry of Agriculture, GOB (3); (12), Hazi Danesh Science and Technology University (HDSTU) (06); National Agricultural Research System (NARS) institutes (NARS) (58): Bangladesh Agricultural Research Council, Bangladesh Agricultural Research Institute (BARI), Bangladesh Institute of Nuclear Agriculture (BINA), Bangladesh Wheat and Maize Research Institute (BWMRI); CIMMYT (2) and FAO (2).

National workshops at BARC, Dhaka, in pictures:


Guest speeches, inaugural session


Speech by Chief Guest


Speech by Chairperson, inaugural Session


Speech by Guest of Honor


Key note presentation: inaugural session


Workshop participants


BAU presentation


FAO presentation: Technical session I


Question-and-answer session

Planning session


Group-wise participatory discussion and IPM package development

National workshops at BWMRI, Dinajpur in pictures:

Mr. Md. Sayedul Islam, Secretary, MOA delivering speech

Keynote speech by Dr. Timothy J. Krupnik

Laboratory visit by guests and participants

Objective 3: Increase the adoption of IPM measures by smallholder farming households to increase agricultural production and productivity, while reducing environmental hazards caused by indiscriminate use of pesticides

Activity 3B: Develop, validate, and scale up IPM packages for rice, maize, sesame, mung bean, sunflower, lentil, mustard and potato in the Feed the Future Zone of Influence and Zone of Resilience regions involving private sector, women, youth and disadvantaged groups

Pest attack is the most significant limiting factor in crop production. Globally, around 30%–40% of crop loss occurs annually due to pest infestation. This is higher in developing countries than in developed countries, with a substantial absolute value of crop losses in Asia. It is therefore essential that effective measures are ensured for protecting crops against this colossal loss caused by pests.

Crop protection in South Asia is mostly dependent on chemical pesticide. Pesticide use in Bangladesh began in the mid-1950s, gaining momentum in the early 1970s with the use of HYV rice as part of the Green Revolution. Consumption began to rise again as agriculture activities expanded. Sales of pesticides doubled from1982–89 and tripled in the last decade. However, Bangladesh farmers continue to be mostly dependent on toxic synthetic pesticides to combat pest attack, in spite of the developments in organic agriculture and pesticide-restricted crop cultivation. Indiscriminate and excessive uses of toxic synthetic pesticides are common in many areas, used to combat destructive pests and diseases. To avoid this measurable pest management system, the best way is to develop eco-friendly, sustainable, socio-economic acceptable bio-rational based integrated pest management

(IPM) strategies. IPM is one of a number of integrated approaches gaining credence for use in sustainable agriculture development. It involves the integration by the farmer of the most appropriate management strategies for pest control where sole dependency on chemical pesticides can be avoided.

Several steps have been taken to increase the adoption of IPM to increase production of important crops (that is, rice, maize, sesame, mung bean, mustard, sunflower, lentil and potato) by smallholder farmers, along with reductions in environmental pollution and health hazards caused by indiscriminate use of chemical pesticides. The most important of these steps is the development of IPM packages to combat major insect pests and diseases, achieved by: (1) reviewing IPM-related literature of these crops from reports, publications and international reviews of research institutes such as CABI, ResearchGate, IPM IL, and (2) in-person meetings with related scientists from BARI, Bangladesh Wheat and Maize research Institute (BWMRI) and Bangladesh Rice Research Institute on their developed IPM packages of rice, maize, sesame, mung bean, mustard, sunflower, lentil and potato. The developed IPM packages will be validated by the scientists of BARI (sesame, mung bean, mustard, sunflower, lentil and potato), BWMRI (maize) and BRRI (rice) during *rabi* 2022–23 and *kharif* 2023 seasons, with financial and technical assistance from the CIMMYT–VT IPMA Activity.

Crops, and the pests and diseases which affect them, with their IPM packages

Maize

Maize (*Zea mays*) (*bhutta*) is a cereal crop of the family Graminae, order Cyperales. In the United States and Canada, it is known as corn and considered an important cereal food crop. In 2021, Bangladesh's maize production reached 5.4 million tons, a sharp rise from 750,000 tons in 2009. However, annual demand for maize still stands at 6.5–7 million (65–70 lakh) tons. Before FAW, maize was attacked by few pests or diseases, and as a result, most farmers were reluctant about the pest management. However, the invasion of the destructive pest FAW changed the scenario. The following is a list of pests and diseases affecting maize, along with their IPM packages.

A. Pests and diseases

Pests of national significance

1. Insect pests

1.1 Fall armyworm: *Spodoptera frugiperda* (Lepidoptera: Noctuidae)
1.2 Cutworm: *Agrotis ipsilon* (Lepidoptera: Noctuidae)
1.3 Spotted stem borer: *Chilo partellus* (Lepidoptera: Crambidae)
1.4 Pink stem borer: *Sesamia inferens* (Lepidoptera: Noctuidae)
1.5 Aphid: *Rhopalosiphum maidis*, (Hemiptera: Aphididae)

2. Diseases

2.1 Smut: (*Sphacelotheca reiliana*), (Microbotryaceae)
2.2 Leaf spot: *Cercospora zeae-maydis* (Mycosphaerellaceae), *Phaeosphaeria maydis* (Physodermataceae)
2.3 Ear rot: *Fusarium verticillioides* (=*Fusarium moniliforme*) (Nectriaceae), *Diplodia maydis* (=*Stenocarpella maydis*) (Diaporthaceae)
2.4 Southern leaf blight of maize: *Helminthosporium maydis* (=*Cochliobolus hetrostrophus*, *Bipolaris maydis*) (Pleosporaceae)
2.5 Downy mildew (*Peronasclerospora* spp.): (Peronosporaceae)
2.6 Maize dwarf mosaic virus (MDMV): (Potyviridae)

2.7 Maize streak virus (MSV): (Geminiviridae)
2.8 Root knot nematode: Meloidogyne incognita (Heteroderidae)

3. Weeds
Striga sp., *Echinochloa colona*, *Eleusine indica*, *Cynodon dactylon* and others

B. IPM packages

- Maintain a field free from weeds (especially bermuda grass) (*durba gash*) by weeding by hand, to avoid alternate hosts of pests and diseases.
- Use clean seeds and well-decomposed farmyard manure/compost; remove weed growth and keep irrigation and drainage channels free from weeds.
- Avoid using sand or soil from the weed-infested area.
- Remove weeds by hand-pulling, hand-weeding, burning, flooding, hoeing and tilling.
- Employ crop rotation to help eliminate crop-associated weeds; avoid tobacco as the previous crop of maize (as in Bangladesh, after maize tobacco is FAW's preferred host).
- Sow crops at the proper time and optimum seed rate, enabling the greatest ground coverage, thus deterring weeds.
- Select pure, high-quality certified seed free of disease, weed seeds and insect damage.
- Treat seeds with Cyantraniliprole (Fortenza 60 FS) to protect them from FAW and cutworm and *Trichoderma* powder to provide protection from soil-borne diseases.
- Carry out innundative release of egg parasitoids *Trichogramma chilonis* and *Telenomus remus* just after emergence of seedlings to parasitize the FAW eggs at (1) the V_0 seeding stage, and (2) again later, according to infestation status.
- Set up pheromone traps to monitor FAW and implement timely interventions (maintain ETL: 1 adult FAW male/trap/day).
- Scout the field from the seedling stage (maintain ETL: seedling stage 20%, vegetative 50%, reproductive 10%. Consult Bangladesh Fall Armyworm Monitor (http://faw-monitor.firebaseapp.com) or FAO's "FAMEWS".
- Apply microbial pesticide nuclear polyhedrosis virus (SfNPV for FAW) during the initial infestation of FAW starting 3–4 weeks after seed (treated with Cyantraniliprole) sowing.
- Apply botanicals *Celestrus angulatus* 1% (Bio-chamak 1% EW @ 2–2.5 ml/liter of water) or bio-pesticides *Beauveria bassiana* (@5 gm/liter of water) or *Bacilllus thuringiensis* (@1 gm/liter of water to manage lepidopteran pests.
- Carry out innundative release of the larval parasitoid, *Habrobracon hebetor* to control lepidopteran pests.
- Apply botanicals, Matrin 0.5% (Biotrin 0.5%) or neem-based products to combat aphids after their visible infestation. Carrying out spot application of neem-based products only in the infested whorl can also control later instar FAW larvae.
- Apply bio-fungicide Oligo-saccharine 3% SL (Bio-Shield 3% SL) or *Trichoderma* powder (3–5 gm/liter of water) to manage fungal infestations after their visible appearance.
- Use chemical pesticides as a last option and do not use pesticides with the same mode of action repeatedly. Follow the manufacturer's recommended dose. Consult local extension officials for chemical pesticide selection.
- Tie reflective ribbons in the field to scare away birds.

Rice

Rice is the staple food of about 135 million people of Bangladesh. It provides nearly 48% of rural employment, about two-thirds of total calorie supply and about one-half of the total protein intake of an average person in the country. The rice sector contributes one-half of agricultural GDP and one-sixth of national income. Almost all of the country's 13 million farming families grow rice, which is grown on about 10.5 million hectares, an area which has remained almost stable over the past three decades. About 75% of the total cropped area and over 80% of the total irrigated area is planted with rice. Rice thus plays a vital role in the livelihood of the people of Bangladesh. Total rice production in Bangladesh was about 10.59 million tons in 1971, when the country's population was only about 70.88 million. Today, it produces about 25 million tons to feed 135 million people, an indication that the growth in rice production has been much faster than population growth. This increased production has been possible largely due to the adoption of modern rice varieties on around 66% of rice land, which contributes to about 73% of the country's total rice production. However, rice can also be attacked by pest and disease. There follows a list of pests and diseases, along with their IPM packages.

C. Pests and disease

A. Pests of national significance

1. Insect pests

1.1 Stem borers: yellow stemborer: *Scirpophaga incertulas*, striped stemborer: *Chilo polychrysus*, dark-headed stemborer: *Chilo suppressalis* (Lepidoptera: Crambidae); pink stemborer (*Sesamia inferens*) (Lepidoptera: Noctuidae)
1.2 Rice gall midge: (*Orseolia oryzae*) (Diptera: Cecidomyiidae)
1.3 White-backed planthopper: *Sogatella furcifera*, (Homoptera: Delphacidae)
1.4 Leaf folders: Cnaphalocrocis medinalis and Marasmia exigua (Lepidoptera: Crambidae)
1.5 Case worm: Nymphula depunctalis (Lepidoptera: Pyralidae)
1.6 Rice bug: Leptocorisa acuta, L. chinensis, L. varicornis, L. oratorius (Hemiptera: Alydidae)
1.7 Rice mealybug: *Brevennia rehi* (Hemiptera: Pseudococcidae)

2. Diseases

2.1 Rice blast*: Magnaporthe oryzae/Pyricularia grisea*
2.2 Brown spot: *Bipolaris oryzae* (*Helminthosporium oryzae*)
2.3 Sheath rot: *Sarocladium oryzae*
2.4 Seedling blight/stem rot: *Sclerotium oryzae*
2.5 Bacterial blight: (*Xanthomonas oryzae* pv. oryzae)
2.6 Rice: grassy stunt virus
2.7 Rice: Tungro virus
2.8 Rice root-knot nematode: *Meloidogyne graminicola* (Nematoda: Meloidogynidae)

3. Weeds

3.1 *Echinochloa crusgalis*
3.2 *E. colonum*
3.3 *Cyperus difformis*
3.4 *C. rotundus*
3.5 *C. iria*
3.6 *Eleusine indica*
3.7 *Fimbristylis miliacea*
3.8 *Ischaemum rugosum*
3.9 *Monochoria vaginalis* and
3.10 *Sphenoclea zeylanica*

D. IPM packages

- Raise a pre-crop of sun hemp or other green manure crop, and incorporate the 45-day-old crop into the soil during land preparation.
- Till, remove weeds, and level the field to maintain an even level of water and minimize weed growth.
- Select insect/disease-resistant varieties (if available).
- Select pure high-quality seed free of disease, weed seeds and insect damage.

- Sort seed by floatation.
- Treat seed with *Trichoderma to* protect from soil-borne diseases.
- Remove disease-infected plants and insect-infested plant parts in the nursery before transferring to the main field.
- Seedlings should be free of weed seedlings at the time of transplanting.
- Apply mechanical weed control methods 2–3 weeks after sowing, and again at 4–6 weeks if necessary.
- Observe a no-pesticide spray period for the first 40 days after sowing or transplanting.
- Plant marigold or vegetables on the bunds to serve as nectar and pollen sources for parasitoids and predators.
- Set up plastic sheet barrier strips around the field for rodent control.
- Ensure balanced use of fertilizers as per local recommendations to reduce planthopper outbreaks.
- Split-apply nitrogen to reduce planthoppers, bacterial blight and stem rot.
- Set up pheromone traps for stem borers to monitor, implement timely interventions, and control the pest (@40 traps/ha for management purpose).
- Apply botanicals *Celestrus angulatus* 1% (Bio-chamak 1% EW @ 2–2.5 ml/liter of water) or bio-pesticides *Beauveria bassiana* (@5 gm/liter of water) or *Bacilllus thuringiensis* (@1 gm/liter of water, to manage lepidopteran pests.
- Carry out innundative release of egg parasitoids *Trichogramma chilonis* and *Trichogramma Japonicum* along with larval parasitoid *Habrobracon hebetor* to control lepidopteran pests.
- Apply botanicals Matrin 0.5% (Biotrin 0.5%) or neem-based products to combat Hemipteran insect pests after their visible infestation.
- Apply bio-fungicide Oligo-saccharine 3% SL (Bio-Shield 3% SL) or *Trichoderma* powder (3–5 gm/liter of water) to manage fungal infestation after their visible appearance.
- Use chemical pesticides (as approved in the Pesticide Evaluation Report and Safer Use Action Plan, or PERSUAP) as the last option and do not use pesticides with the same mode of action repeatedly. Follow the recommended dose of the manufacturer. Consult local extension officials for chemical pesticide selection.

Sesame

Sesame (*Sesamum indicum* L.; Family: Pedaliaceae) is a flowering plant of the genus Sesamum. It is widely naturalized in tropical regions around the world and cultivated for its edible seeds, which grow in pods. It has one of the highest oil contents of any seed, and is drought-tolerant and able to grow where many other crops fail. The average sesame yield in Bangladesh is about 957 kg/ha. About 38,923 ha of land are currently under sesame cultivation and annual production is about 37,260 million tons. Sesame is cultivated in both *kharif* and autumn seasons, with two-thirds produced in the *kharif* season. However, it can also be attacked by pests and diseases, listed below along with their IPM packages.

A. Pests and diseases

Pests of national significance

1. Insect pests

1.1 Leaf webber or roller and capsule borer: *Antigastra catalaunalis* Duponchel (Lepidoptera: Crambidae)
1.2 Leaf hopper: *Orosius albicinctus* Distant (Hemiptera: Cicadellidae)
1.3 Hawk moth: *Manduca sexta* (Lepidoptera: Sphingidae)

2. Diseases
2.1 Phyllody: *Phytoplasma*-like organism
2.3 *Phytophthora* blight: *Phytophthora parasitica* var. *sesame* Dastur
2.4 *Alternaria* blight: *Alternaria sesame* Kawamura (Mohanty and Behera)

3. Weeds
3.1 Purple nutsedge: Cyperus rotundus L. (Cyperaceae)
3.2 Flat sedge: Cyperus iria L. (Cyperaceae)
3.3 Bermuda grass: Cynodon dactylon (Poaceae)
3.4 Rabbit/crowfoot grass: *Dactyloctenium aegyptium* Willd (Poaceae)
3.5 Goose grass: *Eleusine indica* L. Gaertner (Poaceae)

B. IPM packages

- Maintain a weed-free field by weeding by hand, to avoid alternate hosts of pests and diseases.
- Use clean seeds and well-decomposed farmyard manure/compost; remove weed growth and keep irrigation and drainage channels free from weeds.
- Remove weeds by hand-pulling, hand-weeding, burning, flooding, hoeing and tilling.
- Create weed barriers by mulching and earthing up.
- Sow crops at the proper time and the optimum seed rate, enabling the greatest coverage and thus deterring weeds.
- Select pure, high-quality certified seeds free of disease, weed seeds and insect damage.
- Apply botanicals *Celestrus Angulatus* 1% (Bio-chamak 1% EW @ 2–2.5 ml/liter of water) or apply bio-pesticides *Beauveria bassiana* (@5 gm/liter of water) or *Bacilllus thuringiensis* (@1 gm/liter of water to manage lepidopteran pests.
- Apply botanicals Matrin 0.5% (Biotrin 0.5%) or neem-based products to combat leaf hoppers after their visible infestation.
- Carry out innundative release of egg parasitoid *Trichogramma chilonis* and larval parasitoid *Habrobracon hebetor* to control caterpillar pests.
- Apply bio-fungicide Oligo-saccharine 3% SL (Bio-Shield 3% SL) or *Trichoderma* powder (3–5 gm/liter of water) to manage fungal infestations after their visible appearance.
- Use chemical pesticides (approved in PERSUAP) as a last option and do not use pesticides with the same mode of action repeatedly. Follow the recommended dose of the manufacturer. Consult local extension officials for chemical pesticide selection.

Mungbean

Mungbean, or mung (*Vigna radiata*) is a common pulse crop of the family Fabaceae. There are two major types of mungbean: (1) aureus, the yellow or golden gram (*sonamung*), which has paler foliage, and yellow seed. The pods have a tendency to shatter and it is mostly grown for fodder or green manure, and (2) typica, the green gram, which has green seeds, a low tendency to shatter, and is grown mostly for grain. In addition, there are grandis (black seeded) and bruncus (brown-seeded) types grown to a small extent on the Indian subcontinent. In Bangladesh, mungbean is traditionally cultivated in the winter months on about 54,982 hectares of land, producing about 34,400 m tons of grain. In the southern regions of Bangladesh, in particular Barisal and Patuakhali districts, cultivation of this crop is expanding very widely. However, mungbean can also be attacked by pests and diseases, listed below along with their IPM packages:

A. Pests and diseases

Pests of national significance

1. Insect pests

1.1 Tobacco caterpillar: *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae)
1.2 Bean fly: *Agromyzas phaseoli, Ophiomyia phaseoli* Tryon (Diptera: Agromyzidae)
1.3 Thrips: *Megaluarothrips distalis* Lindeman (Thysanoptea: Thripidae)
1.4 Pod borer complex: *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae)
1.5 Bean pod borer: *Maruca vitrata* (Fabricius) (Lepidoptera: Crambidae)
1.6 Blue butterfly: *Euchrysops cnejus* (Fabricius) (Lepidoptera: Lycaenidae)
1.7 Hairy caterpillar: *Spilosoma oblique* Walker (Lepidoptera: Erebidae)
1.8 Bruchids: *Callosobruchus chinensis* (Coleoptera: Bruchidae)

2. Diseases
2.1. Anthracnose: *Colletotrichum truncatum* (Schwein.) Andrus and Moore
2.2. Powdery mildew: *Erysiphe pisi* DC.
2.3 Cercospora leaf spot: *Cercospora canescens*
2.4. Sclerotinia rot/collar rot: *Sclerotinia rolfsii* Sacc.
2.5. Bacterial leaf spot: *Xanthomonas* sp.
2.5. Bean yellow mosaic virus

3. Weeds
3.1. Purple nutsedge: *Cyperus rotundus* L. (Cyperaceae)
3.2. Flat sedge: *Cyperus iria* L. (Cyperaceae)
3.3. Bermuda grass: *Cynodon dactylon* (Poaceae)
3.4. Wild onion : *Asphodelus tenuifolius* Cav. (Liliaceae)
3.5. Sweet clover: *Melilotus indica* (L.) All. (Fabaceae)

B. IPM packages

- Maintain a weed-free field by weeding by hand, to avoid alternate hosts of pests and diseases.
- Use clean seeds and well-decomposed farmyard manure/compost; remove weed growth and keep irrigation and drainage channels free from weeds.
- Avoid the use of sand or soil from the weed-infested area.
- Remove weeds by hand-pulling, hand-weeding, burning, flooding, hoeing and tilling.
- Create barriers by mulching and earthing up.
- Sow crops at the proper time at optimum seed rate, enabling the greatest coverage and thus deterring weeds.
- Select pure, high-quality certified seeds free of disease, weed seeds and insect damage.
- Uproot the damaged plants along with the young larvae of hairy caterpillar at the gregarious phase and bury under the soil.
- Treat seeds with *Trichoderma* powder to protect them from soil-borne diseases.
- Set up pheromone traps for the tobacco caterpillar to (1) ensure timely intervention, and (2) control the pest (30 traps/ha)
- Apply microbial pesticide nuclear polyhedrosis virus (SNPV for tobacco caterpillar) during visible infestation.
- Apply botanicals *Celestrus angulatus* 1% (Bio-chamak 1% EW @ 2–2.5 ml/liter of water) or bio-pesticides *Beauveria bassiana* (@5 gm/liter of water) or *Bacilllus thuringiensis* (@1 gm/liter of water) to manage lepidopteran pests.
- Carry out innundative release of egg parasitoid *Trichogramma chilonis* with larval parasitoid *Habrobracon hebetor* to control lepidopteran pests.
- Apply botanicals Matrin 0.5% (Biotrin 0.5%) or neem-based products to combat bean fly/hairy caterpillar after their visible infestation.
- Sun-drying or solar treatment (exposing to 70°–80°C) of seeds, and applying bentonite dust and hydrated lime controls bruchids.
- Apply bio-fungicide Oligo-saccharine 3% SL (Bio-Shield 3% SL) or *Trichoderma* powder (3–5 gm/ liter of water) to manage different fungal infestation after their visible appearance.

- Apply bio-viricide 1% Fungus Proteoglycan (Bio-anvir 1% SL) at the initial infestation of virus, at the same time take actions to control of its vector, aphids.
- Use chemical pesticides (approved in PERSUAP) as a last option and do not use pesticides with the same mode of action repeatedly. Follow the recommended dose of the manufacturer. Consult local extension officials for chemical pesticide selection.

Mustard

Mustard is a leading oilseed crop, covering about 80% of the total oilseed area and contributing to more than 60% of the total oilseed production in Bangladesh. Mustard (*sarisa*) herbs that give oil from its seeds, such as *Brassica napus* (rape), and *Brassica nigra* (black mustard), of the Cruciferae family. Only a few decades ago, mustard oil was the exclusive cooking oil in Bangladesh. It is a cold-loving crop, grown during the *rabi* season. However, mustard crops can also be attacked by various pests and diseases, listed below along with their IPM packages.

A. Pests and diseases

Pests of national significance

1. Insect pests

1.1 Tobacco caterpillar: *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae)
1.2 Mustard aphid: *Lipaphis erysimi (*Kaltenbach) (Hemiptera: Aphididae)
1.3 Mustard saw fly: *Athalia lugens proxima (*Klug) (Hymenoptera: Tenthredinidae)
1.4 Mustard leaf miner: *Chromatomyia horticola* (Goureau) (Diptera: Agromyzidae)

2. Diseases

2.1 *Alternaria* blight: *Alternaria brassicae* (Berk.)
2.2 White rust: *Albugo candida* (Pers.) Kuntze
2.3 Powdery Mildew: *Erysiphe cruciferum* Opiz ex L. Junnell

3. Weeds

3.1 Purple nutsedge: Cyperus rotundus L. (Cyperaceae)
3.2 Flat sedge: Cyperus iria L. (Cyperaceae)
3.3 Bermuda grass: Cynodon dactylon (Poaceae)
3.4 Wild onion : *Asphodelus tenuifolius* Cav. (Liliaceae)
3.5 Burcloveru: *Medicago denticulata* Willd. (Fabaceae)

B. IPM packages

- Maintain a weed-free field by weeding by hand, to avoid alternate hosts of pests and diseases.
- Use clean seeds and well-decomposed farmyard manure/compost; remove weed growth and keep irrigation and drainage channels free from weeds.
- Avoid using sand or soil from the weed-infested area.
- Remove weeds by hand-pulling, hand-weeding, burning, flooding, hoeing and tilling.
- Create weed barriers by mulching and earthing up.
- Sow crops at the proper time at optimum seed rate, enabling the greatest coverage and thus deterring weeds.
- Select pure, high-quality certified seeds free of disease, weed seeds and insect damage.
- Treat seeds with Cyantraniliprole (Fortenza 60 FS) to protect them from cutworm and *Trichoderma* powder to protect them from soil-borne diseases.
- Set up pheromone traps for the tobacco caterpillar to monitor, ensure timely interventions and control the pest (30 traps/ha for management purpose)
- Apply microbial pesticide nuclear polyhedrosis virus (SNPV for tobacco caterpillar) during their visible infestation.

- Apply bio-pesticides *Beauveria bassiana* (@5 gm/liter of water) and *Bacilllus thuringiensis* (@1 gm/liter of water to manage lepidopteran pests.
- Apply botanicals Matrin 0.5% (Biotrin 0.5%) or neem-based products to combat aphids/saw fly/leaf miner after their visible infestation.
- Apply bio-fungicide Oligo-saccharine 3% SL (Bio-Shield 3% SL) or *Trichoderma* powder (3-5 gm/liter of water) for the management of different fungal infestations after their visible appearance.
- Use chemical pesticides (approved in PERSUAP) as a last option and do not use pesticides with the same mode of action repeatedly. Follow the recommended dose of the manufacturer. Consult local extension officials for chemical pesticide selection.

Sunflower

Sunflower (*Helianthus annuus* L., Family: Compositae) is one of the four most important annual crops in the world grown for oil, along with soybean, mustard and groundnut. Demand for sunflower oil is increasing in Bangladesh, where it is an important addition to the list of the country's edible oilseed crops, and where annual sunflower production is about 1.8 thousand tons (Bangladesh Bureau of Statistics, 2019). Sunflower oil is in high demand as it has various health benefits including low cholesterol. However, sunflower can also be attacked by various pests and diseases, listed below along with their IPM packages.

A. Pests and diseases

Pests of national significance

1. Insect pests

1.1 Tobacco caterpillar: *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae)
1.2 Head borer: *Helicoverpa armígera* Hübner (Lepidoptera: Noctuidae)
1.3 Jassids: *Amrasca biguttula* Ishida (Homoptera: Cicadellidae)
1.4 Thrips: *Scirtothrips dorsalis* Hood (Thripidae: Thysanoptera)
1.5 Cutworm: *Agrotis ípsilon* Rott (Lepidoptera: Noctuidae)

2. Diseases

2.1 *Alternaria* leaf spot: *Alternaria helianthi* (Hansf.) Tubaki and Nishi
2.2 Sunflower necrosis disease: *Tobacco streak virus*
2.3 Downy mildew: *Plasmopara halstedii* Farl. Berl. And De Toni
2.4 Rust: *Puccinia helianthi* Schwein
2.5 *Sclerotium* wilt: *Sclerotium rolfsii* Sacc

3. Weeds

3.1 Purple nutsedge: Cyperus rotundus L. (Cyperaceae)
3.2 Flat sedge: Cyperus iria L. (Cyperaceae)
3.3 Bermuda grass: Cynodon dactylon (Poaceae)
3.4 Rabbit/crowfoot grass: *Dactyloctenium aegyptium* Willd (Poaceae)
3.5 Goose grass: *Eleusine indica* L. Gaertner (Poaceae)

4. Vertebrates

4.1 Birds

B. IPM packages

- Maintain a weed-free field by weeding by hand, to avoid alternate hosts of pests and diseases.

- Use clean seeds and well-decomposed farmyard manure/compost; remove weed growth and keep irrigation and drainage channels free from weeds.
- Avoid using sand or soil from the weed-infested area.
- Remove weeds by hand-pulling, hand-weeding, burning, flooding, hoeing and tilling.
- Create weed barriers by mulching and earthing up.
- Sow crops at the proper time at optimum seed rate, enabling the greatest coverage and thus deterring weeds.
- Select pure high-quality certified seeds free of disease, weed seeds and insect damage.
- Treat seeds with Cyantraniliprole (Fortenza 60 FS) to protect them from cutworm, and *Trichoderma* powder to protect them from soil-borne diseases.
- Set up pheromone traps for tobacco caterpillar and head borer, to monitor, implement timely interventions and control these pests (30 traps/ha for management purpose).
- Apply microbial pesticide nuclear polyhedrosis virus (SNPV for tobacco caterpillar and HNPV for head borer) during their visible infestation.
- Apply botanicals Matrin 0.5% (Biotrin 0.5%) or neem-based products to combat thrips and jassids after their visible infestation.
- Apply bio-fungicide Oligo-saccharine 3% SL (Bio-Shield 3% SL) or *Trichoderma* powder (3–5 gm/liter of water) to manage fungal infestation after their visible appearance.
- Use chemical pesticides (approved in PERSUAP) as last option and do not use pesticides with the same mode of action repeatedly. Follow the recommended dose of the manufacturer. Consult local extension officials for chemical pesticide selection.
- Tie reflective ribbons in the field to scare away birds.

Lentil

Lentil is a staple pulse in many developing countries, including Bangladesh. It is the preferred pulse with respect to consumption, among dozens grown in the country. It is a rich source of dietary protein and micronutrients and is eaten as a soup (*dal*) with rice.

Only the red cotyledon type is used as food in Bangladesh, where it is boiled into soup-like dhal and eaten with flatbread (*roti*) or rice. Lentil is also important in crop diversification in the cropping systems of Bangladesh, where it is grown after the rainy season on conserved soil moisture. When grown after upland *aus* paddy or jute, it can be sown in late October. When following the harvest of transplanted rice, it is sown in November to mid-December. However, lentil can also be attacked by various pests and diseases, listed along with their IPM packages as follows:

C. Pests and diseases

A. Pests of national significance

1. Insect pests

1.1. Cow pea aphid: *Aphis craccivora* Koch (Hemiptera: Aphididae)
1.2. Pea aphid: *Acyrthosiphon pisum* Haris (Hemiptera: Aphididae)
1.5. Cut worm: *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae)
1.6. Thrips: *Thrips tabaci* Lindeman (Thysanoptea: Thripidae)
1.7. Pod borers: *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae)
1.9 Pulse beetles: *Callosobruchus* spp. (Coleoptera: Bruchidae)

2. Diseases

2.1. Root rot and seedling disease: *Pythium ultimum* Trow, *Rhizoctonia solani* Kühn
2.2. Fusarium wilt : *Fusarium oxysporum* (Schlecht)
2.3. Lentis rust: *Uromyces fabae* (Pers.) Schröt.
2.4. Anthracnose: *Colletotrichum truncatum* (Schwein.) Andrus and Moore
2.5. Powdery mildew: *Erysiphe pisi* DC.,

2.6. Sclerotinia rot/collar rot: *Sclerotinia rolfsii* Sacc.
2.7. Bean yellow mosaic virus

3. Weeds
3.1. Purple nutsedge: *Cyperus rotundus* L. (Cyperaceae)
3.2. Flat sedge: *Cyperus iria* L. (Cyperaceae)
3.3. Bermuda grass: *Cynodon dactylon* (Poaceae)
3.4. Wild onion : *Asphodelus tenuifolius* Cav. (Liliaceae)
3.5. Sweet clover: Melilotus indica (L.) All. (Fabaceae)

D. IPM packages

- Maintain a weed-free field by weeding by hand, to avoid alternate hosts of pests and diseases.
- Use clean seeds and well-decomposed farmyard manure/compost; remove weed growth and keep irrigation and drainage channels free from weeds.
- Avoid using sand or soil from the weed-infested area.
- Remove weeds by hand-pulling, hand-weeding, burning, flooding, hoeing and tilling.
- Create weed barriers by mulching and earthing up.
- Select pure high-quality certified seeds free of disease, weed seeds and insect damage.
- Treat seeds with Cyantraniliprole (Fortenza 60 FS) to protect them from cutworm and *Trichoderma* powder to protect them from soil-borne diseases.
- Set up pheromone traps for pod borers to monitor, implement timely interventions and control the pest (30 traps/ha for management purpose).
- Apply microbial pesticide nuclear polyhedrosis virus (HNPV for pod borer) during their visible infestation.
- Apply bio-pesticides *Beauveria bassiana* (@5 gm/liter of water) and *Bacilllus thuringiensis* (@1 gm/liter of water to manage lepidopteran pests.
- Apply botanicals Matrin 0.5% (Biotrin 0.5%) or neem-based products to combat thrips and aphids after their visible infestation.
- Carry out sun-drying or solar treatment (exposing to 70°–80°C) of seeds and application of bentonite dust and hydrated lime to control bruchids.
- Apply bio-fungicide Oligo-saccharine 3% SL (Bio-Shield 3% SL) or *Trichoderma* powder (3–5 gm/liter of water) to manage fungal infestations after their visible appearance.
- Apply bio-viricide 1% Fungus Proteoglycan (Bio-anvir 1% SL) at the initial infestation of the virus at the same time take actions to control of its vector, aphids.
- Use the CIMMYT-developed early warning system (EWS) for movement of agents – Stemphylium blight risk forecasting using 'Stempedia,' a weather-based model.'
- Use chemical pesticides (approved in PERSUAP) as a last option and do not use pesticides with the same mode of action repeatedly. Follow the recommended dose of the manufacturer. Consult local extension officials for chemical pesticide selection.

Potato

The potato (*alu*) is an edible tuber of the cultivated plant *Solanum tuberosum* of the family Solanaceae. It was the major crop for the Americans and is now one of the staple foods in Bangladesh. Bangladesh witnessed remarkable progress in potato production since independence, which reached 9.61 million tons in 2019/20 from only 0.75 million tons in 1972/73. The area, production and yield of potato grew by 4.58%, 6.61% and 1.95% respectively per annum during this period. However, potato can also be attacked by various pests and diseases, listed below:

E. Pests and disease

Pests of national significance

1. Insect pests

1.1 Aphids: *Myzus persicae* Sulzerand, *Aphis gossypii* Glover (Hemiptera: Aphididae)
1.2 Cutworm: *Agrotis ipsilon* Hufnagel. (Lepidoptera: Noctuidae)
1.3 Potato tuber moth: *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae)
1.4 Jassids/leaf hoppers: *Amrasca devastans* Dist. and *Empoasca fabae* Harris (Hemiptera: Cicadellidae)
1.5 Whitefly: *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae)

2. Diseases
2.1 Late blight: *Phytophthora infestans* (Mont.) de Bary
2.2 Leaf spot complex: *Alternaria* sp, *Phoma* sp.
2.3 Early blight: *Alterneria solani* Sorauer
2.4 Common scab: *Streptomyces scabies* Lambert and Loria
2.5 Bacterial wilt: *Ralstonia solanacearum* Smith
2.6 Viral diseses (Potato virus X, S, Y and Potato leaf roll virus)

3. Weeds
3.1 Lamb's quarter: *Chenopodium album* L. (Chenopodiaceae)
3.2 Scarlet pimpernel: *Anagallis arvensis* L. (Primulaceae)
3.3 Sweet clover: *Melilotus indica* (L.) All. (Fabaceae)
3.4 Goat weed: *Ageratum conyzoides* L. (Asteraceae)
3.5 Rough medic: *Medicago denticulata* Willd (Fabaceae)

F. IPM packages

- Maintain a weed-free field by weeding by hand to avoid alternate hosts of pests and diseases.
- Use clean seeds and well-decomposed farmyard manure/compost; remove weed growth and keep irrigation and drainage channels free from weeds.
- Remove weeds by hand-pulling, hand-weeding, burning, flooding, hoeing and tilling.
- Create weed barriers by mulching and earthing up.
- Sow crops at the proper time and the optimum seed rate, enabling the greatest coverage and thus deterring weeds.
- Select pure, high-quality certified tubers free of disease and insect damage.
- Treat cut tubers with Cyantraniliprole (Fortenza 60 FS) before sowing to protect against cutworm and *Trichoderma* powder to protect against soil-borne diseases. Apply *Trichoderma* manure (available as Bio-derma solid) during the last ploughing of land preparation @ 20–30 kg/acre to protect against soil-borne diseases.
- Set up pheromone traps for the potato tiber moth to ensure timely interventions and to control the pests (30–40 traps/ha for management purpose).
- Apply botanicals *Celestrus angulatus* 1% (Bio-chamak 1% EW @ 2–2.5 ml/liter of water) or bio-pesticides *Beauveria bassiana* (@5 gm/liter of water) or *Bacilllus thuringiensis* (@1 gm/liter of water to manage lepidopteran pests.
- Apply D-Lemonin 5% SL (Bio-clean) or Phyto Clean to manage whitefly/ aphids after their visible infestation.
- Apply botanicals Matrin 0.5% (Biotrin 0.5%) or neem-based products to combat aphids after their visible infestation.
- Apply bio-fungicide Oligo-saccharine 3% SL (Bio-Shield 3% SL) or *Trichoderma* powder (3–5 gm/liter of water) to manage fungal infestations after their visible appearance.
- Apply bio-viricide 1% Fungus Proteoglycan (Bio-anvir 1% SL) at the initial infestation of virus at the same time take actions to control of its vector, aphids.
- Use chemical pesticides (approved in PERSUAP) as a last option and do not use pesticides with the same mode of action repeatedly. Follow the recommended dose of the manufacturer. Consult local extension officials for chemical pesticide selection.